



ASSOCIATION OF ENGINEERS,
ARCHITECTS AND GRADUATES
IN TECHNOLOGICAL SCIENCES
IN ISRAEL

משרד המדע
הטכנולוגיה והחלל
Ministry of Science, Technology & Space



Digital Abstract Book

27-28 February, 2017 | David Intercontinental Hotel, Tel-Aviv

Conference website: oasis6.org.il

Organized by: **KALEIDOSCOPE**

Conferences | Events | Multimedia

Dear Friends and Colleagues,

It gives us great pleasure to invite you to OASIS 6 (Optical Engineering And Science in Israel) of ILEOS (The Israel Lasers and Electro Optics Society). The meeting will be held on 27-28 February 2017 in Tel Aviv, Israel.

The field of optics and electro optics continue to grow rapidly in Israel, especially over the last few years. It is estimated that there are more than ten thousand electro-optics professionals involved in seven universities, several colleges and over 250 companies in Israel.

The OASIS meeting will present the latest advances in the field of electro-optics worldwide, as well as to be a showpiece for Israeli optics, electro-optics and laser research and technologies. This meeting will focus on encouraging interdisciplinary research as well as international cooperation. The meeting's program reflects some of the areas of current interest in modern optics, including sessions on remote sensing, non-linear optics, optical engineering, electro-optics in industry, quantum optics, lasers and applications, electro optics devices, solar energy, photonics in defense, ultrafast phenomena, micro and nano optics, and optics in medicine and biology.

The conference will host distinguished plenary speakers. In addition there will be several keynote speakers and over a hundred lectures.

The target audience includes optical scientists and engineers working in these fields. We encourage students from all institutions of higher learning to participate in this meeting. It will expose them to the latest research and development, and help them interact with representatives of Academia and Industry.

I invite you to actively participate in our sixth OASIS meeting.

***Prof. Abraham Katzir
Chairman, Organizing Committee***

**Organizing Committee****Conference Chair**

Prof. Abraham Katzir, Tel Aviv University

Members

Dr. Eyal Agassi, Israel Institute of Biological Research

Dr. Michael Berger, ELOP

Prof. Oren Cohen, Technion

Dr. Barak Dayan, Weizmann Institute of Science

Dr. Ariela Donval, KiloLambda

Prof. Amiel Ishaaya, Ben-Gurion University

Prof. Dan Marom, The Hebrew University

Prof. Meir Orenstein, Technion

Dr. Ephi Pinsky, Rafael

Prof. Jacob Scheuer, Tel Aviv University

Dr. Joelle Schlesinger, Rafael

Dr. Natan T. Shaked, Tel Aviv University

Dr. Yoav Sintov - Soreq

Dr. Yaakov Tischler, Bar-Ilan University

Table of Contents

Organizing Committee - Page 3

Conference Program - Page 5

Keynote Speakers - Page 14

Oral Presentations; Monday, 27 February, 2017 - Page 16

Oral Presentations; Tuesday, 28 February, 2017 - Page 74

Poster Presentations; Monday, 27 February, 2017 - Page 133

Poster Presentations; Tuesday, 28 February, 2017 - Page 180



Monday, February 27, 2017

08:00-09:00	COFFEE AND REGISTRATION
09:00-11:00	OPENING SESSION Plenary Hall
	Chairperson: Prof. Abraham Katzir, Chairman of Oasis 2017
09:00-09:15	Greetings: Prof. Abraham Katzir, Chairman, Oasis 2017 Eng. Ehud Noff, Chairman, AEAI - Association of Engineers, Architects and Graduates in Technological Sciences in Israel Mr. Carlos Lee, Director General, EPIC - European Photonics Industry Consortium
09:15-09:30	Prof. Alan Willner, USC, USA - Lessons Learned from U.S. National Photonics Initiative
09:30-10:15	Prof. William Moerner, Nobel Prize Winner, Stanford University, USA - The Promise and Challenges of 3D Super-Resolution Microscopy and Single-Molecule Tracking in Cells
10:15-11:00	Prof. Ursula Keller, ETH, Zurich, Switzerland - Gigahertz Laser Frequency Combs
11:00-11:30	COFFEE BREAK AND POSTERS REVIEW OF TOPICS: LASERS AND APPLICATIONS AND IFLA – FIBER LASERS AND APPLICATIONS

PARALLEL SESSIONS					
11:30-13:00	Medicine and Biology Prof. Natan Shaked Hall A	Remote Sensing Dr. Eyal Agassi Hall B	Optical Engineering Dr. Ariela Donval Hall C	Non-linear Optics Prof. Meir Orenstein Hall D	IFLA Fiber Laser Technology Dr. Yoav Sintov Hall E
Clinical Detection of Dysplasia using Light Scattering and Interferometry Adam Wax , Duke University, USA*	Atmospheric Limitations on the Performance of Electro-Optical Systems Karin Stein , Fraunhofer Institute, Germany*	Recent Developments in High Performance Quantum Cascade Lasers Kumar Patel , Pranalytica, USA*	Quantum Imaging Robert Boyd , University of Rochester, USA*	Opening Remarks: Prof. Amiel Ishaaya	
Applications of Inverse Scattering Principles with Digital Holography YongKeun Park , KAIST, South Korea*	Ray Tracing Engine for Atmospheric Propagation Itay Naeh , Rafael	Restoring Light Sensitivity to Blind Retina David Rand , Tel Aviv University*	Nonlinear Plasmonics at High Temperatures and Thermo-Optic Metamaterials Yonatan Sivan , Ben-Gurion University	Keynote Technical Advances and Future Prospects of Fiber Lasers and Amplifiers Andreas Tunnerman , Friedrich-Schiller-University, Germany	
Imaging with Scattered Light: Looking Through the 'Fog' Ori Katz , The Hebrew University*	Ceilometer Evaluation of the East Mediterranean Mixing Layer Height and Dust Movement - First Study of a Few Israeli Sites Leenes Uzan , Tel Aviv University	Optics Manufacturing in a Digitalized Production Environment Holger Kreilkamp , Fraunhofer IPT, Germany	Three-Dimensional Spatiotemporal Pulse-Train Solitons: First Experimental Observation of 3D Solitons Oren Lahav , Technion	Fiber Amplifiers and Lasers using Optical Orbital Angular Momentum (OAM) Modes Moshe Tur , Tel Aviv University*	
Theranostics Techniques based on Plasmon-Coupled Probes Dror Fixler , Bar-Ilan University*	Analysis of Space based Cloud Images and Comparison to a Previous Model Shimshon Lashansky , ELBIT	Optical Coating by Atomic Layer Deposition (ALD) Rami Cohen , Elbit Systems, Electro-Optics-ELOP	Phase Sensitive Parametric Amplification in InGaP Photonic Crystal Waveguide Amnon Willinger , Technion	Tunable Fiber Lasers in the 1μm and 2μm Wavelength Range using Fiber Bragg Grating Arrays Matthias Jäger , Leibniz Institute of Photonic Technology, Germany*	
EView - Automated Spectral Interpretation System Tal Feingersh , IAI	EOview - Automated Spectral Interpretation System Tal Feingersh , IAI	Optical Engineering with Compressive Sensing Adrian Stern , Ben-Gurion University	Photonic Topological Insulators and Topological Lasers Moti Segev , Technion*		
13:00-14:00	LUNCH				
13:30-14:00	POSTERS REVIEW OF TOPICS: MEDICINE AND BIOLOGY AND OPTICAL ENGINEERING				
Lunch Symposium Spin-Controlled Multitasking Geometric Phase Metasurfaces Erez Hasman , Technion	Sponsored by: KLA Tencor 				
14:00-15:30	Medicine and Biology Prof. Natan Shaked Hall A	Photonics in Defense Dr. Joelle Schlesinger Hall B	Lasers and Applications Prof. Amiel Ishaaya Hall C	Non-linear Optics Prof. Meir Orenstein Hall D	IFLA Material Processing Dr. Kobi Lasri Hall E
Physical Properties of Cells in Biology and Medicine Jochen Guck , Dresden University, Germany*	Eyesafe Standoff Detection of Threats using Monolithically Tunable QCL Arrays Mark Witinski , Pendar Technologies, USA*	Mid-Infrared Microresonator Frequency Combs Alexander Gaeta , Columbia University, USA*	Nanosystems in Ultrafast and Superstrong Fields: Attosecond Phenomena Mark Stockman , Georgia State University, USA*	Advanced Pulsed Fiber Lasers for Clean Energy Applications Doron Barness , Spectra-Physics*	
Multi-Modal Digital Holographic Microscopy for Cancer Research, Drug Screening and Toxicity Testing Björn Kemper , University of Muenster, Germany*	III-V Semiconductor Photodetectors at SCD Itay Shtrichman , SemiConductor Devices (SCD)*	Microbubble Resonators based Lasers: From Brillouin to Raman, from Single Lines to Broadband Combs Silvia Soria Huguet , CNR-IFAC Institute of Applied Physics, Italy*	Solitons and Faraday Waves in Nonlinear Metasurfaces Roman Noskov , Tel Aviv University	From Laser Design Textures to New Field of Technical Functional Surfaces Applied on the Mold Industry Jérôme Drouet , Georg Fischer, Switzerland*	
Monte Carlo Computational Tool for the Needs of Biophotonics and Biomedical Optics Igor Meglinski , University of Oulu, Finland *	Reactive Magnetron Sputtered Multilayer SiO ₂ /Er ₂ O ₃ Antireflection Coatings for Dual Band Infrared Transmission Rakefet Samuely , Rotem Industries	Topological Insulator Laser Gal Harari , Technion	Nonlinear Chip Scale Light-Vapor Interactions for all Optical Switching, Spectroscopy and Frequency Stabilization Uriel Levy , The Hebrew University*	The Fiber Laser Revolution in Metal Processing, Taking Industries towards Absolute Excellence Arvind Patel , Sahajanand Laser Technology Limited, India*	
Recent Progress in Transcranial Optical Vascular Imaging Vyacheslav Kalchenko , Weizmann Institute of Science*	First Field Demonstration of Standoff Detection of Buried Landmines using Fluorescent Bacterial Sensors Yossef Kabessa , The Hebrew University	Digital Degenerate Cavity Laser for Forming Intra-Cavity Images and Rapidly Solving Inverse Problems Chene Tradonski , Weizmann Institute of Science	Advances in High-Resolution Brillouin Optical Correlation Domain Analysis Avi Zadok , Bar-Ilan University	Fiber Lasers – A Universal Tool for Industrial Production Wolfram Rath , Coherent-ROFIN, Germany*	
Optical Blood Count Dvir Yelin , Technion*	Derivative based Focal Plane Array Non-Uniformity Correction Gal Ness , Technion	New Types of Plasma Lasers Lev Nagli , Ariel University	Breaking Laser Axioms on Thermal Equilibrium and Lasing without Inversion in Erbium-Doped Fibers Baruch Fischer , Technion*	Water Jet Guided Green Fibre Lasers and its Applications Bernold Richerzhagen , Synova S.A., Switzerland*	
15:30-16:00	COFFEE BREAK AND POSTERS REVIEW OF TOPICS: NONLINEAR OPTICS, PHOTONICS IN DEFENSE, REMOTE SENSING AND SOLAR ENERGY				

16:00-17:30	PARALLEL SESSIONS				
	Solar Energy Dr. Yaakov Tischler Hall A	Remote Sensing Dr. Eyal Agassi Hall B	Lasers and Applications Prof. Amiel Ishaaya Hall C	Micro and Nano Optics Prof. Jacob Scheuer Hall D	IFLA Fiber Sensing Prof. Avishay Eyal Hall E
	<p>Photoluminescence: An Optical Heat Pump for Harvesting Thermal Losses in Photovoltaics Carmel Rotchild, Technion*</p> <p>Understanding the Microscale Heterogeneity in Metal Halide Perovskite Solar Cells Samuel D. Stranks, Cambridge University, UK*</p> <p>Graphitic Carbon Nitride Layers as Light-Harvesting Semiconductors for Photoelectrochemical Cells Menny Shalom, Ben-Gurion University*</p> <p>Photodiode Pyranometers Uri Maurice, QCC Hazorea Calibration Technologies</p>	<p>Detection and Identification of Hazmat using Thermal Hyperspectral and Spectropolarimetric Imaging Michal Shimoni, Signal and Image Centre (SIC-RMA), Belgium*</p> <p>Standoff Thermal Infrared Hyperspectral Imaging for Ground-based and Airborne Remote Sensing Applications Jean Giroux, Telops Inc., Canada*</p> <p>Towards Optical Detection of Condensed Phase Materials Ran Aharoni, IIBR</p> <p>Using Optical Gas Imaging to Enforce Air Pollution Reduction Omer Yanai, Opgal Optronics Industries</p> <p>Drone based Raman/Luminescence Spectroscopy for Remote Homeland Security Michael Gaft, Laser Detect Systems</p>	<p>Novel Packaging Scheme using Femto-Second Laser 3D Patterning Yuval Berg, Orbotech Ltd.</p> <p>Passively Q-Switched 2um Lasers, for Medical and Industrial Applications Salman Noach, JCT</p> <p>Non-Contact and Non-Disruptive Laser based Characterization of High Aspect Ratio Micro Structures Niv Gorodesky, Bar-Ilan University & Orbotech Ltd.</p> <p>Strengthening of Large Nd:YAG Laser Rods for High Power Applications Shuki Shimony, Soreq NRCn</p> <p>Pump-to-Laser Beam Overlap Optimization in Ti:Sapphire Pumped and Diode Pumped Alkali Lasers (DPALs) Boris Barmashenko, Ben-Gurion University</p> <p>Substrate-Transferred Crystalline Coatings for the Near- and Mid-Infrared Garrett D. Cole, Crystalline Mirror Solutions, USA</p>	<p>Novel Materials for Next Generation Photonic Devices Michal Lipson, Columbia University, USA*</p> <p>High Detection Limit Polymer-based Optofluidic Sensors for Water Pollutant Monitoring Isabelle Ledoux-Rak, Ecole Normale Supérieure de Cachan, France</p> <p>Tunable Photonic Crystals by Holographic Optical Tweezers Yael Roichman, Tel Aviv University</p> <p>Overtone Spectroscopy with Reconfigurable Microfibers Alina Karabchevsky, Ben-Gurion University</p> <p>Super Resolution Microscopy based on Photo-Modulated Reflectivity Ori Cheshnovsky, Tel Aviv University*</p>	<p>Dynamic Fiber Sensing with High Spatial Resolution Lih Shiloh, Tel Aviv University*</p> <p>Waveform-processing LIDAR versus Geiger-mode LIDAR Andreas Ullrich, RIEGL LMS GmbH, Austria*</p> <p>The Statistical Properties of Distributed Acoustic Sensing Haniel Gabai, Tel Aviv University*</p> <p>Opto-Mechanics of Single-Mode and Multi-Core Fibers Avi Zadok, Bar-Ilan University*</p>

End of Day 1

Tuesday, February 28, 2017

08:00-09:00	COFFEE AND REGISTRATION
09:00-11:00	OPENING SESSION Plenary Hall
	Chairperson: Prof. Asher Friesem
09:00-09:30	Prof. Asher Friesem , Weizmann Institute of Science - Looking Back and Looking Ahead Dr. Andrey Broisman , Ministry of Science, Technology and Space - The Mission of the Ministry of Science, Technology and Space CERTIFICATE AWARD CEREMONY
09:30-10:15	Prof. Sir David Payne , Optoelectronics Research Center at the University of Southampton, UK - Optical Fibres: The Next Generation
10:15-11:00	Prof. Victor Malka , Weizmann Institute of Science, Israel - Manipulating Electrons with Intense Laser Pulses
11:00-11:30	COFFEE BREAK AND POSTERS REVIEW OF TOPICS: QUANTUM OPTICS AND ULTRAFAST PHENOMENA

11:30-13:00	PARALLEL SESSIONS				
	Quantum Optics Prof. Barak Dayan Hall A	Photonics in Defense Dr. Joelle Schlesinger Hall B	Ultrafast Phenomena Prof. Oren Cohen Hall C	Micro and Nano Optics Prof. Jacob Scheuer Hall D	IFLA High Power Fiber Lasers Dr. Boaz Lissak Hall E
	<p>Quantum Optical Diode and Circulator based on the Chiral Interaction Between a Single Atom and Photons with Transverse Spin Arno Rauschenbeutel, TU Wien, Austria*</p> <p>Photon-Number Reconstruction and Photon Generation in an Ion-Cavity System Tracy Northup, University of Innsbruck, Austria*</p> <p>Demonstration of Deterministic and Passive Photon-Atom SWAP Quantum Gate Adrien Borne, Weizmann Institute of Science</p> <p>Molecular Vibrational Strong Coupling: Novel Route to Modify Materials Properties Atef Shalabney, Ort Braude College</p> <p>Quantum Superresolution and Spectral Intensity Interferometry Erez Ribak, Technion</p>	<p>Active and Passive EO-Systems: Future Trends and Evaluation Helge Buersing, Fraunhofer IOSB, Germany*</p> <p>EO Imaging Systems and Detectors - Performance Optimization Michael Ben-Ezra, IMOD\IDF*</p> <p>TRM4 for Sensor Performance Calculations Dov Steiner, IARD Sensing Solutions</p> <p>Prediction of Objects Detection, Recognition and Identification [DRI] Ranges at Color Scene Images, based-on Quantifying Human Color Contrasts Perception Ephi Pinsky, Rafael</p> <p>Hybrid Video Simulator for Guided Projectile Seeker Idan Paiss, Israeli Aerospace Industries</p>	<p>Free-Electron Quantum Optics Studied by Ultrafast Transmission Electron Microscopy Claus Ropers, University of Gottingen, Germany*</p> <p>Stimulated Radiation Interaction of a Single Electron Quantum Wavepacket Avraham Gover, Tel Aviv University</p> <p>Isolating Strong-Field Dynamics in Molecular Systems Gal Orenstein, Weizmann Institute of Science</p> <p>On the Fly Control of High Harmonic Generation using a Structured Pump Beam Liran Hareli, Tel Aviv University</p> <p>Optical Access to Topological Insulator Spin Dynamics Dmitry Panna, Technion</p>	<p>Extreme Photonics Nader Engheta, University of Pennsylvania, USA*</p> <p>Laser Beam Shaping with Intra-Cavity Gradient Metasurfaces Ronen Chriki, Weizmann Institute of Science</p> <p>Topological Defects in Coupled Laser Networks Vishwa Pal, Weizmann Institute of Science</p> <p>Advanced Optical 3D-microstructures Elements made of Sol-gel Derived Hybrids prepared by Nano-imprint Lithography (NIL) Raz Gvishi, Soreq</p> <p>Water-Walled Optofluidics and Water-Wave Lasers Tal Carmon, Technion*</p>	<p>Keynote Coherent Time-Domain Combining of Femtosecond Pulses for the Next Generation of Power Scalable Fiber Lasers Almantas Galvanauskas, University of Michigan, USA</p> <p>250 W Average Power Inner-Cladding Pump Raman Fiber Laser Yariv Shamir, Soreq*</p> <p>kW-Class Lasers based on Coherent Beam Combining Yaniv Vidne, Civan Advanced Technologies Ltd*</p>
13:00-14:00	LUNCH				
13:30-14:00	POSTERS REVIEW OF TOPIC: MICRO AND NANO OPTICS				
13:00-14:00	<p>Lunch Symposium 140W Wavelength-Stabilized Fiber-Coupled Diode Laser at 976nm <u>Bob (Chao) Lang</u> on behalf of Ray Xu, BWT_Beijing</p> <p>Sponsored by: BWT_Beijing</p> 				
14:00-15:30	PARALLEL SESSIONS				
	Quantum Optics Prof. Barak Dayan Hall A	Electro Optics in Industry Dr. Michael Berger Hall B	Ultrafast Optics Prof. Oren Cohen Hall C	Electro-Optic Devices Prof. Dan Marom Hall D	IFLA Optical Fiber Technology Dr. Ariel Bruner Hall E
	<p>Optical Homodyne with Optical Bandwidth Yaakov Shaked, Bar-Ilan University</p> <p>Quantum Correlations Enhanced Super-Resolution Localization Microscopy Yonatan Israel, Weizmann Institute of Science</p> <p>Measuring Incompatible Observables of a Single Photon Eliahu Cohen, University of Bristol, UK</p> <p>Simulating Spatial Distribution of Spontaneously Down Converted Photon Pairs in Nonlinear Crystals Sivan Trajtenberg-Mills, Tel Aviv University</p> <p>Diffusion-Free Beams Slava Smartsev, Weizmann Institute of Science</p> <p>Demonstration of a Bit-Flip Correction for Enhanced Sensitivity Measurements Lior Cohen, The Hebrew University</p>	<p>Automated Assembly and Testing of Photonics Devices: Addressing the Needs of Growing Production Volumes Ignazio Piacentini, ficonTEC Service GmbH, Germany</p> <p>Wave-Front Reconstruction for Wafer and Mask Inspection Sensitivity Enhancement Yinon Glickman, Applied Materials</p> <p>A New Automated Optical 3D-Shaping Machine for Printed Circuit Boards Oded Mor, Orbotech</p> <p>Challenges of New Product Introduction for the Semiconductor Industry Adam Baer, KLA-Tencor</p> <p>MTF Measurement of IR Optics Hannes Duncker, Trioptics Inc, Germany</p> <p>Smart Thermal Imaging Platforms for the Widest Range of Applications Frederic Mathieu, Device-Alab, France</p>	<p>Ultrafast Adiabatic Second Harmonic Generation by Aperiodically Poled Nonlinear Crystal Haim Suchowski, Tel Aviv University</p> <p>Leakage Imaging and Tracking of Ultrafast Surface Plasmon Pulses Yuri Gorodetski, Ariel University</p> <p>Giant AC Stark Effect in a Strongly-Coupled Light-Matter System Nadav Landau, Technion</p> <p>Nonlocal Nature of the Ultrafast Nonlinear Response of Metals Yonatan Sivan, Ben-Gurion University</p> <p>High-Speed Holography of the Retina Michael Atlan, CNRS, France</p>	<p>Harnessing Photonic Integrated Circuits Andrea Melloni, Politecnico di Milano, Italy*</p> <p>Induced Mode Mixing via Spatial Phase Masks Directly Printed on Fiber Facet Miri Blau, The Hebrew University</p> <p>Optimized Depth of Field Methodology using Annular Liquid Crystal Spatial Light Modulator assisted by Image Processing Naama Shukrun, Ben-Gurion University</p> <p>Hybrid Combination of InP and Silicon Nitride based TriPlex™ Waveguides for a Broad Application Range Arne Leinse, Lionix International, Netherlands*</p>	<p>Keynote Realizing a Moore's Law for Fibers Yoel Fink, Massachusetts Institute of Technology, USA</p> <p>Silica Fibre Fabrication at the Photonics Institute in Nanyang Technological University Seongwoo Yoo, Nanyang Technological University, Singapore*</p> <p>Fluoride Glass Fibers for Active Applications Robert Pafchek, ThorLabs, USA*</p> <p>Advances in Phosphate Glass Optical Fibers for Lasers and Optical Amplifiers Daniel Milanese, Politecnico di Torino – DISAT, Italy*</p>

15:30-15:50	COFFEE BREAK AND POSTERS REVIEW OF TOPICS: ELECTRO OPTIC DEVICES AND ELECTRO OPTICS IN INDUSTRY				
15:50-17:40	PARALLEL SESSIONS				
	Nano and Quantum Optics Prof. Jacob Scheuer Hall A	Electro Optics in Industry Dr. Michael Berger Hall B	Enhanced Optical Sensing Techniques Dr. Eyal Agassi Hall C	Electro-Optic Devices Prof. Dan Marom Hall D	IFLA Fiber Components Eyal Shekel Hall E
	<p>The Quantum Knitting Machine: A Deterministic Route for Producing Large Scale Entanglement David Gershoni, Technion*</p> <p>Directing Single Photons: A Highly Directional Room-Temperature Single Photon Device Hamzu Abudayyeh, The Hebrew University</p> <p>Enhanced Nitrogen-Vacancy Concentration in Diamond through Optimized Electron Irradiation Demitry Farfurnik, The Hebrew University</p> <p>Plasmonic "Templar Cross" Antennas for Subwavelength Addressing of Spin States in Diamonds Tzach Jaffe, Technion</p> <p>High Resolution Trapping using Structured Super-Oscillating Light Beams Harel Nagar, Tel Aviv University</p> <p>Observation of Anderson Localization in Disordered Nanophotonic Structures Hanan Herzog, Technion</p> <p>Multitasking Geometric Phase Metasurfaces Elhanan Maguid, Technion</p>	<p>Fetura Advanced Zoom: An Ultrafast Zoom Lens Thomas Schaeffler, Qioptiq, Germany</p> <p>Application of Phase Matching Autofocus in Airborne Long-Range Oblique Photography Camera Vladimir Petrushevsky, Elbit Systems Electrooptics - ELOP</p> <p>4 Decades of Space Optics, Optical Design, in Israel Aharon Nir, Elbit systems, ELOP</p> <p>Minimization of Light Power Losses in Diffractive Optics and Computer Generated Holograms Michael Golub, Tel Aviv University</p> <p>InAs/(GaSb,InAsSb) and HgTe/CdTe Superlattices: Detector Materials with Topological Properties Philip Klipstein, SemiConductor Devices</p>	<p>Fast Electrically Switchable IR Notch Filter using Liquid Crystal Karni Wolowelsky, Technion</p> <p>Plasmon-Waveguide Resonances with Enhanced Figure-of-Merit and their Potential for Unisotropic Bio-Sensing in the Near Infrared Region Said Mahajna, Ort Breude College</p> <p>Radiometric Imaging by Double Exposure of Blurred and Sharp Thermal Images Iftach Klapp, Volcani Center-ARO</p> <p>Practical Considerations in MTF Measurement of a Digital Head-Up Display System Yuval Erez, Elbit Systems ISTAR</p> <p>Chromatic Confocal Sensors Matthieu Desjacques, STIL SA, France</p> <p>Improving the Sensitivity of Fluorescence-based Immunoassays by Reducing the Auto-Fluorescence of Magnetic Beads Amos Danielli, Bar-Ilan University</p>	<p>Integrated Nanophononic Circuits: Harnessing On-Chip Photon-Phonon Interactions Benjamin J. Eggleton, School of Physics, University of Sydney, Australia*</p> <p>Light-Enhancing Plasmonic-Nanopore Biosensor for Superior Single-Molecule Detection Amit Meller, Technion</p> <p>Feasibility of using Nano-Columnar PbSe Thin Films Grown by CBD as a SWIR Photodetector Hadar Manis Levy, Ben-Gurion University</p> <p>High-Speed InAs/InP Quantum Dot Laser with Low Sensitivity to Temperature Change Ori Eyal, Technion</p> <p>Optoelectronic Adventure in 2D Land Ilya Goykhman, University of Cambridge, UK*</p>	<p>Concepts for High Brightness Fiber Coupled Diode Laser Modules for Fiber Laser Pumping and Direct Diode Cutting Applications Jörg Neukum, Coherent DILAS, Germany*</p> <p>Femtosecond Inscription of Bragg Gratings in Various Fibers and Planar Transparent Materials using a Phase Mask Amiel Ishaaya, Ben-Gurion University*</p> <p>Fs Lasers for Complex Gratings, Integrated Circuits and Beam Shaping with Novel Optical Fibres Kyriacos Kalli, Cyprus University of Technology, Cyprus*</p> <p>Very High Power Fiber-to-Fiber Coupled Devices Zachary Sacks, Elbit Systems Elop</p>
17:40-18:00	Concluding Remarks Prof. Abraham Katzir, Chairman of Oasis 2017				
	End of Day 2				

Key

* Invited Lectures

Keynote Speakers



Prof. William Moerner, Nobel Prize Winner

W. E. (William Esco) Moerner, the Harry S. Mosher Professor of Chemistry and Professor, by courtesy, of Applied Physics at Stanford University, conducts research in physical chemistry and chemical physics of single molecules, single-molecule biophysics, super-resolution imaging and tracking in cells, and trapping of single molecules in solution. His interests span methods of precise quantitation of single-molecule properties, to strategies for three-dimensional imaging and tracking of single molecules, to applications of single-molecule measurements to understand biological processes in cells, to observations of the photodynamics of single photosynthetic proteins and enzymes. He has been elected Fellow/Member of the NAS, American Academy of Arts and Sciences, AAAS, ACS, APS, and OSA. Major awards include the Earle K. Plyler Prize for Molecular Spectroscopy, the Irving Langmuir Prize in Chemical Physics, the Pittsburgh Spectroscopy Award, the Peter Debye Award in Physical Chemistry, the Wolf Prize in Chemistry, and the 2014 Nobel Prize in Chemistry.



Prof. Ursula Keller

Ursula Keller has been a tenured professor of physics at ETH Zurich since 1993 (www.ulp.ethz.ch), and also a director of the Swiss multi-institute NCCR MUST program in ultrafast science since 2010 (www.nccr-must.ch). She received the Ph.D. from Stanford University in 1989 and the Physics "Diplom" from ETH in 1984. She was a Member of Technical Staff (MTS) at AT&T Bell Laboratories from 1989 to 1993, a "Visiting Miller Professor" at UC Berkeley 2006 and a visiting professor at the Lund Institute of Technologies 2001. She has been a co-founder and board member for Time-Bandwidth Products (acquired by JDSU in 2014) and for a venture capital funded telecom company GigaTera (acquired by Time-Bandwidth in 2003).

Her research interests are exploring and pushing the frontiers in ultrafast science and technology. She invented the semiconductor saturable absorber mirror (SESAM) which enabled passive modelocking of diode-pumped solid-state lasers and established ultrafast solid-state lasers for science and industrial applications. Pushed the frontier of few-cycle pulse generation and full electric field control at petahertz frequencies. Pioneered frequency comb stabilization from modelocked lasers, which was also noted by the Nobel committee for Physics in 2005. In time-resolved attosecond metrology she invented the attoclock which resolved the electron tunneling delay and observed the dynamical Franz-Keldysh effect in condensed matter for the first time.



Prof. Sir David Payne

Prof Sir David Payne is a Professor of Photonics and Director of the Optoelectronics Research Centre (ORC) and the Zepler Institute at the University of Southampton. He has published over 650 Conference and Journal papers and is co-inventor on over 40 patents.

Over the last forty years, he has made numerous key contributions in optical fibre communications and laser technology. His work in fibre fabrication in the 1970s resulted in most of the special fibres used today, including the revolutionary erbium-doped fibre amplifier (EDFA) and kilowatt-class fibre lasers for manufacturing and defence. He is a Fellow of the UK Royal Society, the UK Royal Academy of Engineering, the Optical Society of America, the UK IET and the UK IoP. As an entrepreneur, he co-founded York Technologies, (now PK Technology Inc.), Fibercore, SENSA (now part of Schlumberger) and SPI Lasers plc (now part of the Trumpf Gruppe). He was the 2014 IEEE/RSE Wolfson James Clerk Maxwell Awardee.

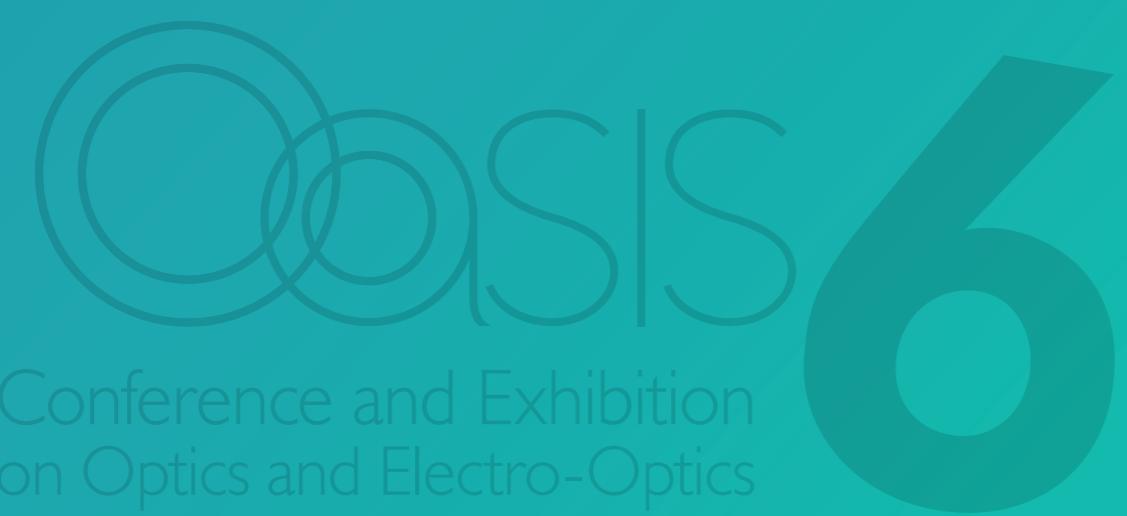


Prof. Victor Malka

Victor Malka, graduated from University of Paris XI-Orsay, did his PhD thesis at Ecole polytechnique (1987–90), is a CNRS research director at Laboratoire d'Optique Appliquée, and since 2015 a Professor at the Weizmann Institute for Science. He has also been Maître de Conference at Ecole Polytechnique (2003–2015). Victor Malka worked on different topics such as atomic physics, inertial fusion, laser plasma interaction. His works now is mainly devoted on relativistic plasmas and on laser plasma accelerators, in which he makes several breakthrough contributions. He has published about 340 articles and has been invited in more than 160 international conferences. He got several national and international prizes. Since 2002, he has coordinated many European projects structuring the laser, plasma and accelerators communities. Victor Malka, fellow of APS and EPS, got 2 Advanced and 2 Proof of Concept grants from ERC.

Oral Presentations

Monday, 27 February, 2017



Conference and Exhibition
on Optics and Electro-Optics

Plenary Session

Lessons Learned from U.S. National Photonics Initiative

Alan Willner

USC, USA

Optics and photonics has enjoyed decades of technological advancement and has cemented itself as being essential for many different application areas that impact society on a daily basis. The markets impacted are many, including: communications, defense, energy, health, and manufacturing. As our field becomes more important, it is also critical that our community advocate for optics and photonics to the decision makers in government, industry, and academia. Such advocacy is important so that there is strategic planning and investment to enable the next period of technical innovation and growth. This presentation will highlight the effort in the United States to form a more cohesive voice that advocates for optics and photonics. The U.S. National Photonics Initiative: (i) was a key recommendation of the U.S. National Academies' Study on Optics and Photonics, (ii) is critically supported by several major professional societies, including APS, IEEE, LIA, OSA, and SPIE, and (iii) helps broadly advocate for optical and photonics to government and industry. The NPI has: (a) helped the community respond to the U.S. government national manufacturing initiative, which ultimately formed AIM Photonics, (b) informed Congress so that optics and photonics language has been inserted into various Congressional Bills, and (c) helped coordinate industry responses in the areas of brain imaging and cancer diagnostics. The presentation will also highlight lessons learned and overall perspectives in the pursuit of effective advocacy for the optics and photonics community.

The Promise and Challenges of 3D Super-Resolution Microscopy and Single-Molecule Tracking in Cells

Prof. William Moerner, Nobel Prize Winner

Department of Chemistry, Stanford University, USA

Super-resolution microscopy based on imaging and controlling the emitting concentration of single molecules has opened up a new frontier in which biological structures and behavior can be observed in fixed and live cells with resolutions down to 20-40 nm and below. Examples range from protein superstructures in bacteria to details of the shapes of amyloid fibrils and much more. Current methods development research addresses ways to extract more information from each single molecule such as 3D position and orientation, and ways to insure that the acquired data are both accurate and precise. At the same time, it is worth noting that in spite of all the current focus on super-resolution, even in the "conventional" low concentration, single-molecule tracking regime where the motions of individual biomolecules are recorded rather than the shapes of extended structures, much can still be learned about biological processes with quantitative measurements and analysis. Examples include studies of protein dynamics in the primary cilium and motions of DNA loci in the nucleus.

Gigahertz Laser Frequency Combs**Prof. Ursula Keller***Department of Physics, ETH Zurich, Switzerland*

This talk will review our progress on gigahertz frequency combs based on modelocked semiconductor and solid-state lasers, stabilized by external silicon nitride waveguides or PCFs with an f-to-2f interferometer. Novel dual comb modelocked lasers are presented where an intracavity birefringent crystal in an ultrafast semiconductor thin disk laser is used for polarization-duplexing to obtain simultaneous emission of two modelocked beams from the same linear cavity sharing all components. Initially surprising was the observation that the cavity length adjustments to stabilize one polarization did not significantly affect the pulse repetition rate of the other, but at the end we successfully stabilized both combs.

Session: Medicine and Biology - Prof. Natan T. Shaked**Clinical Detection of Dysplasia using Light Scattering and Interferometry *****Adam Wax***Department of Biomedical Engineering, Duke University, USA*

Detection of pre-cancerous (dysplastic) tissues in the clinic remains a challenge. Current methods often rely on systematic biopsies with no visual cues to guide the physician to areas likely to harbor dysplasia. We have developed a novel spectroscopic techniques for assessing cell structure and diagnosing disease based on combining interferometry with light scattering. Angle-resolved low coherence interferometry (a/LCI) combines the depth gating of coherence imaging with the high resolution structural information that can be obtained with light scattering spectroscopy. The a/LCI approach has been validated with in vitro measurements of phantoms and in vitro cells to recover structure with sub-wavelength accuracy and precision. Discrimination of pre-cancerous tissue states was initially demonstrated using animal models and ex vivo human tissues. We have developed a clinical a/LCI system, including an endoscope compatible fiber probe for in vivo measurements. The capabilities of a/LCI will be shown with results from clinical studies to detect precancerous cells in both the esophagus and cervix during routine clinical examination.

Applications of Inverse Scattering Principles with Digital Holography ***YongKeun Park***Department of Physics, KAIST, Republic of Korea
Tomocube Inc., Daejeon Republic of Korea*

In this talk, we will present the applications of inverse scattering principles with digital holography. First, I will present the recently developed 3-D holotomography setup using a dynamic mirror device, which is an optical analogous to X-ray computed tomography. In particular, I will discuss the visualization of 3D refractive index distributions of biological cells and tissues measured with the 3-D holotomography using the transfer function method. For a weakly scattering sample, such as biological cells and tissues, a three-dimensional refractive index tomogram of the sample can be reconstructed with the inverse scattering principle from multiple measurements of two-dimensional holograms. The outcome demonstrates outstanding visualization of 3D refractive index maps of live. In addition, we also discuss the applications of inverse scattering principle for highly scattering layers. With wavefront shaping techniques using digital holography, we demonstrate ultra-high-definition dynamic holographic display exploiting large space-bandwidth in volume speckle. Exploiting light scattering in diffusers, we also demonstrate the holographic image sensor which does not require for the use of a reference beam

1. Kyeoreh Lee et al, arXiv preprint:1612.00044
2. Kyeoreh Lee et al, Nature Communications, 7:13359 (2016)
3. Hyeyoung Yu et al., Nature Photonics, in press

Imaging with Scattered Light: Looking Through the 'Fog' *

Ori Katz

*Department of Applied Physics, The Selim and Rachel Benin School of Computer Science & Engineering
The Hebrew University of Jerusalem, Israel*

Scattering of light in complex samples such as biological tissue renders most samples opaque to conventional optical imaging techniques, limiting the penetration depth of even the state of the art microscopy techniques to a fraction of a millimeter in tissue. However, although random, scattering is a deterministic process, and it can be undone, controlled, and even exploited by carefully shaping the input wavefront, forming the basis for the emerging field of optical wavefront-shaping [1,2], and opening the path to imaging through visually opaque samples [3] and to the control of scattered ultrashort pulses [4]. Unfortunately, many of these pioneering demonstrations [1-4] required an invasive implantation of an optical probe at the target for determining the wavefront distortions. I will present some of our recent efforts in addressing this challenge [5-10]. These include the use of the photoacoustic effect to focus and control light non-invasively inside a scattering medium [5-7], and the use of optical nonlinearities to focus light noninvasively through scattering samples [8]. I will also show how one can surprisingly image through opaque samples and 'around corners' using nothing but a smartphone camera [9], by exploiting the inherent correlations of scattered light, challenging the common view on diffuse scattered light as an information-less halo. If time permits I will present our efforts in exploiting these principles for endoscopic imaging [10].

References

- [1] Z. Merali, "Optics: Super vision", *Nature* 518, 158 (2015). [2] A.P. Mosk et al., "Controlling waves in space and time for imaging and focusing in complex media", *Nature Photonics* 6, 283 (2012). [3] O. Katz et al., "Looking around corners and through thin turbid layers in real time with scattered incoherent light", *Nature Photonics* 6, 549 (2012). [4] O. Katz et al., "Focusing and compression of ultrashort pulses through scattering media", *Nature Photonics* 5, 372 (2011). [5] T. Chaigne et al. "Controlling light in scattering media noninvasively using the photo-acoustic transmissionmatrix.", *Nature Photonics* 8, 58 (2014). [6] T.Chaigne et al. "Super-resolution photoacoustic fluctuation imaging with multiple speckle illumination", *Optica* Vol. 3, 1, 54-57 (2016) [7] E.Hojman et al. "Photoacoustic imaging beyond the acoustic diffraction-limit with dynamic speckle illumination and sparse joint support recovery", arXiv:1612.08278 (2016) [8] O.Katz et al., "Noninvasive nonlinear focusing and imaging through strongly scattering turbid layers", *Optica*, 1, 3, 170-174 (2014). [9] O. Katz et al., "Non-invasive single-shot imaging through scattering layers and around corners via speckle correlations", *Nature Photonics*, 8, 784-790 (2014) [10] A.Porat et al., "Widefield lensless imaging through a fiber bundle via speckle-correlations", *Optics Express* (2016).

Session: Remote Sensing - Dr. Eyal Agassi

Atmospheric Limitations on the Performance of Electro-Optical Systems *

Karin Stein, Szymon Gladysz, Dirk Seiffer, Andreas Zepp

Fraunhofer Institute of Optronics, System Technologies and Image Exploitation, Germany

Atmospheric effects limit the performance of any electro-optical (EO) system. Tasks such as laser communications or horizontal-path imaging for long-range surveillance are highly affected by environmental effects. In the majority of cases, atmospheric effects impose a fundamental limitation to the capability of EO systems. The main limiting factors are atmospheric transmission, turbulence and refraction. For military reconnaissance and surveillance, limiting factors as described above cause reduced range for detection, recognition and identification. Here, it is absolutely exigent to make a fast decision whether a suspicious object is a threat or not. Loss in signal quality could lead to incorrect decisions which in turn could have grave consequences.

To investigate the statistical behaviour of turbulence effects, Fraunhofer IOSB performed several long-term measurements of optical turbulence close to the ground in different environments, over land and over sea, in sub-arctic, moderate and arid climates. We have built a large database of diurnal and seasonal variations of turbulence. These measurements serve the purpose of basic meteorological research and have lead to improvement of atmospheric models.

A correction of atmospheric effects on the propagation of light can be done by adaptive optics (AO). AO technology shows great promise for improving the performance of laser communications and directed-energy weapons even in strong turbulence and/or horizontal-path propagation. Knowledge of statistics of atmospheric turbulence is essential for practical design of AO systems.

The presentation gives an overview of the work at Fraunhofer IOSB related to atmospheric measurements and modelling. Moreover, it describes the possibilities to improve the performance of horizontal-path EO systems.

Keywords: imaging through turbulent media, atmospheric turbulence, atmospheric simulation model, adaptive optics

Theranostics Techniques based on Plasmon-Coupled Probes *

Dror Fixler

Faculty of Engineering, Bar-Ilan University, Israel

Light and tissue-cells interaction is common in clinical treatments and bio-medical researches. In our talk, we will describe biological application using nanophotonics techniques in medicine. Identification and treatment of inflamed, unstable atherosclerotic lesions is challenging. Recent studies have shown that gold nanoparticles (GNPs) are taken up by macrophages, and that high density lipoprotein (HDL) attenuates atherosclerotic vascular disease by exerting anti-inflammatory effects. I will present a new method that we developed for highly sensitive dual modal imaging system designed for GNPs conjugated to various fluorophores and these GNPs coupled with HDL to enable both detection and treatment targeted directly to macrophage-rich plaques.

Ray Tracing Engine for Atmospheric Propagation

Itay Naeh

Rafael, Israel

Introduction: Modeling the process of propagation in turbulent atmosphere is of great importance and great difficulties. Within the same simulation there are 9 orders of magnitude to be modeled simultaneously: The propagation of $1\mu\text{m}$ wavelength through 1mm features of turbulent atmosphere for a distance of kilometers. The common simulative approaches treat the atmosphere and the propagation process in a statistical manner, and fail to provide deterministic and accurate description of the process.

This work presents a newly developed method that treats the propagation process, for the first time, as a deterministic and accurate process. The insights that will emerge from this work will be relevant for any turbulence strength, at any propagation distance and any type of source.

Background: The most commonly used approach for modeling propagation of laser radiation through turbulent atmosphere is the Split-Step Fourier approach. This approach reduces the 3D turbulent atmosphere into 2D phase screens positioned along the propagation path. The distance between the phase screens is several meters at least, which causes critical misrepresentation of the media.

Objective: In order to increase the validity of the simulation and produce reliable results under all atmospheric condition, several abilities were developed. These abilities will allow treating the process in a realistic and deterministic manner.

Methods: The new simulative approach includes the modeling of the atmosphere using the Sparse Spectrum Harmonic Augmentation method, and modeling the propagation process as a continuous ray calculation using a newly developed ray tracing engine.

Results: This simulation allows, for the first time a deterministic observation on the fine features of the propagation process, without the approximations that undermine the reliability of the results.

Ceilometer Evaluation of the East Mediterranean Mixing Layer Height and Dust Movement - First Study of a Few Israeli Sites

Leenes Uzan

Tel Aviv University, Israel

Introduction: Understanding of the main properties of atmospheric layer structure, their height (MLH) and temporal evolution is essential for meteorological forecasting, climate studies and air-quality assessments. For the first time, high resolution measurements (every 15s and 10m between 0–4.5km) of attenuated backscatter, taken from a few CL31 ceilometers located on shore an inland in Israel, enabled evaluation of the mean MLH diurnal-cycle MLH and dust movement in the east Mediterranean region.

Background: Temperature profiles are measured in Israel by radiosondes (RS) twice a day at a single point, providing rough estimates of the MLH, due to the arbitrary ascents in thermals or between thermals. However, ceilometers, originally intended for cloud detection, produce attenuated backscatter plots directly relative to the atmospheric aerosol content and are therefore potentially useful for investigation of the MLH cycle and aerosol movement.

Objectives: Evaluation of the mean diurnal-cycle of the MLH and aerosol movement over Israel.

Methods: The ceilometer output profiles and MLH were processed by a MATLAB script and wavelet covariance transform calculations as a tool to detect the aerosol structure, MLH and cloud cover. MLH was compared to the adjacent radiosonde profiles and referenced to prevailing synoptic system, sea breeze front entrance time, back trajectories, and dust forecasting models.

Results and Conclusions: 2014 summer (2014) study, showed a 200 m difference between onshore and inland sites and the influence of the sea breeze front inland progresses. RS measurements showed good correlation with the ceilometer MLH. 2014 was a cloudy summer in contrary to the clear sky commonly expected. Evolution of dust above the region proved to be 3D and more complicated than evaluated by the models- temporally and spatially.

Analysis of Space based Cloud Images and Comparison to a Previous Model

Shimshon (Steven) Lashansky, Yuval Erez, Yossi Kamari

Elbit Systems ISTAR, Israel

In prior work performed by the author a spatial and statistical model for ground based IR cloud images was developed. This model has been widely used by a number of authors for simulating cloud images. The availability of multispectral space based cloud images provides an opportunity for extending and improving the model. The power spectrum and autocorrelation functions were calculated for the multispectral space based cloud images. The results are compared to a previous model. The results are analyzed and an improved model is presented.

EView - Automated Spectral Interpretation System**Tal Feingersh, Efraim, Y. and Traistman***Israel Aerospace Industries, Israel*

Processing of spectral imagery from space requires several calibration procedures, an application-wise interpretation process for information extraction, geometric correction of the resulting map and production to a geographical information system (GIS). Most of this processing chain is done manually by value adding companies and requires expert knowledge. Specific requirements also arise for specific sensors, especially in terms of the calibration process. The system processes images that contain at least four spectral bands having wavelengths in the solar reflective range of 400–2500nm. EView is able to support multiple spectral-EO missions (operational & planned, of IAI and others), including VENµS (CNES & ISA research mission) with 12 spectral bands within 400–950nm, SHALOM (ASI & ISA commercial mission) with 210 effective spectral bands within 400–2500nm, among others. EView performs various calibrations, interpretation and production of thematic maps automatically. Inputs are raw images and metadata, and processing is dynamic according to algorithms chosen by the user within a UI. Applications met by EView cover a variety of economic sectors including Precision Agriculture & Forestry, Illicit crop detection, Energy & Mineral exploration, Water quality & fishery, Coastal management, Environment monitoring & pollution, Urban growth, Spectral change detection and Disaster management. EView is flexible and extensible, and as such supports the addition of new spectral sensors and new algorithms by users, via a simple graphic interface. EVIEW architecture is also flexible, and designed using a modular data access layer to algorithms and sensors, being replaceable easily if required. Research and Development of EView is carried out in MBT-Space, at the MTH Division of IAI. The first version of EView is to be released within Q1 of 2017. Further development is planned throughout 2017 towards version 2.0 with additional features added.

Session: Optical Engineering - Dr. Ariela Donval**Recent Developments in High Performance Quantum Cascade Lasers *****Kumar N. Patel***Pranalytica, Inc., USA*

Mid wave infrared (MWIR) and long wave infrared (LWIR) quantum cascade lasers are becoming increasingly accepted for broad range of defense, homeland security and commercial applications. The defense applications, which led the early as well as recent development of QCL technology, include infrared countermeasures to protect aircraft from MANPADS, targeting and illumination, personnel beacons and detection of chemical warfare agents and improvised explosive devices (IEDs). The commercial applications include the semiconductor industry, healthcare and biopharma industries and environmental monitoring. The expansion of applications have come about because of the improvements QCL performance in the MWIR and LWIR regions (covering 3.5 µm to about 12 µm), which include increase in the power output from these lasers as well as from improvement in wall plug efficiency, lifetime and reproducibility. A recent development is the ultra rapidly and broadly tunable quantum cascade laser that provides wavelength switching speeds of < 1µs for jumping between any wavelengths in the operating spectrum of the QCL. Furthermore, the tuning is achieved using all electronic mechanism with no moving parts, making the system very rugged and immune to mechanical vibrations and shocks. The switching speed capability and ruggedness makes the system ideal for vehicle mounted applications including IED detection. The fast scanning capability also points to vast range of applications where spectral information needs to be acquired before the changes in the spectrum occur, such as combustion and explosion dynamics. The all electronic tuning has also made possible the first operation of a tunable QCL simultaneously at two distinct and independently switchable and tunable wavelengths. This capability has also allowed us to measure the QCL lasing level lifetimes in an operational high power QCL. Thus, the all electronic rapid tuning capability opens up new application areas for QCLs. I will describe the details of recent developments and also focus on the future of QCL technology.

Restoring Light Sensitivity to Blind Retina *

David Rand^{1,2}, Dorit Raz-Prag^{1,2}, Lilach Bareket^{1,2}, Gur Lubin^{1,2}, Nir Waiskopf³, Eric Daniel Głowacki⁵, Moshe David-Pur^{1,2}, Marie Jakesova⁴, Niyazi Serdar Sariciftci⁴, Uri Banin³ and Yael Hanein^{1,2}

1. School of Electrical Engineering, Tel Aviv University, Israel

2. Tel Aviv University Center for Nanoscience and Nanotechnology, Israel

3. School of Chemistry, The Hebrew University, Israel

4. JLinz Institute for Organic Solar Cells (LIOS), Johannes Kepler University, Austria

5. Physics and Electronics Division, Linköping University, Sweden

Retinal prosthetic devices aim to restore sight in patients suffering from degenerative diseases of the retinal photoreceptor layer, such as Age related Macular Degeneration (AMD) and Retinitis Pigmentosa (RP). In these diseases the inner neuronal layers of the retina remain largely intact. Thus, retinal implants attempt to replace the photosensitive elements of the retina and electrically stimulate the surviving neurons. Contemporary retinal implants currently on the market or in development are miniaturized electronic devices, based on standard materials used by the semiconducting industry: metals and silicon. Their rigidity and the requirement to operate in a dry environment make these electronic devices an inappropriate solution for the soft and wet biological tissue.

Our novel approach to retinal prosthesis is based on photosensitive nanomaterials that offer a flexible, biocompatible, and wireless solution. The device is based on carbon nanotubes (CNTs) electrodes that are modified to become photosensitive by either conjugating them to semiconducting-nanocrystals (Quantm Rods -QR)1 or coating them with organic semiconductor nanocrystalline dyes (OSND). These photosensitive CNT electrodes are transferred onto biocompatible film that serve as a carrier to form a retinal implant. We have shown the ability of such photosensitive CNT electrodes to evoke neural responses of retinal ganglion cells in an isolated blind retina and tested them for biocompatibility in both rats and rabbits.

References

1. Bareket, L. et al. Semiconductor nanorod–carbon nanotube biomimetic films for wire-free photostimulation of blind retinas. *Nano Lett.* 14, 6685–92 (2014).

Optics Manufacturing in a Digitalized Production Environment

Holger Kreilkamp

Fraunhofer-Institute for Production Technology IPT, Germany

Digitalization, adaptivity and networked production are dominant issues for state of the art manufacturing technologies and will continue to have a substantial impact on their advancement and development. This applies especially to complex process chains, characterized by multiple and non-trivial interdependencies, such as the replicative manufacturing of optical components and systems. Ranging from the optical design, the FEM simulation and the mold manufacturing, down to the actual molding process and the assembly of the optical system, this process chain today reveals a low grade of automation as well as insufficient (data-)standards and an inadequate information flow over the different process steps. Since most of the single technologies are at the brink of technical feasibility, future components will need the ability to exploit the vast potential of interconnected and adaptive process chains. In order to promote and advance this transition in the field of replicative optics manufacturing the Fraunhofer IPT has elaborated an innovative and comprehensive data solution concept, which has been implemented within the precision glass molding process (PGM). In a specially equipped glass molding machine, tailored sensor systems are collecting multiple data concerning the molding process, such as temperature, force and pressure profiles. This information is acquired in real time and serves the purpose of immediate visualization and the reconstruction of the manufactured component as digital twin. The visualization is being demonstrated by smart devices such as Smart Glasses, suppling digital process data as valuable insights to a black box manufacturing step in addition to the real world vision of the operator. Beyond this, all data are fed into a superior data backbone, allowing the reconstruction of an exact digital image of the component, highly valuable to adapt downstream and upstream processes, granting a glance on what future optics production in a totally digitalized production environment will look like.

Optical Coating by Atomic Layer Deposition (ALD)

R. Cohen¹, L. Riber², A. Shechter², A. Glushko¹, H. Einati¹, D. David¹

1. RD&E, Optical Fab, Israel

2. Elbit Systems, Electro-Optics-ELOP, Israel

Atomic layer deposition (ALD) is a chemical vapor deposition technique based on sequential self-terminating gas-solid reactions capable of producing thin films of a variety of materials.

The potential use of this technique for optical coatings of electro-optics components has been investigated using spectroscopic measurements, Laser damage threshold testing's and environmental durability assessment in accordance with MIL-C-675.

Single and multilayers AR coatings of SiO₂, TiO₂ and HfO₂ on BK-7, fused silica and Sapphire substrates were evaluated.

The optical spectral performance of the coating was in correlation with the optical simulation design.

The coatings have passed environmental endurance per MIL-C-675 successfully. AR coatings of SiO₂ and HfO₂ on BK-7 substrates showed high laser damage threshold of above 1 GW/cm². The potential use of ALD technique for optical coating will be discussed.

Keywords: Optical coating, ALD, Laser damage.

Optical Engineering with Compressive Sensing

Adrian Stern

Electro-Optics Engineering Unit, Ben-Gurion University of the Negev, Israel

The theory of compressive sensing (CS) has revolutionized the way that scientist and engineers think on data acquisition. CS has broken the celebrated Shannon-Nyquist sampling paradigm that has dominated for nearly a century. It has introduced a much more economical sensing framework promising many system design and performance benefits. CS has found natural applications in imaging and optical sensing sciences, yielding a great number of publications. By employing CS principles for optical imaging and sensing it was possible to demonstrate reduction of the acquisition effort, improvement of the sensing performances, reduction of the data saving memory and transmission bandwidth, and reduction of the size and weight of the optical systems. Now, from more than a decade perspective, we will survey the main applications and will present representative examples from our group results. We will highlight the benefits gained from the application CS in optical engineering, discuss its limitations and its potential future applications.

Expanded Range of Sapphire Configurations using Bonding Techniques

Jeremiah Fitzgibbon

Gavish Inc., USA

Industrial sapphire has many applications in aerospace, medical devices, semiconductor manufacturing, chemical manufacturing, analytical instruments, and many more. Joining sapphire to itself and other materials is an important capability to enable industrial applications. Currently, methods to join sapphire are limited to adhesives, solders, and direct-bonding. Adhesives and solders are not compatible with many applications, specifically those requiring elevated temperatures and/or corrosive chemistries. Direct-bonding has very limited applications; it is extremely costly, low yield, and applicable only for matched crystal structures. We have demonstrated the feasibility of using a newly developed process to bond sapphire which provides high-temperature, corrosion resistant bonds which can join sapphire regardless of crystal structure to itself and to other materials. This capability opens significant new market opportunities for industrial sapphire. Gavish and CRC will review a number of successful applications of this bonding technology as well as overview applications now in the early development phase.

Session: Non-linear Optics - Prof. Meir Orenstein

Quantum Imaging *

Robert W. Boyd

University of Rochester, USA

University of Ottawa, Canada

In this talk, I present an overview of three topics of significance to the field of quantum sensing. I first review the field of quantum imaging. This field strives to develop methods for making images sharper or clearer through the use of quantum aspects of light. Specific topics to be treated include two-color ghost imaging, interaction-free ghost imaging, imaging with photon-added states, and imaging with “undetected photons.” I will then turn to a brief discussion of structured light fields and their potential for the dense coding of information onto individual photons. I also describe a quantum communications system that can transmit more than one bit of information per photon. Lastly, I turn to a discussion of materials and structures for quantum sensing. Specific topics include the large nonlinear response available from epsilon-near-zero materials, single-photon sources, and chip-scale devices for quantum sensing.

Nonlinear Plasmonics at High Temperatures and Thermo-Optic Metamaterials

Yonatan Sivan

Unit of Electro-Optics engineering, Ben-Gurion University, Israel

Recently, intriguing experimental results of the scattering of intense visible CW light from single Au and Ag nanoparticles were reported in [1]. Specifically, it was shown that at moderately high incident intensities, the scattering was lower than the linear prediction, showing “saturation-like” behaviour, whereas for even higher incident intensities, the scattering grew rapidly, even exceeding the linear prediction, see Fig. 1; the results were fully reversible, and no damage to particles was observed. Notably, this is one of the highest nonlinear responses ever reported, as more than a 100% strong effect is obtained within a deep subwavelength volume, and probably the first quantitative experimental study of the slow nonlinearity of metals. Most remarkably, no convincing explanation to the physical origin of this effect was reported.

Based on newly measured permittivity data of Au under increasing temperatures [2], we show that the initial decrease of the scattering can be explained by the thermal nonlinear optical response of the metal to CW light [3]. In contrast to the multitude of studies of the ultrafast regime and the electron temperature contribution, we provide an elaborate solid state model that explains for the first time, the dependence of the metal permittivity on the lattice temperature.

Lastly, we report calculations of thermo-optical metamaterials, whereby the thermal nonlinearity of the metal spheres, embedded in a dielectric host can give rise to high effective nonlinear coefficients. Importantly, unlike the standard nonlinear metamaterials based on an ultrafast nonlinearity, we maintain a low overall absorptivity for the composite, enabled by the long range nature of the thermal response.

We believe that this work is the first out of a series of future studies of the slow nonlinearity of metals, and its exploitation in applications of high temperature nonlinear plasmonics, especially for refractory metals, both for CW and pulsed illumination.

References

- [1] S.W.Chu et al, Saturation and reverse saturation of scattering in a single plasmonic nanoparticle. ACS Photon 2013;1:32-7. Y.-T. Chen et al., Study of Nonlinear Plasmonic Scattering in Metallic Nanoparticles. ACS Photonics 2016; 3:1432-1439.

- [2] P.-T Shen et al, Temperature- and -roughness dependent permittivity of annealed/unannealed gold films. *Optics Express* 2016; 24:19524. H. Reddy et al, Temperature-dependent optical properties of gold thin films. *Optical Materials Express* 2016; 6: 2776-2802.
[3] Y. Sivan, S.W. Chu, Nonlinear plasmonics at high temperatures. *Nanophotonics* 2016.

Three-Dimensional Spatiotemporal Pulse-Train Solitons: First Experimental Observation of 3D Solitons

Oren Lahav, Ofer Kfir, Pavel Sidorenko, Maor Mutzafi, Avner Fleischer and Oren Cohen*

Department of Physics and Solid State Institute, Technion, Israel

Three dimensional optical spatiotemporal solitons (STS) – fully localized wavepackets that are self-trapped simultaneously in two transverse directions and one longitudinal (temporal) direction [1,2] – have been attracting much interest since they were first proposed in 1990 [3]. While 2D STS [4] and quasi 3D STS [5,6] in waveguide array were demonstrated, the experimental demonstration of 3D STS, especially in homogeneous media, is still considered a ‘grand challenge’ in nonlinear optics [1,2]. Here, we demonstrate experimentally the first 3D spatiotemporal solitons. In 2009, the concept of spatiotemporal pulse-train solitons was proposed [7,8] which employs two nonlinearities with very different response times. Consequently, the pulse-train beam is self-trapped in space due to a slowly responding self-focusing nonlinearity (with response time that is much longer than the time interval between consecutive pulses in the train) and simultaneously each pulse is temporally self-trapped by a fast nonlinearity. Here, we demonstrate the first experimental observation of three-dimensional spatiotemporal pulse train solitons. We use a 30 fs pulse-train beam from a Ti:Sapphire laser ($\lambda=0.8 \mu\text{m}$) with 1 KHz repetition rate. Since the dispersion is normal in this wavelength, dark pulses are used to get temporal self-trapping. Using a pulse shaper, we generated short dark pulses with $\sim 100\text{fs}$ pulse width in a relatively wide background and focus the beam ($\text{FWHM} \approx 15 \text{ m}$) to a photorefractive strontium barium niobate bulk crystal with $L=15\text{mm}$ propagation distance. We recorded the spatial intensity distribution of the beam and simultaneously reconstructed the temporal shape of the pulses by spectral interferometry measurements. In the linear propagation regime, the spatiotemporal wavepacket broadened spatially ($\sim \times 29$) and temporally ($\sim \times 2$). At high intensity, the pulse-train beam formed a 3D spatiotemporal pulse train solitons, maintaining the wavepacket spatial and temporal widths. We also observed 3D spatiotemporal pulse train solitons in $L=6\text{mm}$ crystal. This work opens the door to experimental investigations of interactions between 3D solitons, for the first time in any system in nature.

References

- [1] F. W. Wise and P. Di Trapani, “The hunt for light bullets – spatiotemporal solitons,” *Opt. Photonics News* 29-32 (2002). [2] B. A. Malomed, D. Mihalache, F. W. Wise, and L. Torner, “Spatiotemporal optical solitons,” *J. Opt. B* 7, R53-R72 (2005). [3] Y. Silberberg, “Collapse of optical pulses,” *Opt. Lett.* 15, 1282-4 (1990). [4] X. Liu, L. J. Qian, and F. W. Wise, “Generation of Optical Spatiotemporal Solitons,” *Phys. Rev. Lett.* 82, 4631-4634 (1999). [5] S. Minardi, F. Eilenberger, Y. V. Kartashov, A. Szameit, U. Röpke, J. Kobelke, K. Schuster, H. Bartelt, S. Nolte, L. Torner, F. Lederer, A. Tünnermann, and T. Pertsch, “Three-Dimensional Light Bullets in Arrays of Waveguides,” *Phys. Rev. Lett.* 105, 263901 (2010). [6] F. Eilenberger et al, “Observation of discrete, vortex light bullets,” *Phys. Rev. X* 3, 041031 (2013). [7] H. C. Gurgov and O. Cohen, “Spatiotemporal pulse-train solitons,” *Opt. Express* 17, 7052-8 (2009). [8] I. B. Burgess, M. Peccianti, G. Assanto, and R. Morandotti, “Accessible Light Bullets via Synergetic Nonlinearities,” *Phys. Rev. Lett.* 102, 203903 (2009).

Phase Sensitive Parametric Amplification in InGaP Photonic Crystal Waveguide

A. Willinger¹, A. Martin², S. Combrié³, A. De Rossi³, G. Eisenstein¹

1. Department of Electrical Engineering and Russell Berrie Nanotechnology Institute, Technion, Israel
2. Centre de Nanosciences et de Nanotechnologies, CNRS, Univ. Paris-Sud, University of Paris-Saclay, C2N Marcoussis, France
3. Thales Research and Technology, France

Phase sensitive parametric amplification (PSA) involves three coherent fields, with the gain experienced by one of them depending on the mutual phase relationship of all three. PSA is unique since it offers, in principle, a noise figure of unity (0dB) [1]. PSA employing nonlinear fibers was used in several experiments which demonstrated low noise amplification and phase noise regeneration [2, 3]. Compact semiconductor waveguide based PSA was also demonstrated in various nonlinear materials [4, 5]. Those use pulsed pumps and reached a phase sensitive extinction ratio (PSER) of about 10dB. Typical lengths are a few cm and the peak pump power is up to 10W. The PSA we report employs a 1.5mm long, dispersion engineered InGaP photonic crystal (PhC) waveguide, according to the design in [6]. The characterization setup uses a fiber laser emitting 1.4ps wide pulses at a repetition rate of 20MHz. The pulse’s spectrum is sliced to form three 60ps coherent pulses at different wavelengths detuned by 0.5nm from each other. The powers of the longest and shortest wavelength pulses (pumps) are 16dB higher than that of the center wave which is the signal. The three waves are amplified and then propagate in free-space before being coupled to the waveguide. The output signal is examined in both the spectral and the time domains. The signal wavelength was set to 1555nm and we measured the phase dependent gain for different total pump peak powers. The gain varies cyclically with a period of π/rad , and the PSER increases with the pump power from 4dB to 10dB, when up to 0.5W total peak pump power was used. The measurements were repeated for a signal wavelength of 1561.8nm keeping the pump detunings at 0.5nm. The PSER decreases at the longer wavelengths due to the higher loss for which the nonlinear parameter cannot compensate. The phase sensitive response was also computed using numerical simulations, showing good agreement with the measured results.

References

1. Y. Mu and C. M. Savage, “Parametric amplifiers in phase-noise-limited optical communications,” *J. Opt. Soc. Am. B* 9, 65-70 (1992).
2. R. Slavik, F. Parmigiani, J. Kakande, C. Lundstrom, M. Sjodin, P. A. Andrekson, R. Weerasuriya, S. Syrigatos, A. D. Ellis, L. Gruner-Nielsen, D. Jakobsen, S. Herstrom, R. Phelan, J. O’Gorman, A. Bogris, D. Syridis, S. Dasgupta, P. Petropoulos, and D. J. Richardson, “All-optical phase and amplitude regenerator for nextgeneration telecommunications systems,” *Nat Photon* 4, 690-695 (2010).
3. T. Richter, C. Meuer, R. Ludwig, and C. Schubert, “Black-box phase-sensitive fiber-optic parametric amplifier assisted by a semiconductor optical amplifier,” in “Optical Fiber Communication Conference,” (Optical Society of America, 2012), p. OM3B.4.
4. R. Neo, J. Schröder, Y. Paquot, D.-Y. Choi, S. Madden, B. Luther-Davies, and B. J. Eggleton, “Phase-sensitive amplification of light in a $\chi(3)$ photonic chip using a dispersion engineered chalcogenide ridge waveguide,” *Opt. Express* 21, 7926-7933 (2013).
5. F. D. Ros, D. Vukovic, A. Gajda, K. Dalgaard, L. Zimmermann, B. Tillack, M. Galili, K. Petermann, and C. Peucheret, “Phase regeneration of dpss signals in a silicon waveguide with reverse-biased p-i-n junction,” *Opt. Express* 22, 5029-5036 (2014).
6. S. Roy, M. Santagustina, P. Colman, S. Combrié, and A. De Rossi, “Modeling the dispersion of the nonlinearity in slow mode photonic crystal waveguides,” *Photonics Journal* 4, 224-233 (2012).

Photonic Topological Insulators and Topological Lasers ***Mordechai (Moti) Segev***Technion, Israel*

I will review the recent progress in the new area of Topological Photonics, discuss Photonic Topological Insulators, and present new ideas among them topological insulator lasers: lasers whose cavity is robust to disorder and defects, with high slope efficiency that remains unchanged even under large disorder, because the cavity acts as a “superconductor for light”.

Session: IFLA, Fiber Laser Technology - Dr. Yoav Sintov**Keynote Lecture: Technical Advances and Future Prospects of Fiber Lasers and Amplifiers****A. Tünnermann***Friedrich Schiller University Jena, Institute of Applied Physics, Germany*

In the past years rare-earth-doped fiber lasers have emerged as attractive and power scalable solid-state laser concept due to the outstanding thermo-optical properties of an actively doped fiber. The large ratio of surface to active volume of such a fiber ensures excellent heat dissipation, furthermore the beam quality is defined by the refractive index profile of the active core and is therefore independent on the pump power. Fiber lasers and amplifiers offer a very high single-pass gain and therefore low laser thresholds and efficient diode-pumped operation. Using advanced fiber designs, in continuous-wave (cw) operation output powers exceeding the 10 kW-level with diffraction-limited beam quality have been demonstrated. In the pulsed regime average powers in the order of several hundred Watt even for few cycle pulses based on fiber lasers have been reported.

However, power and energy scaling of cw and pulsed single-mode fiber lasers and amplifiers is restricted due to nonlinear pulse distortions, which are enforced by the large product of intensity and interaction length inside the fiber core. In addition, transverse mode instabilities are observed which degrade the beam quality emitted by high-power fiber laser systems once that a certain average power threshold has been reached. This sudden degradation of the output beam quality is accompanied by temporal fluctuations of the beam profile. Most recently, strategies have been developed to mitigate or even, ideally, to overcome these limitations – which will enable in future a further power scaling of lasers and amplifiers.

In this contribution the state of the art of science and technology in fiber lasers and amplifiers is reviewed. The prospects for future developments will be discussed.

Fiber Amplifiers and Lasers using Optical Orbital Angular Momentum OAM) Modes) ***Moshe Tur¹, Guodong Xie² and Alan Willner²**

1. School of Electrical Engineering, Tel-Aviv University, Israel

2. Department of Electrical Engineering, University of Southern California, USA

There exist beam wave solutions of Maxwell equations which carry orbital angular momentum (OAM) in the form of a helical transverse phase of the form, where ϕ is the azimuthal angle and, the OAM charge, is an unbounded integer (with either negative or positive signs) that represents the number of 2π phase changes in the azimuthal direction. In free space an OAM beam has a ring-shaped intensity profile with a central null. With an additional characteristic integer, which is related to the number of rings in the radial direction, the set $\{OAM_p\}$ is orthogonal and two-dimensional complete. OAM is yet another degree of freedom of the beam, orthogonal to all other multiplexing modes. Thus, in optical-, as well as in millimeter-wave communications, independent data streams can be transmitted over different OAM beams, simultaneously using time-, polarization-, wavelength and quadrature multiplexing. Indeed, an optical data link has been demonstrated involving the multiplexing/demultiplexing of 1008 data channels carried on 12 OAM beams (of different, 2 polarizations and 42 wavelengths. Each channel was encoded with 100 Gbit/s quadrature phase-shift keying, providing an aggregate capacity of 100.8 Tbit/s ($12 \times 2 \times 42 \times 100$ Gbit/s). OAM transmission in optical fibers has been also demonstrated over 1.1 km of a specially designed optical fiber that minimizes mode coupling, achieving 400-Gbit/s data transmission using four angular momentum modes at a single wavelength, and 1.6-Tbit/s using two OAM modes over 10 wavelengths. While the actual advantages of OAM transmission over other spatial division multiplexing schemes is still debatable, these demonstrations suggest that OAM could provide an additional degree of freedom for data multiplexing in future fiber networks.

Any serious use of OAM waves in communications networks or in other foreseeable applications requires optical amplification. Several publications already exist, describing amplifiers for OAM beams in both fiber and free space. Thus, 12 OAM modes have been simultaneously amplified in an air-core erbium doped fiber, while a Nd:YAG rod was used for the amplification of free space OAM beams. Lasers emitting OAM beams have also been studied.

The talk will describe the state-of-the-art of this technology, including current challenges.

Tunable Fiber Lasers in the 1μm and 2μm Wavelength Range using Fiber Bragg Grating Arrays ***Tobias Tiess¹, Martin Becker¹, Manfred Rothhardt¹, Hartmut Bartelt^{1,2}, Matthias Jäger²**

1. Leibniz Institute of Photonic Technology (IPHT) Jena, Germany

2. Abbe Center of Photonics, Friedrich Schiller University Jena, Germany

Due to the broad emission spectra of rare earth ions in glassy hosts, fiber lasers provide an excellent basis for widely tunable laser sources, also emphasized by their alignment-free operation, excellent beam quality and efficiency. We will report on a fiber-integrated tuning method that employs an array of fiber Bragg gratings (FBG) together with an optical modulator. The use of an FBG array (vs. a chirped FBG) has several advantages: It allows the electronic selection of wavelength and pulse width independent of each other, while providing narrow linewidth emission tunable over a wide spectral range, limited only by the gain spectrum. Furthermore, the draw tower grating technology provides easy access to customized FBG arrays with large numbers of FBGs and hence tailored emission wavelengths.

Two types of resonators have been investigated. The sigma cavity involves a single FBG reflection per roundtrip and was demonstrated for pulsed Ytterbium(Yb)- and Thulium(Tm)-doped fiber lasers with spectral tuning ranges of 74nm and 90nm, respectively. The spectral signal contrast is very good and typically better than 40dB. The Tm-doped laser was amplified in a master oscillator power amplifier (MOPA) configuration providing a tunable source near 2μm with an average power of 28W. The new theta cavity employs two FBG reflections per roundtrip (one from each side), effectively equalizing the path difference between various wavelengths. Consequently, it allows the operation with a constant wavelength-independent repetition rate, which is essential for applications requiring synchronization with the laser source. This important feature was verified in a first implementation of a theta cavity allowing a tuning range of 25nm with 10ns pulses. Future work will concentrate on increasing the tuning range, reducing the pulse duration into the picosecond range, and exploring the feasibility of a multi-wavelength operation. This work is funded in part by the BMBF Germany (contract 13N13865).

Session: Medicine and Biology - Prof. Natan T. Shaked

Physical Properties of Cells in Biology and Medicine *

Jochen Guck

Dresden University, Germany

While most current biological research focuses on molecular, biochemical aspects of cell processes, we are interested in the physical properties of cells and their importance for biological function. Many physiological and pathological changes of cells involve a restructuring of the cytoskeleton, and corresponding changes in their mechanical fingerprint. We are exploiting cell deformability as a sensitive marker of such functional changes using different photonic and microfluidic techniques. One such technique is a dual-beam laser trap called an optical stretcher. In order to quantify the cell deformations caused by optically induced stress, we determine the cells' 3D refractive index distribution using digital holographic microscopy (DHM) in combination with optical cell rotation and tomographic reconstruction by optical diffraction tomography (ODT). A surprising recent result is that, contrary to wide-spread belief, the nuclei of cells have a lower refractive index than the rest of the cell. Our optical stretcher findings suggest the use of cell compliance to monitor physiological processes, such as differentiation or cell division, as well as diagnosing pathologies, including cancer or infections. Wide-spread utilization of this insight has so far been impeded by the lack of sufficient throughput. To address this need, we have introduced real-time deformability cytometry (RT-DC) for the continuous mechanical single-cell characterization of large populations (> 100.000 cells) with analysis rates of 1,000 cells/s, approaching that of conventional fluorescence-based flow cytometers. Using RT-DC we can sensitively detect cytoskeletal alterations, distinguish cell cycle phases, track hematopoietic stem cell differentiation and characterize cellpopulations in whole blood by their mechanical fingerprint. Our results indicate that cell mechanics can define cell function, can be used as an inherent cell marker and could serve as target for novel therapies. Mechanical phenotyping adds a new functional, marker-free dimension to flow cytometry with diverse applications in biology, biotechnology and medicine.

Jochen Guck received his PhD in Physics from the University of Texas at Austin in 2001. After being a group leader at the University of Leipzig, he moved to the Cavendish Laboratory at Cambridge University as a Lecturer in 2007 and was promoted to Reader in 2009. Since 2012 he is Professor of Cellular Machines at the Biotechnology Center of the Technische Universität Dresden. He has authored over 80 peer-reviewed publications and four patents. His work has been recognized by several awards, amongst them the Cozzarelli Award in 2008, the Paterson Prize in 2011 and an Alexander-von-Humboldt Professorship in 2012.

Multi-Modal Digital Holographic Microscopy for Cancer Research, Drug Screening and Toxicity Testing *

Björn Kemper

Biomedical Technology Center of the Medical Faculty, University of Muenster, Germany

Label-free quantitative in-vitro imaging of living cell cultures with light microscopy is important for various research fields in life sciences. Quantitative phase microscopy (QPM) provides high resolution label-free imaging by detection of optical path length changes. As the object is illuminated in transmission only low light intensities are required. Thus, QPM minimizes the interaction with the sample which is highly beneficial for minimally-invasive long-term monitoring of sensitive biological specimens. Quantitative phase images provide data for simplified image segmentation and automated object tracking. Moreover, absolute biophysical cell parameters such as volume, refractive index and dry mass are accessed that are related to various cellular features and functions.

Digital holographic microscopy (DHM), an interferometry-based variant of QPM, can be integrated modular into various commercial microscopes for multi-modal imaging in a biomedical laboratory environment. The reconstruction of quantitative DHM phase images is performed numerically from digitally captured holograms. Hence, (subsequent) numerical refocusing, autofocusing and 3D tracking is achieved without mechanical focus realignment.

In overview DHM systems and methods for live cell observation, the extraction of biophysical parameter sets from quantitative phase images and selected applications in cancer research, drug screening and toxicity testing are presented. This includes the characterization of suspended cells and intracellular organelles as well as the quantification of the response of biophysical cell parameters to drugs, toxins, nanomaterials and genetic modifications. Furthermore, it is shown how DHM can be utilized for quantification of motility, migration and morphology of living cell cultures in 2D and 3D environments as well as for determination of inflammation mediated tissue density changes. Finally, biophysical phenotyping and dynamic multi-modal imaging of cellular growth during wound healing in-vitro is demonstrated. In conclusion, digital holography and related techniques of quantitative phase microscopy have high potential to become a powerful multifunctional routine tool for label-free cell and tissue imaging.

Monte Carlo Computational Tool for the Needs of Biophotonics and Biomedical Optics *

Igor Meglinski

Faculty of Information Technology and Electrical Engineering, University of Oulu, Finland

Conceptual engineering design and optimization of laser-based imaging techniques and optical diagnostic systems used in the field of biomedical optics requires a clear understanding of the light-tissue interaction and peculiarities of localization of the detected optical radiation within the medium. The description of photon migration within the turbid tissue-like media is based on the concept of radiative transfer that forms a basis of Monte Carlo (MC) modelling. An opportunity of direct simulation of influence of structural variations of biological tissues on the probing light makes Monte Carlo a primary tool for biomedical optics and optical engineering. Due to the diversity of optical modalities utilizing different properties of light and mechanisms of light-tissue interactions a new Monte Carlo code is typically required to be developed for the particular diagnostic application. Based on the collation of Monte Carlo simulation and the Bethe-Salpeter equation, represented as the series of ladder diagrams, we generalize the computational technique in framework of a common approach of Coherent Back Scattering (CBS) and temporal autocorrelation functions calculation, as well as for the Optical Coherence Tomography (OCT). The results of these simulations agree rather well with theoretical predictions of generalized Milne solution, as well as with the known experimental and numerical results. Current presentation reviews the approach that the author deals with the last years, and is introducing an online object oriented concept of Monte Carlo tool specially developed for the major applications in Biophotonics and Biomedical Optics.

Recent Progress in Transcranial Optical Vascular Imaging *Vyacheslav Kalchenko*Weizmann Institute of Science, Israel***Optical Blood Count ***Dvir Yelin*Technion, Israel*

Measuring the composition of a patient blood is often the first step in clinical diagnosis, and is commonly performed by extracting a blood sample for laboratory analysis. The use of invasive blood extraction, however, is often problematic with chronic patients, infants, and patients with needle phobia. Moreover, in areas with poor accessibility to large healthcare facilities and poor sanitary conditions, blood tests become challenging due to high risk of infection, sample contamination, and long waits for the test results. Several technologies exist for measuring single blood parameters (oxygen saturation, hemoglobin etc.) without using needles; however, these techniques suffer from relatively low accuracy, high sensitivity to skin color, and provide very few parameters that are often insufficient for diagnosis. A novel optical encoding technology, recently developed by our research group, allows high-resolution confocal microscopy of individual blood cells flowing within small blood vessels in the oral mucosa. The technique uses encoded imaging that allows real-time microscopy of a single transverse line within a blood vessel, producing detailed images of the passing blood cells, which are then analyzed for measuring the blood content and cell morphology. This *in vivo* blood microscopy technology could be incorporated into a portable instrument with a small handheld probe that is placed against the patient's lips. Based on the subcellular-resolution image data, the system can study blood cell flow within the body and potentially provide blood testing noninvasively at the point of care.

Session: Photonics in Defense - Dr. Joelle Schlesinger**Eyesafe Standoff Detection of Threats using Monolithically Tunable QCL Arrays ***Mark Witinski*Pendar Technologies, USA*

This presentation introduces the spectroscopic concepts and results enabled by arrays of Distributed Feedback (DFB) QCLs, with each element at a slightly different wavelength than its neighbor. In portable optical systems, such as standoff threat detectors and *in situ* gas analyzers, this increases analyte sensitivity and selectivity by broadening spectral source coverage while also allowing for extremely fast all-electronic wavelength tuning with no moving parts.

This talk will first present the QCL array and its packaging, then move into the description of an integrated prototype standoff detection system, and finally show condensed phase standoff threat detection results from a handheld system from over 1 meter. These data are each compared with legacy contact-based methods to ensure that the technique can be reliably deployed to handheld chemical analysis using suitable chemometric algorithms.

The data show how monolithic and all-electronic tuning enables next-generation spectrometers that are not only more robust and miniature than those that utilize external cavity-tuned lasers, but that are inherently more stable in terms the shot-to-shot amplitude and wavelength parameters. This enhanced stability increases signal to noise for a given configuration (pathlength, averaging time, concentration, etc...). Some discussion of how to maximize the benefits of high speed, highly reproducible tuning is presented, including detector, preamplifier, and digitization considerations.

III-V Semiconductor Photodetectors at SCD *Itay Shtrichman*SemiConductor Devices (SCD), Israel*

SCD is a leading manufacturer of infrared (IR) detectors for both defense and commercial applications. Over the last few years SCD has developed a range of advanced two-dimensional array detectors based on III-V semiconductor materials for high-end imaging in the Short-Wave IR (SWIR), Mid-Wave IR (MWIR), and Long-Wave IR (LWIR). Lattice-matched hetero-structure devices are grown by MOCVD or MBE on InP, InSb and GaSb substrates. Standard photolithography defines the detector array, up to 3M-pixel format and down to 10 mm pitch. Flip-chip bonding is used for coupling the detector array to the CMOS based Readout IC (ROIC), and backside thinning finally forms the Focal Plane Array (FPA). The FPA is then packaged in a vacuum Dewar and cooled to its operating temperature. In this work I will focus mainly on two relatively new types of photodetector: The XBn-InAsSb for High Operating Temperature (HOT) MWIR detectors, and the InAs/GaSb Type-2 SuperLattice (T2SL) for LWIR detectors.

Reactive Magnetron Sputtered Multilayer SiO₂ Er₂/ O₃ Antireflection Coatings for Dual Band Infrared Transmission

Rakefet Samueli¹, I. Zukerman², S. Waichman¹, R. Manor¹, A. Raveh¹

1. Advanced Coatings Center, Rotem Industries Ltd., Israel

2. NRC-Negev, Israel

Introduction: The continuous advancement of high performing intelligence, surveillance and high-energy laser systems has created a need for specialized optical coatings. Erbium oxide (Er₂O₃) is a specifically interesting coating material, with its chemical and thermal stability at high temperatures, and high transparency and refractive index.

Objectives: In this study, we've compared different coating structures comprised of Er₂O₃ and silicon dioxide (SiO₂) for ultra-efficiency, dual band antireflection (AR) coatings on three substrate materials: (1) sapphire (2) fused silica (3) zinc sulfide (ZnS) for the wavelength ranges of 1.9–2.5μm; 3.6–5μm, and robust environmental durability.

Methods: The coatings developed are nanocomposite thin films, alternating between high index Er₂O₃ and low index SiO₂. Two coating designs were simulated on each substrate by using a simulation software, OpenFilters1 : (1) a double-layer coating of SiO₂/Er₂O₃ (2) a quadruple-layer coating of SiO₂/Er₂O₃/SiO₂/Er₂O₃. We optimized the layers for broadband (1.9–2.5μm; 3.6–5μm) and omnidirectional (0° – 45° incidence) antireflection. The coatings were experimentally deposited on the substrates using reactive magnetron sputtering. The Er₂O₃ coatings were dense and contained a mixture of cubic and monoclinic phases, a maximum compressive stress of 1 GPa, a refractive index of 1.82, and a high deposition rate of 100 nm/min. The SiO₂ coatings were deposited with an amorphous structure at a typically low deposition rate of ~2–4 nm/min, with a maximum compressive stress of 0.2 GPa and a refractive index of 1.49.

Results and Conclusions: The optimal coating for sapphire and fused silica was the quadruple layer coating, with an average reflectance of 2.1% and 1.4%, respectively. Alternatively, the optimal coating for ZnS was the double layer design, resulting in 1.5% average reflectance. The theoretical calculations of the average reflectance and the experimentally measured results showed a mean difference up to 7.8%, evidencing the reliability of OpenFilters as a multi-layer coating design tool.

Keywords: photonics in defense, optical engineering, antireflection coating, dual band transmission, infrared, nanocomposite thin film

1. Larouche, S. & Martinu, L. OpenFilters: open-source software for the design, optimization, and synthesis of optical filters. *Appl. Opt.* 47, 219–230 (2008).

First Field Demonstration of Standoff Detection of Buried Landmines using Fluorescent Bacterial Sensors

Yossef Kabessa¹, Victor Korouma¹, Tali Septon¹, Yonatan Anati¹, Sharon Yagur-Kroll², Cheinat Zohar-Perez³, Zahi Rabinovitz³, Amos Nussinovitch³, Shimshon Belkin², and Aharon J. Agranat¹

1. Applied Physics and the Brode Center for Innovative Engineering and Computer Science

2. Institute of Life Sciences

3. Robert H. Smith Faculty of Agriculture, Food and Environment, The Hebrew University of Jerusalem, Israel

The detection of buried landmines is an acute worldwide problem in both the military and civilian arenas. The available techniques still require actual presence in the minefield with obvious risks to personnel and equipment. Standoff detection techniques that are currently under development have hitherto failed to provide the required capability to detect buried landmines with sufficient reliability.

We henceforth present the results of a first field demonstration of a standoff detection scheme of buried landmines based on fluorescent bacterial sensors. These sensors are genetically engineered bacteria that produce Green Fluorescent Protein (GFP) in response to the presence of TNT and its derivative DNT. The weak fluorescent signals emitted by the bacteria, are detected by a special purpose standoff detection system that scans the suspected area, excites the fluorescent bacterial sensors, and collects and processes their emitted fluorescent signals.

The field experiment was carried out in a testing area in which antipersonnel landmines, and layers of TNT and DNT flakes, were buried in specific locations under 2 cm of different types of soil and remained untouched for several weeks. Prior to the measurement session the testing area was covered with alginate beads containing the bacteria, water, and nutrient. Following a dwell period of 22 hours the testing area was scanned from a distance of 20 meters by the standoff detection system. It was observed that locations under which the targets were buried emitted strong fluorescent signal, whereas control areas that did not contain any targets emitted weak signals. This provides a proof of concept for our fluorescent bacterial sensor based standoff detection scheme and validates its viability.

It should be noted that this method is inherently generic, and can be employed for standoff detection of multitude of substances scanning large outdoor areas either from the air or from a vehicle.

Derivative based Focal Plane Array Non-Uniformity Correction *

Gal Ness, Amit Oved, Itzik Kakon

Technion, Israel

Introduction: We present a general and robust method for non-uniformity correction (NUC) of fixed pattern noise (FPN) in focal plane arrays (FPAs), which does not require neither mechanical shutter nor long calibrations. To extract the FPN from the raw video, we utilize the sparsity of spatial derivatives in natural scenes.

Background: Traditionally, this problem of non-uniformity in microbolometers was solved by calibrating the array in front of a spatially uniform scene (e.g. shutter) and attribute the measured image non-uniformity to the FPN. This interrupts the continuous capture of the scene which is crucial for many applications. Alternative solutions are based on elaborate FPN calibration in a variety of conditions at the manufacturing phase, which affects manufacturing costs. Both of which usually does not corrects the optics and mechanics contribution to the FPN. Advanced techniques analyze frame statistics and extract FPN using image processing techniques, thus avoid the necessity of a shutter or costly calibrations. Yet, most of these scene-based NUC methods require initial reasonable image SNR to converge.

Objectives: Develop a scene-based NUC technique that doesn't pose any constraint on the initial image quality. Avoid the necessity of shutter or long calibrations while continuously estimating the FPN.

Methods: Preforming a single pixel shift of the image w.r.t. the FPA enables us to estimate the spatial derivatives of the FPN. These can be used to reconstruct the FPN continuously and independent of SNR.

Results: Process simulations showed the algorithm robustness to significant FPN combined with temporal noise and interscene movements. Experiment using microbolometer validated the method.

Conclusions: We present a method for FPN correction based on minute transverse shifts of the FPA, which is robust to unexpected camera shakes and interscene movements, provided with a demonstration of the algorithm performance and accuracy in complex scenes.

Session: Lasers and Applications - Prof. Amiel Ishaaya

Mid-Infrared Microresonator Frequency Combs *

Alexander Gaeta

Columbia University, USA

Microbubble Resonators based Lasers From Brillouin to Raman, from Single Lines to Broadband Combs *

Daniele Farnesi^{1,2}, Giancarlo Righini^{1,2}, Gualtiero Nunzi Conti¹, and Silvia Soria¹

1. IFAC-CNR, Institute of Applied Physics "N. Carrara", Italy
2. Centro Studi e Ricerche "E. Fermi", Italy

Whispering gallery mode resonators (WGMR) because of their extraordinary high quality factors and small mode volumes strongly enhance light-matter interactions and are ideally suited for nonlinear optical interactions. They can be specifically exploited for low power continuous wave (CW) nonlinear frequency conversion, which is still a challenge in nonlinear optics. We have investigated the case of silica microspheres, which are the easiest to fabricate micro-optical resonators, and microbubbles and both are ideally suited for fiber-coupled architecture. In silica glass, because of inversion symmetry, second order nonlinear interactions are forbidden, and the primary nonlinear interaction occurs through c(3) effects, in which four photons are coupled. Thus, we report efficient generation of nonlinear phenomena related to third order optical non-linear susceptibility c(3) interactions in resonant silica microspheres and microbubbles in the regime of normal dispersion. The interactions here reported are: Stimulated Brillouin Scattering, Stimulated Raman Scattering (SRS), and four wave mixing processes comprising Stimulated Anti-Stokes Raman Scattering (SARS), third harmonic generation and broad hyper-parametric oscillation in forward and backward directions. Unusually strong anti-Stokes components and extraordinarily symmetric spectra have been observed. Resonant SARS and SRS corresponding to different Raman bands were also observed. The anti-Stokes Raman components are known to be coupled to the Stokes Raman ones, even for large dispersion. This coupling results in the growth of the anti-Stokes wave along the microresonator in direct proportion to the Stokes wave through an effectively phase-matched hyper-parametric process. Cascaded Brillouin Scattering with high efficiency has been also observed in both forward and backward directions. A proof of the cavity-enhanced phenomenon is given by the lack of correlation among the pump, signal and idler: a resonant mode has to exist in order to obtain the pair of signal and idler.

Topological Insulator LaserGal Harari*Technion, Israel*

Topological insulators are a phase of matter with an insulating bulk and conducting edges. A topological insulator is characterized by a bulk bandgap where topological gapless unidirectional edge states reside. These edge states are robust to any perturbation that does not close the bandgap. In this way, deformations of the system like disorder, strain, or imperfections have little effect on the transport of such topological edge modes. The discovery of topological insulators has subsequently motivated the search of topological systems in optics and photonics towards robust optical devices. In photonics, the first topological insulators were demonstrated using strong magnetic fields in microwave frequencies, and more recently at optical frequencies in a modulated photonic lattice and silicon ring resonators arrays. On this background, it is interesting to ask: how can topological protection improve optical devices?

Here, for the first time, we introduce the topological insulator laser: a photonic topological insulator that lases. The design of such a laser system is highly non-standard - a laser is an open, non-Hermitian (due to gain/loss) and nonlinear (due to saturation) system. Our model consists of an array of microring resonators arranged in a honeycomb pattern with hopping terms emulating the so called topological Haldane mode. By selecting where to add the gain (via an optical pump), the configuration of the edges and the shape of the lattice, we designed a topological system in which the topological edge-states are the first modes to lase. In this way, the lasing modes are confined to the edge of the cavity, and are topologically protected: the lasing mode is unidirectional and robust to backscattering and imperfections. This creates a laser cavity that is topological protected: robust to disorder and defects, with high slope efficiency that remains unchanged even under large disorder. We are now working towards experimental realization.

Digital Degenerate Cavity Laser for Forming Intra-Cavity Images and Rapidly Solving Inverse ProblemsChene Tradonski*Weizmann Institute of Science, Israel*

We developed a novel method for forming images with controlled coherence within a digital degenerate cavity laser and using it for rapidly solving optical inverse problems. Forming images with controlled coherence involves a computer controlled spatial light modulator and a mask inside the degenerate cavity that can support many degenerate lasing modes (about 1 million), i.e. the potential spatial resolution that can be obtained with our method is very high.

The inverse problem, which is to calculate the source field from the scattered intensity distribution, is considered difficult problem because there is no information about the phase distribution. In case, there is some prior knowledge about the source (e.g. boundaries - compact support), it is possible to use iterative algorithms to reconstruct the source. Unfortunately, such algorithms are time consuming, even with advanced computational resources, and they do not always converge to the right solution.

The same algorithms are used in order to determine the lasing modes in a single laser and the lasing supermode in an array of lasers arrays.

In order to solve the inverse problem we formed the image of the scattered intensity distribution and apply the compact support with mask. The lasing process mimics the iterative algorithm, used to obtain a solution to the inverse problem, to yield a consistent and rapid solution that satisfies both the scattered intensity distribution and the compact support. The laser arrangement, simulations and experimental results that clearly demonstrate the validity and speed of our method will be presented.

New Types of Plasma Lasers

Lev Nagli¹, Michael Gaft¹, Igor Gornushkin³, Reto Glaus³

1. Department of Physics, Ariel University, Israel

3. BAM Federal Institute for Materials Research and Testing, Germany

We demonstrate the possibility of creating miniature laser sources made of laser induced plasmas (LIP). Elongated plasma pencils are formed by focusing a Nd:YAG laser with a cylindrical lens on various metallic and non-metallic surfaces. After 5 to 15 microseconds, a second tunable laser (e.g., an OPO) irradiates the plasma end-on or transversely. The pumping laser is in resonance with a strong atomic transition of one of plasma major elements. Strong collimated emission originates from both ends of the plasma pencil which exhibits properties of laser light: the narrow line width, high temporal and spatial coherence, and low divergence. The radiation inherits the polarization of the pump laser.

Lasing effects in broad spectral range from UV up to Mid IR are observed for Al, Ga, In, Tl, Ge, Sn, Pb, Ca, Ti, Zr, Fe and Ni. To achieve lasing, values for Einstein coefficients for spontaneous emission for both pumped and lasing transitions must be higher than 107 s^{-1} . Using this criterion, it is possible to predict which elements and at which transitions might be exhibiting lasing effects. High optical gains of up to 100 cm^{-1} can be achieved in these systems; this allows LIP-lasers to operate without optical cavities.

A collisional radiative plasma model based on kinetic equations is proposed to explain the creation of the population inversion and lasing in LIP.

Keywords: Laser Induced Breakdown Spectroscopy (LIBS; Optically pumped plasma lasers

References

L. Nagli, M. Gaft, I. Gornushkin, R. Glaus, Stimulated Emission and Lasing in Laser-Induced Plasma Plume, *Optics Communication*, 378 (2016) 41–48.

Session: Non-linear Optics Prof. Meir Orenstein

Nanosystems in Ultrafast and Superstrong Fields: Attosecond Phenomena *

Mark I. Stockman

Center for Nano-Optics (CeNO) and Department of Physics and Astronomy, Georgia State University, USA

We present our latest results for a new class of phenomena in condensed matter nanooptics when a strong optical field changes a solid within optical cycle. Such a pulse drives ampere-scale currents in dielectrics and adiabatically controls their properties, including optical absorption and reflection, extreme UV absorption, and generation of high harmonics in a non-perturbative manner on a 100-as temporal scale. Applied to a metal, such a pulse causes an instantaneous and, potentially, reversible change from the metallic to semimetallic properties. We will also discuss our latest theoretical results on graphene (semimetal) and other two-dimensional solids such as transitional metal dichalcogenides (semiconductors), black phosphorus, and boron nitride (dielectric). Such materials in the reciprocal space are characterized by such nontrivial topological properties as Berry curvature and Berry flux. In particular, graphene in a strong ultrashort pulse field exhibits unique behavior related to its topological properties. The corresponding phenomena are among the fastest processes in optics unfolding within a half period of light. They offer potential for petahertz-bandwidth signal processing, generation of high harmonics on a nanometer spatial scale, valleytronics, etc.

Solitons and Faraday Waves in Nonlinear Metasurfaces

Roman Noskov^{1,*}, Daria Smirnova^{2,3}, Dmitry Filonov¹, Pavel Ginzburg¹

1. Tel-Aviv University, Israel

2. Nonlinear Physics Centre, Australian National University, Australia

3. Institute of Applied Physics, Russia

Introduction: Studies of metasurfaces, based on very thin and densely packed planar arrays of resonant subwavelength elements, play a central role in the emerging novel technologies, employing optical component, operating beyond the diffraction limit. Numerous functionalities of such structures, defined by specific features of individual elements, as well as their coupling mechanisms have been predominantly considered in a linear regime so far. Here we bridge this gap by exploration of spatiotemporal nonlinear dynamics in two types of metasurfaces composed of arrays of optically driven metallic nanoparticles and graphene flakes with a Kerr-like nonlinear response.

Objectives: The major goal concerns development of dynamically reconfigurable ultracompact nanophotonic devices, whose performance stems from intrinsic nonlinear response of individual elements of a metasurface and long-range dipole-dipole coupling between them. While previous works on nonlinear metasurfaces were focused on the steady-state generation of the second and the third harmonics only, in this communication we reveal a rich nonlinear dynamics inherited in metasurfaces.

Methods and Results: Accounting for realistic parameters for intrinsic nonlinearities of metallic nanoparticles and graphene flakes, we demonstrate formation of Faraday waves as well as deeply subwavelength localized states in the form of long-lived standing and moving nonlinear localized modes of several distinct types such as solitons, oscillons, and domain walls. We analyze the properties of these nonlinear localized modes and reveal different scenarios of their dynamics including transformation of one type of mode to another.

Conclusions: Nonlinear metasurfaces offer a unique playground to develop novel concepts for dynamical light steering at the nanoscale. We believe that our findings may pave a way towards further experimental studies of nonlinear plasmonic nanostructures, which could have important implications for active nanophotonic devices operating beyond the diffraction limit.

Keywords: bistability, modulation instability, soliton, kink, metallic nanoparticle, graphene

Nonlinear Chip Scale Light-Vapor, Interactions for all Optical Switching Spectroscopy and Frequency Stabilization *

Uriel Levy

The Hebrew University, Israel

Advances in High-Resolution Brillouin Optical Correlation Domain Analysis

Eyal Preter¹, Orel Shlomi¹, Dexin Ba^{1,2}, Yosef London¹, Yair Antman¹, and Avi Zadok¹

1. Faculty of Engineering, Bar-Ilan University, Israel

2. National Key Laboratory of Science and Technology on Tunable Laser, Harbin Institute of Technology, China

Brillouin optical correlation-domain analysis (B-OCDA) allows for random-access distributed and dynamic monitoring of strain and temperature with sub-cm resolution [1]. Current BOCDA schemes involve scanning over both the frequency offset between pump and probe waves, and the spatial location of measurement points. Typically 50–100 spatial scans are necessary to address an entire fiber, and 50 frequency scans are required in each [2]. Here we present two new configurations for B-OCDA: the first reduces the number of spatial scans [3], and the second reduces the number of frequencies [4]. The first protocol merges between B-OCDA and double-pulse-pair analysis, previously incorporated in time-domain Brillouin sensors [5]. Phase coding of the pump and signal waves with a repeating, high-rate code stimulates interactions in a large number of narrow correlation peaks. Unambiguous measurements are achieved by repeating each experiment twice, using a pair of pulses of different durations, and subtracting the two output traces. The principle is demonstrated in analysis of a 43 m-long fiber with 2.7 cm resolution. The entire 1,600 resolution points are addressed using only 11 pairs of scans per frequency [3]. Local hot-spots are identified. Uncertainty in the local Brillouin frequency shift (BFS) is ± 1.9 MHz. In a second protocol, the local BFS is extracted from temporal transient analysis of the signal wave. Measurements are taken at only two arbitrary frequency offsets. No spectral scanning is necessary. The BFS of a 2 meters-long fiber was measured with 1 MHz accuracy and a dynamic range of 200 MHz. Transient measurements were also performed in a B-OCDA experiment with 4 cm resolution, experimental uncertainty of ± 2.4 MHz and 100 MHz dynamic range. A 4 cm-wide hot-spot was properly identified. Multiple correlation peaks could be addressed in a single flight of a pump pulse. The results represent the first B-OCDA without spectral scanning.

References

- [1] K. Hotate and T. Hasegawa, "Measurement of Brillouin gain spectrum distribution along an optical fiber using a correlation-based technique –proposal, experiment and simulation," IEICE T. Electorn, E83-C(3), 405–412 (2000).
- [2] D. Elooz, Y. Antman, N. Levanon, and A. Zadok, "High-resolution long-reach distributed Brillouin sensing based on combined time-domain and correlation-domain analysis," Opt. Exp. 22(6), 6453–6463 (2014).
- [3] O. Shlomi, E. Preter, D. Ba, Y. London, Y. Antman, and A. Zadok, "Double-pulse pair Brillouin optical correlation-domain analysis," Opt. Express 24, 26867–26876 (2016).
- [4] E. Preter, D. Ba, Y. London, O. Shlomi, Y. Antman, and A. Zadok, "High-resolution Brillouin optical correlation domain analysis with no spectral scanning," Opt. Express 24, 27253–27267 (2016).
- [5] Y. Dong, H. Zhang, L. Chen, and X. Bao, "2 cm spatial-resolution and 2 km range Brillouin optical fiber sensor using a transient differential pulse pair," Appl. Optics 51, 1229–1235 (2012).

Breaking Laser Axioms on Thermal Equilibrium and Lasing without Inversion in Erbium-Doped Fibers *

Rafi Weill, Alexander Bekker, Boris Levit, Michael Zhurahov and Baruch Fischer

The Andrew & Erna Viterbi Faculty of Electrical Engineering, Technion, Israel

Contrary to what is commonly accepted in lasers, we show that photons in standard erbium-doped fibers (edf) and lasers can be in thermal equilibrium and show lasing without an overall population inversion. The thermalization with Bose-Einstein spectra is found in edf cavities and even in open fibers in a broad spectral range up to ~200nm at the 1550nm wavelength regime. We also find in the edf cavities coexistence of thermal-equilibrium with oscillation without an overall inversion that can be attributed to lasing or Bose-Einstein condensation (BEC). The experimental results are supported by a theoretical analysis based on the rate equations.

Session: IFLA, Material Processing - Dr. Kobi Lasri

Advanced Pulsed Fiber Lasers for Clean Energy Applications *

Doron Barness, Alexander Kosachevski and Kobi Lasri

Spectra Physics Tel Aviv V-Gen, Israel

Growing demand for renewable energy related applications have paved the way for IR and Green fiber based lasers to become a key enabling technology for clean energy investments, harnessing their typical characteristics such as high flexibility and efficiency combined with low maintenance and cost. In this work we focus on three major clean energy related applications empowered by Spectra-Physics' V-Gen fiber lasers range of products and capabilities: High-quality Li-ion battery foil processing, Advanced solar cell processing (thin-film scribing, Si and PERC) and LEDs multi-stage processing (wafer marking and cutting, ceramic scribing). For typical Li-ion cell manufacturing, several processes make use of laser technology in the production of these cells. We demonstrate the advantages gained from the use of the industry leading IR (1064nm) fiber lasers with up to 100W average power and 1.5mJ pulse energy for high quality, high throughput, Cu and Al foils cutting, battery coating ablation and coated foils texturing. For advanced solar cell processing we demonstrate TCO patterning using the capabilities of our pulse-on-demand (POD) 20W 1064nm MOPA laser for achieving high repetition rates for high quality and high throughput results. Absorber and metal patterning processes are demonstrated using our unique Green (532nm) 20W fiber laser for processing both amorphous and microcrystalline silicon. Crystalline silicon manufacturing process for Passivated Emitter Rear Cell or Contact (PERC) is also shown using the green fiber laser, which is the most advanced and versatile green fiber laser tool on the market with the highest peak and pulse energy levels (20kW and 200uJ, respectively), POD capabilities, adjustable pulse durations, high PRR, and fast ON/OFF switching characteristics. For LED technology, several wafer processing are demonstrated with our IR and Green fiber lasers, including Ceramic scribing, wafer marking and cutting at 532nm and 1064nm as well as for MOCVD diamond cutting.

From Laser Design Textures to New Field of Technical Functional Surfaces Applied on the Mold Industry *

Jérôme Drouet

*Laser Technology Unit, GF Machining Solutions
Agie Charmilles New Technologies SA, Switzerland*

Laser fine ablation has opened new possibilities to apply design texture on a part or an injection mold during the past decade, replacing chemical etching and moving toward environmentally-friendly digital technology.

The general process used is similar to the famous 3D metal printing, except that in our case we start from plain material and remove slice by slice till the final design texture is performed. We could name our process 3D laser ablation.

The design texture is generated either from a 3D CAD when geometric surface is applied typically, or from a 3D design image for generating a full 3D design volume into a programmed cloud of pixels.

The laser ablation process will generate lines or vectors of dots, using several laser type or wavelength (depending material to perform or quality to obtain) and 2D to 3D scanning systems, while the part to process will move within a 3 to 5 axis system.

We can see the result of this laser ablation technology everyday , with various equipment we commonly use such as cars where interior & exterior design is more and more critical and branded value , our mobile phones (mobile itself or protection)....

Recently the need to extend laser texturing process not only to design surface purposes is increasing, toward so called functional technical surfaces, such as hydrophobic, hydrophilic, anti-bacterial, anti-fouling, glossy- mat-brilliant, light capture or light reflection - refraction.

This talk aimed to describe typical examples of technical surface already used in industrial production on a part or on a molded part, emphasizing the use of advanced fiber laser technology for next generation digital 3D laser ablation. And as a conclusion the need to continuously progress on laser and optics performances, such as speed or ablation quality, pointing stability, repeatability...and cost or ownership.

The Fiber Laser Revolution in Metal Processing, Taking Industries towards Absolute Excellence *

Arvind Patel

Sahajanand Laser Technology Limited, India

On the contrary to its existing applications, this technology had invented for the enhancement of telecom sector. Within few years, it got experimented in some other procedure like metal forming and cutting. After tireless attempts, an Indian scientist attained this breakthrough in cutting metal by using same fiber technology which went on to be known as fiber laser technology.

Prior to fiber laser, it was solid state and CO₂ laser technology were into existence, however, they had their own set of limitations and shortcomings leading to lack of productivity, accuracy, and utility in small set ups. Fiber laser has overcome all these limitations with orbit shifting outcomes. Primarily, it went on to become the most effective metal processing tool at cutting the cost yet delivering the incredible productivity. The vital enhancement in productivity has been achieved due to the speed fiber laser brought to the metal cutting works. The high power with consistent beam quality coupled with ease of operations of fiber laser technology is what sets it apart from the other contemporary laser alternatives.

When it comes to undertaking meticulous metal processes, the fiber laser marks it marvel in the same, with the facility of controlling pulse. It enables to control the power and concentration of the laser beams and accomplishes the tasks for as small as micro-machining. Metal cutting, marking, and welding are the procedures which fiber has been taken to the all-new height.

Having been known for immense utility, the fiber laser holds the key to the future where not only the industrial process but the day to day work of a routine human life will be executed by it. Considering the current momentum at which the technology is being adopted and implemented, that future might be just at round the corner.

Fiber Lasers - A Universal Tool for Industrial Production *Wolfram Rath*Coherent-ROFIN, Germany*

High power continuous wave fiber lasers have firmly established themselves within the industrial production sector and are synonymous with efficiency, precision and costeffectiveness in a large number of laser material processing applications. They offer excellent single-mode or multimode beam qualities, which can be precisely adapted to the processing task and therefore represent a universal tool for industrial production. Latest developments allow also the realization of kW average power short pulse MOPA fiber lasers emitting Megawatt peak power. These lasers can be used for industrial surface ablation processing i.e. removal of AlSi coatings from high strength steel, cleaning and ablation of thin films. On the basis of selected application examples of metal and nonmetal cutting, welding and surface treatment, the technology and the manifold application possibilities of the fiber lasers in the power range from 0,5 to 8 kW is reviewed.

Water Jet Guided Green Fibre Lasers and it's Applications *Bernold Richerzhagen*Synova S.A, Switzerland*

The turnover of luxury goods and medical device markets is continuously rising as it is connected to the improvement of the life conditions in many industrial countries. Within that spectrum, watch industry plays a significant role. It manufactures consumer goods and parts with highly demanding requirements. Inter alia, preservation of the original material properties and high quality surface finish are usually requested. Some of these components are second wheels, springs and set bridges where low material impact and net shape processing are of high relevance.

Next to the EDM milling, short pulse laser processing has become a widely accepted manufacturing technology demonstrating the advantages of flexibility, high precision and relatively high processing speed. Application of green laser radiation facilitates, hereby, an efficient processing since the majority of the metals demonstrates a much better absorption in green spectrum as compared to the infrared optical range. Moreover, in green, the zone of the light penetration is reduced which - combined with short pulse duration - provides a "chip-by-chip" ablation of the material and, therefore, near-net shape part manufacturing.

Even though the modern green fibre lasers represent highly competitive systems, their straightforward application in a classical "dry" laser cutting/shaping does not respond sufficiently to the market requirements. The combination of the short pulse green fibre technology with the unique features of the laser microjet (LMJ) intends, however, to close the existing gap. For the first time, application of the self-adapting water jet guided laser beam has enabled cut-out features with depths up to 0.3 mm, roughness values down to 200 nm and trajectory radii down to 30 microns at once. Generation of vertical and straight features in such materials like Nickel silver, maraging steel (Durnico), CuBe, Brass, CoCrNi alloy (Phynox) and amorphous steel is reported.

Session: Solar Energy Dr. Yaakov Tischler**Photoluminescence: An Optical Heat Pump for Harvesting Thermal Losses in Photovoltaics ***Carmel Rotchild*Technion: Israel Institute of Technology, Israel*

The Shockley-Queisser efficiency limit of 40% for single-junction photovoltaic cells is primarily caused by heat dissipation during energetic-photon absorption. Solar-thermo-photovoltaics attempt to harvest this heat loss, but their practical realization is challenging due to the high operating temperatures involved (i.e., above 2000 K). Conversely, we recently demonstrated how thermally enhanced photoluminescence (TEPL) is an efficient optical heat pump operating in comparably low temperatures.

The physical mechanism involves is as follows: In contrast to thermal emission, when temperature rises the photon-rate in photoluminescence is conserved while the spectrum is blue- shifted. This allows harvesting heat losses with minimal generation of entropy.

In this talk I will present our theoretical and experimental study on a TEPL solar energy converter in which solar radiation is impinging a low bandgap photoluminescent absorber that emits TEPL toward a high bandgap photovoltaic cell. We show record efficiency at comparably low temperatures.

Understanding the Microscale Heterogeneity in Metal Halide Perovskite Solar Cells *Samuel D. Stranks*Cavendish Laboratory, Cambridge University, United Kingdom*

Metal halide perovskites such as $\text{CH}_3\text{NH}_3\text{PbI}_3$ are highly promising materials for solar cells, with certified power conversion efficiencies already exceeding 22%. A key enabling property of the perovskites for photovoltaics is their high photoluminescence quantum efficiency, suggesting that these materials could in principle approach the thermodynamic device efficiency limits in which all recombination is radiative. However, recent reports have demonstrated the presence of non-radiative recombination sites which vary heterogeneously from grain to grain and limit performance.

Here, I will present results towards understanding the origin of this heterogeneity and non-radiative decay, and how this understanding can reveal pathways to eliminate these parasitic losses. Specifically, we assess the impact of local variations in structure on the local photophysical properties of high quality neat $\text{CH}_3\text{NH}_3\text{PbI}_3$ perovskite films. We use time-resolved confocal photoluminescence (PL) measurements to map the local variations in emission intensities across the grains and grain boundaries. We then correlate these variations in emission with local variations in crystallinity and stress by utilizing the X-Ray micro-diffraction beamline at the Advanced Light Source facility. Our results reveal substantial variations in local structure, morphology and chemistry which correlate with the variations in local PL emission and lifetime. Our work highlights the intimate relationship between structure and optoelectronic behavior, and suggests that controlling local structure is crucial for minimizing non-radiative decay and ultimately reaching device efficiency limits.

Graphitic Carbon Nitride Layers as Light-Harvesting Semiconductors for Photoelectrochemical Cells *

Menny Shalom

Department of Chemistry, Ben-Gurion University of the Negev, Israel

One of the most promising future sources of alternative energy involves water-splitting photoelectrochemical cells (PECs) – a technology that could potentially convert sunlight and water directly to a clean, environmentally-friendly, and cheap hydrogen fuel. Practical PEC-mediated hydrogen production requires robust and highly efficient semiconductors, which should possess good light-harvesting properties, a suitable energy band position, stability in harsh condition, and a low price. Despite great progress in this field, new semiconductors that entail such stringent requirements are still sought after.

Over the past few years, graphitic carbon nitride (g-CN) has attracted widespread attention due to its outstanding electronic properties, which have been exploited in various applications –including in photo- and electro-catalysis, heterogeneous catalysis, CO₂ reduction, water splitting, light-emitting diodes, and PV cells. g-CN comprises only carbon and nitrogen, and it can be synthesized by several routes. Its unique and tunable optical, chemical, and catalytic properties, alongside its low price and remarkably high stability to oxidation (up to 500 °C), make it a very attractive material for photoelectrochemical applications. However, to date, only a few reports regarded the utilization of g-CN in PECs, due to the difficulty in acquiring a homogenous g-CN layer on a conductive substrate and to our lack of basic understanding of the intrinsic layer properties of g-CN.

In this talk I will introduce new approaches to grow g-CN layers with altered properties on conductive substrates for photoelectrochemical application. The growth mechanism as well as their chemical, photophysical, electronic and charge transfer properties will be discussed.

Photodiode Pyranometers

Uri Maurice

QCC Hazorea Calibration Technologies, Israel

Introduction: As solar radiation passes through the earth's atmosphere, some of it is scattered or absorbed by water vapor, air molecules, and aerosols. The Solar radiation that reaches the surface is measured by a Pyrheliometer (direct irradiance) or a pyranometer (global irradiance and diffuse reflections).

Background: Most Pyrheliometers and pyranometers use thermopile sensors. However, in recent times photodiode pyranometers entered the market in increasing numbers due to low manufacturing costs. While thermopile coating's material have relatively uniform absorbance and hence Responsivity over the solar spectrum, photodiode Responsivity is highly dependent on wavelength. To measure solar irradiance using a photodiode, a filtering window with response curve similar to midday sun spectrum, as well as an adjustable coefficient are used.

Objective: Discuss the drawbacks of photodiode pyranometers and the effect of sun angle on equipment reading.

Methods: Calibration of photodiode based pyranometer in comparison to a thermopile master device at different times of the day.

Results: The photodiode pyranometer was calibrated at 9:00, 10:00, and 12:00 during three consequent days with global irradiance greater than 700 W/m². The photodiode coefficient was adjusted at noon. The photodiode readings with comparison to the thermopile sensor was consistent at noon, but were found to consequently diverge at 10:00 and even more so at 9:00.

Conclusions: The difference in results is assumed to be due to the thicker layer of atmosphere, sun radiance transverse when the sun is not in the zenith. The greater atmospheric attenuation by absorbance and reflection (mainly Rayleigh scattering) causes a change in sun spectrum, which deteriorates the suitability of the photodiode filtering window and/or adjustable coefficient. Since the atmospheric layer transverse by sun radiance change continuously, according to this findings, the use of photodiode based pyranometers in addition to thermopile based pyranometers rather should be reassessed.

Keywords: solar measurement, photodiode, pyranometer, spectrum, calibration, solar radiation.

Session: Remote Sensing - Dr. Eyal Agassi

Detection and Identification of Hazmat using Thermal Hyperspectral and Spectropolarimetric Imaging *

Michal Shimoni

Signal and Image Centre, Belgium

Remote sensing detection and measurement of hazmat (i.e. HazMat; hazardous chemicals) is becoming more important and is receiving much greater emphasis within environmental, military and security communities. The choice of the detection technique depends on the agent being sought, expected background interferences, and the required ranges. Most species can be detected and quantified due to their unique spectral properties in the thermal InfraRed wavelength regions. With tens to hundreds of spectral bands, thermal hyperspectral sensors pose an advantage over traditional open-path sensors in their ability to detect and quantify chemical molecular absorption and concentration along a large area of interest. Novel spectropolarimetric imaging provides complementary polarimetric information in large spectral dimension and therefore allows improving confidence in chemical identification and reducing false alarms rate. These pioneer technical combinations expect to outperform other spectral methods. This presentation addresses the remote detection of hazmat using hyperspectral and spectropolarimetric imaging. Specifically, it will review the principles of the spectropolarimetric technology and the phenomenology behind the detection and identification of chemical agents and hazmat using thermal hyperspectral and spectropolarimetric imaging. Experimental results that were achieved by the collection of a large set of realistic scenarios using various sensor data will be presented and discussed.

Standoff Thermal Infrared Hyperspectral Imaging for Ground-based and Airborne Remote Sensing Applications *

Jean Giroux

Telops Inc., Canada

Thermal infrared (3-12 μm) imaging represents a highly versatile measurement technique as experiments can be carried out under various illumination conditions. The inherent self-emission associated with thermal infrared removes the need for an illumination source, which makes it very useful for remote sensing applications. However, since the infrared self-emission of most gases, materials and minerals is function of wavelength, spectral resolution is often needed in order to get quantitative information from infrared data. Over the last decades, technological progresses have allowed combining Fourier-transform spectroradiometer instruments with focalplane array imaging in order to provide a combination of high spatial, spectral and temporal resolutions. Thermal infrared hyperspectral imaging remote sensing can then be used to identify the chemical nature of targets based on their unique infrared spectral signature. This is especially useful for characterizing targets in hard-to-reach environments or in hazardous situations. In order to illustrate the benefits of this technology under these contexts of operation, results for gas cloud imaging carried out on ships, after a shale gas drilling accident and during a volcanic eruption will be presented. The same technology is also available in an airborne configuration, expanding the number of possible applications. Results from airborne mineral surveys for mineral mapping applications and buried object detection will be presented. The unique pointing system of the airborne platform allows two types of airborne surveys: the mapping mode, and the targeting acquisition mode. Comparison of the two acquisition modes will be presented in order to illustrate how they can be useful for airborne gas cloud imaging.

Towards Optical Detection of Condensed Phase Materials

Ran Aharoni

Israel Institute for Biological Research (IIBR), Israel

Absorption and scattering spectroscopy is a fast and efficient detection and sensing technique for HLS, forensic, industrial, and environmental applications. We present sensing method based on an open-path mid-IR active sensing (Quantum cascade lase - QCL) for fast spatial detection and identification of gaseous plumes as well as of condensed phase threat materials. The detection and identification approach and our system is designed to achieve fast and sensitive detection while maintaining low false alarm rate (FAR).

The gas sensing set-up was tested in realistic environmental conditions, Gases are released in a 500 m^3 hall at a distance of 30 meters (round trip) in three different lines of sight. A concentration of 200 ppb was detected.

The set-up was modified to allow condensed phase sensing. It was used in a laboratory conditions to study liquid and condensed materials disseminated on solid substrates. Sensing and identification in such a scenario poses a technical challenge for the sensing, and a theoretical challenge for the identification- since it requires a supporting numerical model or an a-priori knowledge. This is due to the strong dependence of spectral signatures of the sediments attached to different grounds, on its particles sizes, shapes and on its spatial distribution, rather on its inherent optical properties.

We demonstrate, through the operation of active sensing technique based on QCL, supported by modelling of the scattering events, the identification of PDMS oil droplets on a metallic substrate. Further improvement of the model may allow the identification of various materials on different substrates.

Keywords: Open-path Spectroscopy, stand-off, EC-QCL, condensed phase, diffused reflectance, scattering

Using Optical Gas Imaging to Enforce Air Pollution Reduction

Gil Abramovich, Omer Yanai

Ogal Optronics Industries, Israel

Detecting and eliminating fugitive Volatile organic compounds (VOCs) leaks is a major concern for oil and gas operators and is a very challenging problem to address. These leaks generate both a significant material loss to the operators and a substantial portion of greenhouse gas emission. Optical Gas Imaging refers to the use of cameras, typically infrared camera, for the detection of hydrocarbon gases relying on the match between the thermal sensitivity spectral waveband of the camera with the absorption spectra of the harmful gases. Optical Gas Imaging (OGI) technology started to play a role about ten years ago, when companies began to use it to reduce the damage caused by gas leaks to public health, the environment, and corporate profits. At that time, the Environmental Protection Agency (EPA) had a series of robust protocols around gas leak detection, known as Method 21, that relied on the use of 'sniffers' - devices that use a physical or chemical reaction to identify the presence of leaked gas. In 2016 the EPA introduced another set of regulation taking place this year for curbing gas emissions from upstream and midstream oil & gas facilities. This regulation designated OGI as the Best System for Emission Reduction (BSER). In this paper we will review the underlying concepts of the OGI technologies and overview the design and of the OGI camera of our development. We will also detail the EPA's regulations, and the way OGI cameras serve O&G operators and environmental protection representatives to detect, monitor and enforce air pollution reduction at the local and national level. We will conclude our presentation by overviewing a few applications where OGI cameras are being used to detect gas leaks.

Keywords: Optical Gas Imaging, Infrared, Volatile Organic Compound

Drone based Raman/Luminescence Spectroscopy for Remote Homeland Security

M. Gaft and L. Nagli

Laser Detect Systems (LDS), Israel

Raman/Luminescence spectroscopy is a good tool for homeland security, but it appears not adequate for the task to detect trace amounts at large distances. Background By 266 and 248 nm excitations Raman signals of explosives are 100–400 times stronger than for visible-IR excitations because of increased Raman scattering probability and Resonance effects. Besides, in UV range, the Raman lines are close to exciting frequency, while in this spectral range the luminescence is very weak because of Stocks shift. Objectives The aim is a new approach where the detection system will be much closer to the target but remains remote in the sense that the operator will be far away. Methods A new kind of drone platform (Airobotics, Israel) allow operate drones without the need for operators. It consists of a drone, which can fly 30-minute missions at a time while carrying a 1.5-kilogram payload; a completely automated base station from which the drone launches and lands on its own. Detection systems may work from such drone from meters distances. Results To accomplish such task, Raman system has to be light and sensitive enough. NASA experience evidences that Raman equipment with diode laser and micro-spectrometer may be suitable for drone missions. Our experiments with industrial and homemade explosives, dangerous chemical and biological substances proves that such system may be sensitive enough from several meters distances. Conclusions Combination of miniaturized UV Raman/Luminescence spectrometer installed on drone platform is promising tool for different homeland security applications, such as explosives and chemical/biological warfare.

Keywords: Raman, luminescence, drone, homeland security Introduction

Session: Lasers and Applications - Prof. Amiel Ishaaya

Novel Packaging Scheme using FemtoSecond Laser 3D Patterning

Yuval Berg^{1,2,*}, Zvi Kotler², and Yosi Shacham¹

1. Department of Physical Electronics, Faculty of Engineering, Tel Aviv University, Israel

2. Additive Manufacturing Group, Orbotech Ltd., Israel

Three dimensional laser micro-fabrication techniques play a key role in modern science and technology and paved the way to the emergence of many interdisciplinary applications. Micro-channels are one of the main components for lab-on-chip applications and in micro-electronics applications for packaging devices and interconnects. In this talk, the speaker will describe a micro-fabrication technique based on ultra short pulses: Femtosecond Laser Irradiation followed by Chemical Etching (FLICE), which has gained interest in the last few years, due to its simplicity and ability to produce buried 3D structures with high aspect ratios. As FLICE is a maskless technology, it enables rapid prototyping of new complex device schemes. Following the FLICE process, metallization of the fabricated channels is necessary in order to form interconnections for electronic packaging applications.

Passively Q-Switched 2um Lasers, for Medical and Industrial Applications

Salman Noach¹, Daniel Sebbag¹, Arik Korenfeld¹, Udi Ben Ami², Amir Herzog³, Amiel A. Ishaaya³

1. Department of applied physics, Electro Optics Engineering Faculty, Jerusalem College of Technology, Israel

2. Optisiv LTD., Israel

3. Department of Electrical & Computer Engineering, Ben-Gurion University of the Negev, Israel

Tm-based lasers at 1936nm and 1885nm in CW and passive Q-switch (PQS)pulsed operation were developed. High pulse energies of up to 4.31 mJ for Tm:YLF and 1.85 mJ for Tm:YAP, correspond peak powers of 200 kW and 52 kW, respectively. Maximum average power reached 2.2 W.

These results are the highest achieved so far using a PQS for a Tm based laser, and make this source attractive for high peak power applications.

High peak power Mid-IR lasers operating in the 1.8-3 μm range are considered to be a potentially disruptive technology in several fields:

- ◆ In the field of medical lasers.
- ◆ The field of industrial processing of transparent materials, such as micromachining of plastics and polymers

Laser design and performance with different PQS will present, as well results of laser interaction with tissue showed successful ablation and preliminary results of plastic welding.

Non-Contact and Non-Disruptive Laser based Characterization of High Aspect Ratio Micro Structures

Niv Gorodesky^{1,2}, Nisan Ozana¹, Yuval Berg^{2,3}, Omer Dolev², Yossef Danan¹, Zvi Kotler² and Zeev Zalevsky¹

1. Faculty of Engineering and the Nanotechnology center, Bar-Ilan University, Israel

2. Additive Manufacturing Lab, Orbotech Ltd., Israel

3. Department of Physical Electronics, Faculty of Engineering, Tel Aviv University, Israel

Optical characterization of 3D high aspect ratio micro structures might face technological difficulties related to their geometry. Therefore currently in order to observe and achieve cross section measurements, long and destructive processes are necessary.

In this paper we will present a novel concept involving a laser, camera and an ultrasonic stimulator to perform a no-contact and non-disruptive characterization of the micro structures. The ultrasonic stimulator induces high frequency ultrasonic pressure sound waves on the sample while it is being illuminated by the laser. The camera analyzes the back scattered secondary speckle patterns generated from the micro structure and inspects how those patterns change in space and time versus the frequency and the intensity of the ultra-sonic stimulation. The spatial-temporal changes of the patterns can be correlated to structural characteristics of the micro structure.

In this presentation we will describe the experimental implementation of the above mentioned sensing concept for characterization of laser based glass drilled vias which were formed at different depths and widths.

Strengthening of Large Nd:YAG Laser Rods for High Power Applications

Shuki Shimony, R. Feldman, S. Jackel, I. Moshe, A. Meir, Y. Shimony

Soreq Research Center, Israel

Large Nd: YAG laser rods are required for the operation of high output power solid-state lasers. The high pump power, which applied on such rods, induces thermal stresses within the rods. Such stresses might cause rod's fracture, when exceeding its fracture strength.

In the course of the present study, a multi-step thermo-chemical strengthening procedure was developed, to increase the fracture strength of large laser rods. The said process combines selection of high quality laser material, fine center-less grinding to remove the outer layer of the rod, high quality ends-polishing, and AR coating. Finally, thermo-chemical etching step was applied on the rods, to remove a thin damaged layer of few tens of microns.

A unique technique of "load-to-fracture" was employed in order to measure the fracture strength of the rods, by their thermal loading (optical-pumping) up to their fracture within an appropriate laser chamber. The results of the strength tests were analyzed by the Weibull distribution statistics, which was modified for experiments within a laser head. The rods subjected of the present study sustained a maximum pump-power density of 500W/cm, which is equivalent to longitudinal thermal loading of 200W/cm. This value is higher by a factor of 3-5 than what was obtained with the non-etched rods as received from their vendor, and also higher than any previously published data.

Laser resonators equipped with such enhanced rods emitted ~3 kW at 1064nm, when pumped by 7 kW. None of these rods were broken under such high pump power. Note that the reliability of the strengthening procedure of the rods was further approved by their successful operation within a high-power laser system in a form of a chain of 8 laser oscillators. Each of these oscillators was equipped with strengthened large Nd:YAG rod, either made of single crystal or of ceramics Nd:YAG.

Pump-to-Laser Beam Overlap Optimization in Ti: Sapphire Pumped and Diode Pumped Alkali Lasers (DPALs)

B. D. Barmashenko¹, T. Cohen¹, E. Lebiush², I. Auslender¹ and S. Rosenwaks¹

1. Department of Physics, Ben-Gurion University of the Negev, Israel

2. Electro-Optics Department, Soreq NRC, Israel

We report on the results of an experimental study of Ti:Sapphire pumped Cs laser and theoretical modeling of these results, where we focused on the influence of the pump-to-laser beam overlap, a crucial parameter for optimizing the output laser power. The dependence of the lasing power on the pump power was found for different pump beam radii at constant laser beam radius. Maximum laser power > 370 mW with an optical-to-optical efficiency of 43% and slope efficiency ~ 55% was obtained. Non-monotonic dependence of the laser power (optimized over the temperature) on the pump beam radius was observed with a maximum achieved at the ratio ~ 0.7 between the pump and laser beam radii. The optimal temperature decreased with increasing pump beam radius. A simple optical model of the laser, where Gaussian spatial shapes of the pump and laser intensities in any cross section of the beams were assumed, was compared to the experiments. Good agreement was obtained between the measured and calculated dependence of the laser power on the pump power at different pump beam radii and also of the laser power, threshold pump power and optimal temperature on the pump beam radius. The model does not use empirical parameters such as mode overlap efficiency but rather the pump and laser beam spatial shapes as input parameters. The present results combined with results of the application of the model to diode pumped alkali lasers (DPALs), including K DPAL, as well as to Ti:Sapphire pumped Cs laser, presented in [1] and [2], respectively, indicate that the model can describe the operation of different optically pumped alkali lasers with arbitrary spatial distributions of the pump and laser beam widths.

References

1. I. Auslender, B.D. Barmashenko, S. Rosenwaks, B.V. Zhdanov, M. Rotondaro, and R.J. Knize, Opt. Express 23, 20986 (2015).
2. B. D. Barmashenko, I. Auslender, E. Yacoby, K. Waichman, O. Sadot, and S. Rosenwaks, Proc. SPIE 9729, 972904 (2016).

Substrate-Transferred Crystalline Coatings for the Near- and Mid-Infrared

Garrett D. Cole^{1,2}

1. Crystalline Mirror Solutions LLC, USA
2. Crystalline Mirror Solutions GmbH, Austria

Substrate-transferred crystalline coatings have recently emerged as a groundbreaking new concept in optical interference coatings. Building upon our initial demonstration of this technology in 2013, we have recently realized significant improvements in the limiting optical performance of these novel single-crystal GaAs/AlGaAs multilayers. In the near-infrared (NIR), for center wavelengths spanning 1064 to 1560 nm, we have reduced the excess optical losses (scatter + absorption) to less than 5 parts per million (ppm), enabling the realization of a cavity finesse exceeding 300,000 at the telecom-relevant wavelength range near 1550 nm. Moreover, we demonstrate the direct measurement of sub-ppm optical absorption at 1064 nm via photothermal common-path interferometry (PCI). Concurrently, we investigate the mid-IR (MIR) properties of these coatings and observe exceptional performance for first attempts in this important wavelength region. Specifically, we verify excess losses at the hundred ppm level for wavelengths of 3300 and 3700 nm, with PCI measurements yielding limiting optical absorption values below 20 ppm. Taken together, our NIR optical losses are now fully competitive with ion beam sputtered films, while our first prototype MIR optics have already reached state-of-the-art performance levels for reflectors covering this portion of the fingerprint region for optical gas sensing. Thus, mirrors fabricated via our crystalline coating technique exhibit the lowest mechanical loss (and thus Brownian noise), the highest thermal conductivity, and, potentially, the widest spectral bandwidth of any "supermirror" technology, owing to ultra-low levels of scatter and absorption losses in both the near and mid IR, all in a single material platform. Looking ahead, we see a bright future for crystalline coatings in applications requiring the ultimate levels of optical, thermal, and optomechanical performance.

Session: Micro and Nano Optics - Prof. Jacob Scheuer

Novel Materials for Next Generation Photonic Devices *

Michal Lipson

Columbia University, USA

Overview: Ultrafast optoelectronics devices, critical for future telecommunication and data ultra-high speed communications and data communications, have been limited in speed due to nature of the materials forming the devices. Only very few materials can be used today as substrates for high speed optoelectronics limiting the applicability of these devices and preventing their integration with other emerging platforms such as RF photonics and silicon photonics. I will discuss novel materials for integrated optics including SiC, SiN and 2D materials. In particular graphene offers the possibility to break the limitation of traditional photonic materials. Graphene has been shown theoretically to have very high electro-optic coefficient with ultra-high speed. We show the first demonstration of graphene-based ultra-high speed device (30GHz) consisting of a graphene sheet integrated on a passive non-electro-optically active substrate.

High Detection Limit Polymer-based Optofluidic Sensors for Water Pollutant Monitoring

Isabelle Ledoux-Rak, Ecole Normale

Supérieure de Cachan, France

Introduction: Monitoring water pollutants currently relies on expensive, not field-deployable equipment, limiting the high-resolution spatio-temporal data required to protect populations, to apply environmental policies and to understand pollutants cycles.

Background: High-sensitivity, cost-effective optofluidic sensors based on waveguide optical microresonators are intensively developed for pollutant detection. Polymeric materials offer low cost, low sidewall scattering loss waveguides, and high coupling efficiency to optical fibers. Moreover, polymer surfaces can be functionalized by recognition ligands targeting specific species (heavy ions or organic pollutants).

Objectives: We propose an integrated approach based on ultrasensitive polymer-based micro-ring resonators combined with specific recognition layers in a microfluidic environment, towards a heavy ion detection limit of a few ng/L.

Methods: We design and fabricate polymeric micro-racetracks optical resonators integrated into an optofluidic device, by combining near-UV photolithography and reactive ion etching. These resonators are vertically coupled to a buried bus waveguide (single mode propagation at 1550 nm), with specific advantages over lateral coupling (cheaper fabrication, no perturbation of the bus waveguide by the solutions used in the optofluidic device). A ligand attached on the microresonator surface is liable to specifically trap cadmium ions. These microracetracks immersed in pure water display high Q-factors (> 35000) and finesse up to 25. Transduction is achieved via the shift of the resonance wavelength resulting from the attachment of heavy ions at the microresonator surface.

Results: We evidence a very low detection limit (5.6 ng/L in pure water and 56 ng/L in tap water) and a fast response (1 ms to 1 s) for cadmium detection; chips can be reused at least 70 60 times via regeneration by perchloric acid.

Conclusions: Parallel detection using several microresonators is also possible, leading to a viable solution for in-situ multi-pollutant measurements in water using portable and communicating sensors.

Keywords: Microresonators, sensors, waveguided optics, microtechnology, polymers, optofluidics.

Tunable Photonic Crystals by Holographic Optical Tweezers

Maya Yevnin¹, Jacob Scheuer², Yael Roichman¹

1. Raymond and Beverly Sackler School of Chemistry, Tel-Aviv University, Israel

2. School of Electrical Engineering, Fleischman Faculty of Engineering, Tel-Aviv University, Israel

Introduction and Objectives: Photonic Chrystal (PhC) devices are designed to control light as semiconductor devices are designed to control electrons. The optical properties of PhC devices stem from the periodic arrangement of their dielectric media, which gives rise to photonic band-gaps, frequencies where light cannot propagate, and to guided modes of light. An alternative route to build photonic crystals is by assembly of colloidal particles, for example by optical trapping using a holographic optical tweezers (HOTs) setup. HOTs offer two main advantages over conventional routes in realizing PhC devices. First, the HOTs construction process is dynamic, with optical measurements that can be taken in-situ, thus facilitating instantaneous adjustments of the device. Second, using the HOTs one can selectively choose and pick the array building blocks, so long as they can be visually distinguished. This makes the HOTs an excellent choice for the construction of 3D PhC heterostructures. **Methods:** We use a holographic optical tweezers (HOTs) setup to assemble a dynamic photonic bandgap material, and to characterize its properties. To this end we trap optically an array of colloidal particles and arrange them into periodic structures between prepositioned optical fibers. The positions of the optical traps are modified in-situ in a well-controlled manner. The spectral properties of the resulting materials are characterized by their transmission as a function of incident beam wavelength. The desired structure and photonic band diagram of the photonic materials are calculated and optimized numerically using plane wave simulations. **Results:** We measured the transmission of several colloidal arrays with increasing lattice parameters, and found that the transmission changes as a result, and that the experimental results fit the simulated band diagrams well. The agreement between experiment and theory shows that the arrays trapped by the HOTs behave as photonic crystals.

Keywords: Beam shaping, optical tweezers, computer generated holograms, photonic crystals

Overtone Spectroscopy with Reconfigurable Microfibers

Alina Karabchevsky, Ilse Katz

Electrooptical Engineering Unit, Ben-Gurion University of the Negev, Israel

Institute for Nanoscale Science and Technology, Ben-Gurion University of the Negev, Israel

Introduction: Optical spectroscopy is an indispensable testing, diagnostics and characterization tool. The desire to develop a method for the surface spectroscopy of vibrational overtone transitions in near-infrared is a long-standing goal of molecular science.

Background: Recent advances in spectroscopic applications, including surface sensing based techniques such as surface enhanced fluorescent spectroscopy, Raman scattering spectroscopy, and absorption spectroscopy, rely on surface-medium interaction to enhance the effect of absorption and to improve the sensitivity beyond the standard spectroscopic limit. However, the surface-medium interaction behavior of many important molecules such as aromatic amines is still unclear.

Objectives: The main objective of this study is to demonstrate a novel sensing concept based on detection of molecular harmonics in near-infrared as an alternative to traditional finger-print detection in mid-infrared.

Methods: The method is based on the absorption of near infrared radiation by molecular vibrations overtones on reconfigurable microfibers.

Results: We observed absorption enhancement of light in amine harmonics of N-Methylaniline molecules electrostatically attracted to gold nanospheres.

Conclusions: We attribute this effect to the increase of the mean trajectory of light in the fiber due to its resonant scattering on metallic nanospheres. This hypothesis is confirmed by comparative studies of the resonant transmission of light in a fiber containing different concentrations of golden nanospheres. The sculpturing of microfibers with metallic nanoparticles paves way to realization of microfiber sensors able to detect ultra-low concentrations of organic molecules with a high spectral accuracy.

Super Resolution Microscopy based on Photo-Modulated Reflectivity *Ori Cheshnovsky, O. Tzang*School of Chemistry, the Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Israel*

Far-field super-resolution (SR) microscopy has developed to be an important tool in life sciences. However, it relies on, and therefore is limited by the ability to control the fluorescence of label molecules or nanoparticles. We introduce a new far field label-free SR methodology that is based on the nonlinear response of the reflectance to photo-modulation [1-3]. It relies on the ability to photo-excite a temperature and/or charge-carriers spatial distribution inside the diffraction limited spot by an ultra-short pump pulse. In Nonlinear photo-modulated Reflectivity (NPMR) an overlapping delayed probe pulse monitors reflectance changes. Spatial resolution within the diffraction limited spot is enhanced due to nonlinearities in photo-modulated properties of the matter. NPMR is measured by recording the high harmonics of the probe laser reflectance, photomodulated by the pump laser. Examples of resolution enhancement due to nonlinearities (lateral and vertical) will be presented: The change of thermo-reflectance of VO₂ upon its characteristic insulator-to-metal transition at ~340K, the heating process of a nanostructured silicon or gold surfaces, and the nonlinear response of photo-modulated Raman spectra. Super-resolution down to 85nm is demonstrated with a probe laser of 800nm wavelength. NPMR is suitable to characterize semiconductors and metals in vacuum, ambient, and liquid, semi-transparent and opaque systems, ultrathin and thick samples alike. [1] O. Tzang, A. Pevzner, R.E. Marvel, R.F. Haglund, O. Cheshnovsky, "Super-Resolution in Label-Free Photomodulated Reflectivity" Nano Letters, 15, 1362 (2015). [2] O. Tzang, O. Cheshnovsky, "New modes in label-free super resolution based on photo-modulated reflectivity" Optics Express, 23, 20926 (2015). [3] O. Tzang, O. Azoury D .Cheshnovsky, "Super resolution methodology based on temperature dependent Raman scattering, Optics Express, 23, 17929 (2015).

Session: IFLA, Fiber Sensing - Prof. Avishay Eyal**Dynamic Fiber Sensing with High Spatial Resolution ***Lihi Shiloh and Avishay Eyal*School of electrical Engineering, Tel Aviv University, Israel*

High spatial resolution in reflectometric sensing can be achieved by using interrogation waveforms such as long and broadband frequency scans. The primary goal is to generate such waveforms dynamically in order to allow sensing at acoustic sampling rates. One common method for implementing dynamic distributed acoustic sensing is Optical Frequency Domain Reflectometry (OFDR).

In OFDR the interrogation waveform is a linearly chirped light (at least in a certain part of the interrogation period) and its amplitude is constant (CW). The light is split between a reference arm and a sensing arm. Backscattered light from the sensing fiber is mixed with the reference and detected. Due to the linear chirp, different beat frequencies at the detector output are associated with different positions along the sensing fiber. The spatial resolution is determined by the total frequency range covered during the linear part of the period. Clearly, it is advantageous to use saw-tooth scans which make use of the entire scan range but this is typically challenging due to bandwidth limitations of the scanning mechanism. To alleviate this limitation we recently introduced a novel technique which make use of non-linear scans. The method is termed as Sinusoidal-Frequency-Scan OFDR (SFS-OFDR). In this method the instantaneous frequency of the laser source is sinusoidally scanned. The backscattered beam is mixed with a reference and detected by an I/Q optical receiver. Using Jacobi-Anger expansion it is shown that the detector output can be transformed into spatial backscatter profiles via a fast ($n \log n$) algorithm. The algorithm was tested using theoretical formulation, computer simulations and experiments. It enabled using extra-long processing windows (up to 45% of the scan rate) which led to high spatial resolution over ~50km sensing fibers.

Waveform-Processing LIDAR versus Geiger-mode LIDAR *

Andreas Ulrich

RIEGL Laser Measurement Systems GmbH, Austria

LIDAR has become the inevitable technology to provide accurate 3D data fast and reliably even in adverse measurement situations and harsh environments. It provides highly accurate point clouds with a significant number of additional valuable attributes per point. These additional attributes include for example the calibrated amplitude of the received optical echo signal, the estimate of the target's normalized cross-section, and additional information on the pulse shape of the optical echo signals. These attributes improve for example the visual representation of the acquired point clouds, but also enables a straightforward radiometric calibration of the data sets or improve the accuracy of the classification of the points into typical classes like bare earth, vegetation, and man-made objects.

LIDAR systems based on Geiger-mode avalanche photo diode arrays, also called single photon avalanche photo diode arrays, earlier employed only for military applications, now seek to enter the commercial market of 3D data acquisition and large-scale surveying, advertising higher point acquisition speeds from longer ranges compared to conventional techniques and thus a higher acquisition efficiency. Publications pointing out the advantages of these new systems refer to the other category of LIDAR as „linear LIDAR“, as the prime receiver element for detecting the laser echo pulses – avalanche photo diodes – are used in a linear mode of operation.

RIEGL offers a broad range of LIDAR engines and LIDAR systems making use of a prime receiver element operated in the linear regime, of digitizing the received echo waveforms, and of processing the data either in an online waveform processing chain or in an offline so-called full waveform processing. This distinct LIDAR technology is addressed as “waveform processing LIDAR” in order to distinguish itself from the simple linear LIDAR approach based on analog signal processing often called discrete return LIDAR, which is still in use.

We analyze the differences between Geiger-mode LIDAR and waveform processing LIDAR and the fundamental differences in the data they provide. Especially we address the LIDAR's capability to penetrate dense vegetation in order to derive precise digital terrain models, the LIDAR's capabilities to acquire data simultaneously on targets with small LIDAR cross sections like power lines and on the bare earth beneath vegetation, and the inevitable measurement errors imposed by the detection scheme. We also point out the different requirements with respect to the laser source of the different LIDARs. The limitations imposed by physics on both approaches to LIDAR are also addressed and advantages of linear LIDAR over the photon counting approach are discussed.

The Statistical Properties of Distributed Acoustic Sensing *

Haniel Gabai and Avishay Eyal

School of Electrical Engineering, Tel Aviv University, Israel

In Distributed Acoustic Sensing (DAS) a telecom type single mode fiber is transformed into an array of thousands of 'virtual microphones'. To enable such functionality, most of DAS systems rely on coherent interference of Rayleigh backscattered light. This sensing approach has gained tremendous popularity in recent years. Its unique qualities, such as cost-effective deployment, immunity to electromagnetic interference, durability, etc. have made it highly attractive in many applications, including intrusion detection, structural health monitoring, oil and gas wells monitoring, monitoring transportation, pipelines security and more. Sensitivity and SNR are among the most significant parameters in the specifications of any sensor. As most DAS systems are based on coherent interference of Rayleigh backscattered light the responsivities their 'virtual microphones' fluctuate randomly along the fiber and so does their sensitivities. Despite the substantial amount of DAS related research in recent years, its SNR and sensitivity were rarely investigated until now. Recently we introduced a statistical theory to describe the SNR and sensitivity of DAS. According to the new theory, the sensing fiber is described as an ensemble of microphones whose responsivities depend on their associated backscatter amplitudes. As the statistical properties of Rayleigh backscattering are well known it is possible to derive many new results regarding the performance of the virtual microphones such as: mean SNR, the minimum input signal which guarantees a specified mean SNR, the minimum input signal which guarantees that a specified fraction of the microphones will have SNR above a desired level, the relation with the static backscatter profile of the sensing fiber and more. The derivation of the new statistical results and their use for comparing between the performances of different DAS systems will be discussed in the presentation as well as experimental demonstrations of their usefulness.

Opto-Mechanics of Single-Mode and Multi-Core Fibers *

H. Hagai Diamandi, Yosef London, and Avi Zadok

Faculty of Engineering, Bar-Ilan University, Israel

Optical fibers support guided acoustic modes. These modes are stimulated by optical waves, and induce scattering and modulation of light. These interactions are referred to as guided acoustic waves Brillouin scattering (GAWBS) [1]. Here we describe a new application of GAWBS in fiber sensing, and extend the study of the effect to multi-core fibers (MCFs). Optical sensors typically rely on absorption, index or scattering. These require spatial overlap between light and the test substance. Standard fibers do not provide such overlap. Hence, chemical sensors rely on photonic crystal fibers, or structural modifications. The transverse profiles of acoustic modes reach the outer cladding boundary. Acoustic oscillations are therefore affected by dissipation to the surrounding medium. We employ GAWBS in sensing of liquids outside unmodified, standard fibers [2]. Acoustic waves are stimulated and monitored from within the core. The mechanical impedance of water and ethanol is measured with 1% accuracy. The method can distinguish between aqueous solutions of different salinity [2]. MCFs are often designed to exhibit weak coupling among cores. Nevertheless, we show that acoustic modes lead to opto-mechanical inter-core cross-talk in MCFs. Analytic expressions are derived for the magnitude and spectrum of inter-core, cross-phase modulation (XPM) that is induced by GAWBS. The spectrum consists of a series of narrowband resonances. The effect is experimentally observed in a commercially-available, seven-core fiber. Agreement between analysis and measurement is excellent. On resonance, the magnitude of optomechanical XPM is comparable with the intra-core Kerr effect. Last, we employ GAWBS in a new electro-opto-mechanical radio-frequency oscillator. An optical pump stimulates guided acoustic modes, which modulate the phase of a copropagating optical probe. The probe modulation is detected and fed back to drive the pump modulation. With sufficient feedback, stable, single-mode oscillations at acoustic resonance frequencies are achieved. No electrical filtering is required.

References

- [1] R. M. Shelby, M. D. Levenson, and P. W. Bayer, "Guided acoustic-wave Brillouin scattering," Phys. Rev. B 31, 5244-5252 (1985).
- [2] Y. Antman, A. Clain, Y. London and A. Zadok, "Optomechanical sensing of liquids outside standard fibers using forward stimulated Brillouin scattering," Optica 3, 510-516 (2016).

Plenary Session

The mission of the Ministry of Science, Technology and Space

Andrey Broisman

Ministry of Science, Technology and Space, Israel

A connecting link between basic research, applied research and industrial development; International scientific collaborations with other countries and international organizations.

Contents:

- ◆ The Ministry's Activities and Strategy
- ◆ Call for Proposals – Applied Science and Engineering
- ◆ Bi-National Scientific Cooperation

The Ministry constitutes a bridge between the Israeli academic research and industrial technological developments, and works to improve knowledge and research infrastructure in order to maximize the benefit of the research results for research with applicative potential.

The Ministry decided to initiate a National Fund for Applied Science and Engineering, in order to strengthen the faculty at the universities and research institutions in this field.

In order to support research that is aimed to benefit the aging population, the Ministry of Science, Technology and Space of the State of Israel decided to provide financial support for research projects relating to the aging population.

Optical Fibres: The Next Generation

David Payne

Director Optoelectronics Research Centre, University of Southampton, UK

The great success of optical fibres in telecommunications has generated numerous applications in a number of related fields, such as sensing, biophotonics and high-power lasers. The topic remains extraordinarily buoyant and new materials, structure and applications emerge unabated. The talk will review recent developments and explore future possibilities.

Following in the footsteps of Marconi and the revolution of wireless, the internet is perhaps the most important and life-changing invention of the 20th century. It too required the invention of a new global communication medium capable of carrying vast quantities of information across trans-oceanic distances, reliably, cheaply and efficiently. This turned out to be the unpredictable, unlikely and extraordinary role of optical fibres made from the two most common elements of the earth's crust, silicon and oxygen (silica).

In recognition of the huge impact of his invention, Charles Kao was awarded the Nobel Prize for Physics in 2009, while Charles Townes, who provided the laser, was similarly honoured in 1964.

As with all new and disruptive concepts, the optical internet has proven a rich source of innovation, from the optical amplifier that compensates for losses in long spans of fibre, through new forms of digital communications appropriate to light as a carrier, to new materials and lasers. Perhaps even to quantum technologies for the future.

But is the innovation over? The demand for capacity continues unabated, fueled by demand for faster connections and a new age of creativity at home – You Tube, Twitter, Facebook – as well as an insatiable demand for high quality videos. You Tube alone consumes more bandwidth today than the entire internet in year 2000 and projections show that a capacity crunch looms in both the internet optical backbone and the wireless final drop in the next decade or so. Yet we are still on the first hardware iteration of the optical infrastructure, so is there an internet 2.0? And was Charles Kao right in his choice of silica for the transmission medium? Or will the hollow-core fibre that uses vacuum supercede it?

Oral Presentations

Tuesday, 28 February, 2017

Oasis 6
Conference and Exhibition
on Optics and Electro-Optics

Manipulating Electrons with Intense Laser Pulses

V. Malka^{1,2}

1. Laboratoire d'Optique Appliquée, CNRS, Ecole Polytechnique, ENSTA ParisTech, Université Paris-Saclay, France
2. Weizmann Institute of Science, Israel

Laser Plasma Accelerators (LPA) rely on the electrons motion control with intense laser pulses [1]. The manipulation of such relativistic electrons with lasers allows a fine mapping of the longitudinal and radial components of giant electric fields with values that can exceed hundred of GV/m [2]. This crucial control permits to optimize laser plasma accelerators for generating ultra-short and ultra-bright energetic particle or radiation beams.

To illustrate the beauty of laser plasma accelerators I will show, how by changing the density profile of the gas target, one can improve the quality of the electron beam, its stability [3] and its energy gain [4], and how by playing with the radial field one can reduce its divergence [5].

I'll then show how by controlling the quiver motion of relativistic electrons intense and bright X-rays beam are produced in a compact and elegant way [6-8]. Finally I'll show some examples of applications.

Keywords: high power lasers, accelerators, X-ray beams, electron beams

References

- [1] V. Malka, Europhysics Letters, 115 (2016) 54001
- [2] V. Malka et al., Science 22, 298, Nov. (2002)
- [3] E. Guillaume et al., Phys. Rev. Lett. 115, 155002 (2015)
- [4] C. Thaury Scientific Report, 10.1038/srep16310, Nov. 9 (2015)
- [5] C. Thaury et al., Nature Comm. 6, 6860 (2015)
- [6] K. Ta Phuoc et al., Nature Photonics 6, 308–311 (2012)
- [7] S. Corde et al., Review of Modern Phys. 85 (2013)
- [8] I. Andriyash et al., Nature Comm. 5, 4736 (2014)

Session: Quantum Optics - Prof. Barak Dayan

Quantum Optical Diode and Circulator based on the Chiral Interaction Between a Single Atom and Photons with Transverse Spin *

Arno Rauschenbeutel

Vienna Center for Quantum Science and Technology, TU Wien, Austria

Controlling the interaction of light and matter is the basis for diverse applications ranging from light technology to quantum information processing. Nowadays, many of these applications are based on nanophotonic structures. It turns out that the confinement of light in such nanostructures imposes an inherent link between its local polarization and its propagation direction, also referred to as spin-momentum locking of light [1]. Remarkably, this leads to chiral, i.e., propagation direction-dependent effects in the emission and absorption of light, and elementary processes of light-matter interaction are fundamentally altered. For example, when coupling an atom to an evanescent field, the intrinsic mirror symmetry of its emission and absorption can be broken. In our group, we observed this effect in the interaction between single rubidium atoms and the evanescent part of a light field that is confined by continuous total internal reflection in a whispering-gallery-mode microresonator [2]. In the following, we employed this chiral interaction to demonstrate an integrated optical isolator [3] as well as an integrated optical circulator [4] which operate at the single-photon level and which exhibit low loss. The latter are the first two examples of a new class of nonreciprocal nanophotonic devices which exploit the chiral interaction between quantum emitters and transversally confined photons.

References

- [1] K. Y. Bliokh, F. J. Rodríguez-Fortuño, F. Nori, and A. V. Zayats, Spin-orbit interactions of light, *Nat. Photon.* 9, 796 (2015).
- [2] C. Junge, D. O'Shea, J. Volz, and A. Rauschenbeutel, Strong coupling between single atoms and non-transversal photons, *Phys. Rev. Lett.* 110, 213604 (2013).
- [3] C. Sayrin, C. Junge, R. Mitsch, B. Albrecht, D. O'Shea, P. Schneeweiss, J. Volz, and A. Rauschenbeutel, Nanophotonic Optical Isolator Controlled by the Internal State of Cold Atoms, *Phys. Rev. X* 5, 041036 (2015).
- [4] M. Scheucher, A. Hilico, E. Will, J. Volz, and A. Rauschenbeutel, Quantum optical circulator controlled by a single chirally coupled atom, *Science*, 10.1126/science.aaj2118 (2016).

Photon-Number Reconstruction and Photon Generation in an Ion-Cavity System *

Tracy Northup

University of Innsbruck, Austria

By coupling ions to a high-finesse optical cavity, we can explore light-matter interactions at the level of single quanta, taking advantage of the existing tools for coherent manipulation and measurement of trapped ions. Furthermore, the ion-cavity system is a promising platform for future quantum networks, as it provides an interface between ions for quantum computing and photons for long-distance quantum communication.

First, I will discuss the nondestructive reconstruction of the cavity photon number, based on the dispersive interaction of the cavity field with a single calcium ion in a linear Paul trap. From Ramsey spectroscopy of the ion, we determine the shift and the broadening of the atomic levels induced by the cavity field. These measurements enable reconstruction of the photon number distribution via a maximum likelihood method. This reconstruction can be seen as the starting point for quantum non-demolition measurement of the optical cavity field and for feedback onto the field.

Second, from a quantum-networks perspective, ongoing work will be presented towards a link between two ion-cavity systems. In the first system, we have demonstrated ion-photon entanglement and quantum state mapping from ions to photons, most recently using two calcium ions as a logical quantum bit. This system operates in an intermediate coupling regime, in which the coherent coupling rate between the ion and the cavity field is similar to the rates of dissipative processes, namely, cavity decay and spontaneous emission. The second system is based on a fiber-based cavity with which it should be possible to access the strong coupling regime, in which coherent processes dominate. A key challenge in creating an efficient, high-fidelity link between the two systems, despite their different parameter regimes, lies in matching the temporal and spectral properties of the single photons produced in the two distant cavities.

Demonstration of Deterministic and Passive Photon-Atom SWAP Quantum Gate

Adrien Borne

Weizmann Institute of Science, Israel

The prospect of quantum networking relies on nodes for the generation, processing and storage of the quantum information, interconnected by links. As the natural candidates for quantum nodes and quantum links are material systems and photons respectively, it is therefore crucial to implement a reliable interface between them. Accordingly, there has been a tremendous effort toward the realization of deterministic light-matter interactions at the single-photon level, especially in the framework of cavity quantum electrodynamics.

Single-photon Raman interaction (SPRINT) is a passive scheme that harnesses quantum interference to create exactly such an interface between single photons and single atoms or atom-like systems. Recently demonstrated in our lab [1-2], SPRINT enables controlling the state of a single atom using another single photon. Importantly, this process is also coherent, and therefore applies for a superposition state as well. We experimentally demonstrate this by using SPRINT to perform a deterministic quantum SWAP gate between a flying photonic qubit (superposition of directions) and a stationary atomic qubit (superposition of ground states) [3]. We use this process twice to demonstrate a passive quantum memory, i.e. to map the state of a photon onto the atom and then back onto a readout photon. Each swapping process is performed with an average fidelity over the whole Bloch sphere of 75.0%, above the classical threshold of 2/3.

The strong interaction necessary for SPRINT is achieved by means of a whispering-gallery mode (WGM) ultrahigh-Q microsphere resonator, coupled to a nanofiber. A laser-cooled single ^{87}Rb atom located in the vicinity of the resonator provides a three-level Λ -system required for SPRINT.

References

- [1] Shomroni*, S. Rosenblum*, Y. Lovsky, O. Bechler, G. Guendelman and B. Dayan, "All-Optical Routing of Single Photons by a One Atom Switch Controlled by a Single Photon", *Science* 345, 903 (2014).
- [2] S. Rosenblum*, O. Bechler*, I. Shomroni, Y. Lovsky, G. Guendelman and B. Dayan, "Extraction of One Photon from an Optical Pulse", *Nature Photonics* 10, 19 (2016).
- [3] O. Bechler, A. Borne, S. Rosenblum, G. Guendelman, O. Mor, M. Netzer, D. Gurovich, T. Ohana, Z. Aqua, N. Drucker, Y. Lovsky, R. Bruch, R. Finkelstein, E. Shafir and B. Dayan, "Mapping a Photonic Qubit into an Atom and Back by a Passive Photon-Atom SWAP Gate", to be submitted.

Molecular Vibrational Strong Coupling: Novel Route to Modify Materials Properties

Atef Shalabney

Physics and optical engineering department, Ort Braude College, Israel

Introduction and background: The optical hybridization of electronic states in strongly coupled molecule-cavity systems have revealed unique properties such as lasing, modification of energy landscape governing reactions pathway, and tuning molecular materials work-function. The hybridization is not limited to electronic transitions and can be applied for instance to vibrational transitions to selectively perturb a given bond, opening new possibilities to change the chemical reactivity landscape.

Recently, we were able to show that molecular vibrational modes of the electronic ground state can be also coherently coupled to a micro-cavity mode at room temperature. Collective coupling of large ensemble of molecules immersed within the cavity mode volume enables the enhancement of the Rabi-exchange rate with respect to the single oscillator coupling strength [1].

Objectives: In this presentation, the influence of vibrational strong coupling on the rate and nature of chemical reactions inside cavities will be presented [2]. In addition, the conditions required to achieve ultra-strong vibrational coupling and the emerging of multiple Rabi splitting with new cavity polariton behavior is shown [3].
Results and conclusions

In order to probe the new hybrid vibro-polariton states on the level of the single molecule, we have used spontaneous Raman scattering spectroscopy by which we confirmed that the collective Rabi splitting occurs at the level of a single selected bond. Moreover, the coherent nature of the vibro-polariton states boosts the Raman scattering cross section by two to three orders of magnitude [4]. These findings agree with the decrease in chemical reactions rate that we have recently observed under vibrational strong coupling. In these experiments, we found that the ground-state deprotection reaction of a simple alkynylsilane slow down by five orders of magnitude when it occurs inside a Fabry-Perot cavity. These results, among others, show that strong coupling modifies the material properties and should have profound consequences on chemical and molecular science.

References

- [1] A. Shalabney et al., *Nat. Comm.*, 2015, 6, 5981.
- [2] A. Thomas et al., *Angew. Chem. Int. Ed.*, 2016, 55, 1-6.
- [3] J. George et al., *Phys. Rev. Lett.*, 2016, 117, 153601.
- [4] A. Shalabney et al., *Angew. Chem. Int. Ed.*, 2015, 54, 1-6.

Quantum Superresolution and Spectral Intensity Interferometry

Erez N. Ribak¹, Georgiy Shoulga¹, Aglaé Kellerer²

1. Department of Physics, Technion- Israel Institute of Technology, Israel

2. Cavendish Laboratory, Cambridge University, UK

Optical resolution is limited by the uncertainty principle: the locations of single photons and their momenta cannot be measured accurately at the same time. By amplifying stellar photons in a gain medium, we create many nearly-identical stimulated photons and can thus surpass the classical resolution limit. Unfortunately, the gain process also involves creation of spurious spontaneous photons. We show that stimulated photons are of higher flux density than spontaneous ones. Using a photon-tagging camera, this allows us to discriminate against these spontaneous photons of lower flux levels. The price to pay is loss of some stellar photons.

The classical intensity interferometry (Hanbury Brown and Twiss) experiment performed correlations between monochromatic photon events in two telescopes. Without the interference phase (as in amplitude interferometry), it was only able to measure the autocorrelation of stellar objects, which was acceptable for symmetric objects. In a laboratory experiment, we were able to measure intensity correlations between three telescopes. The extra information from the third telescope allowed us to also calculate the phase of the objects. To increase the very low signal-to-noise ratio of the method, we designed a compact dispersion system which allows us to measure photon arrivals in many spectral channels in parallel. Thus photons at each wave length can be correlated with their own kind from other channels. Such parallel channels can tile the surface of a large light collector (or its exit pupil), with even more cross-correlations among them. The expected gain is linear with the number of spectral channels, and the number of channels depends on the optical quality of the light collector.

Session: Photonics in Defense - Dr. Joelle Schlesinger

Active and Passive EO-Systems: Future Trends and Evaluation *

Helge Buersing

Fraunhofer IOSB, Germany

Since 1965 when the first commercial IR imagers were produced, the development of new sensors and devices never stopped. Electro-optical systems in the IR became smaller and the resolution increased steadily up to HD-format today. Along the development, one of the obvious questions was which sensor or system has the better or even the best performance. The Optronics department at IOSB has a long tradition in evaluating electro-optical sensors in the IR and VIS spectral range. Over the years, the analytical thermal range model TRM (TRM4 v2) for passive image sensors was developed. Together with the analytical model, laboratory measurements and field tests took place. In the presentation, the status of the evaluation will be shown. In parallel to the progress in passive sensor technology, the development of lasers advanced. Consequently there are small and powerful lasers of the shelf at almost any wavelength available. Therefore, the potential of small active sensor-systems increased. Today it is possible to get a good deal more information of the scene, such as spectral information, vibration of objects and 3D-images. Furthermore, new image exploitation algorithms combined with powerful but small computers extend the possibilities in detection and identification of objects. These developments result in new challenges with respect to evaluation of systems, since especially the algorithms are not necessarily published. The current work on this matter will be presented and an outlook will be discussed.

EO Imaging Systems and Detectors Performance Optimization *

Michael Ben-Ezra¹, Yoav Livneh²

1. IMODVDF, Israel

2. Rafael, Israel

System level performance optimization is one of the most important tasks of the system-engineering work. In order to get optimal observation range performance for EO imaging systems, technical specifications for detectors must take into account system level scenarios and parameters. In some cases, optimal detector performance (in the lab) does not guarantee the best observation range performance in the field. In this lecture we present 3 different examples of EO systems, in 3 different spectral ranges (NIR-SWIR, MWIR and LWIR) in which optimal system level performance requires detector level performance to be somehow less than the “very best possible” (regarding lab conditions). In addition, optics design considerations and constraints, in some cases, determine detector and system level working point as a trade-off between spatial resolution and overall system sensitivity. This approach can also be used when we need to specify required performance and design goals in the R&D phase of new generation detectors development

TRM4 for Sensor Performance Calculations

Dov Steiner¹, I. Layani²

1. IARD Sensing Solutions Ltd., Israel

2. DDR&D IMOD, Israel

TRM4 is a tool for the assessment of electro-optical sensor performance. It operates an analytical model and deals with the detection range estimation for opto-electronic imagers, operating in various wavelength bands from the visible to the long IR. The model is based on the perception of a standard 4-bar test-pattern and uses the modified Johnson criteria to calculate appropriate detection ranges.

The release of version TRM4v2 includes a new model for un-cooled IR detectors as well as the ability to run the calculations by a user-created MATLAB program (Batch-mode). The Batch-mode gives the user an ability to investigate the effect of the sensor parameters in more efficient way and to find the best set of parameters for a given purpose.

A physical model of ICCD was developed for the next TRM4v3 version. The ICCD signal, noise and the MTFs are calculated by using the available parameters in datasheets and by taking into account the contribution of the image-intensifier tube, the coupling to CCD element and the CCD itself.

Keywords: Sensor performance, Detection range, Sensor models, ICCD

Prediction of Objects Detection Recognition and Identification [DRI] Ranges at Color Scene Images, based-on Quantifying Human Color Contrasts Perception

Ephi Pinsky, Ilia Levin and Ofer Yaron

RAFAEL Advanced Defense Systems LTD., Israel

We propose a novel approach to predict, for observation by a specified color imaging system and for objects with known characteristics, their detection, recognition, identification (DRI) ranges in a colored dynamic scene, based on quantifying the human color contrast perception. The method refers to the well established $L^*a^*b^*$, 3D color space. The nonlinear relations of this space are intended to mimic the nonlinear response of the human eye. The metrics of $L^*a^*b^*$ color space is such that the Euclidian distance between any two colors in this space is approximately proportional to the color contrast as perceived by the human eye/brain. The result of this metrics leads to the outcome that color contrast of any two points is always greater (or equal) than their equivalent grey level contrast. This meets our sense that looking on a colored image contrast is superior to the gray level contrast of the same image. Yet, color loss by scattering at very long ranges should be considered as well. The color contrast derived from the distance between the colored object pixels to the nearby colored background pixels, as derived from the $L^*a^*b^*$ color space metrics, is expressed in terms of gray level contrast. This contrast replaces the original standard gray level contrast component of that image. The resulted DRI ranges, as expected, are, in most cases, larger than those predicted by the standard gray level image. Upon further elaboration and validation of this method, it may be combined with the next versions of the well accepted TRM codes for DRI predictions. Accurate prediction of DRI ranges implies a careful evaluation of the object and background color contrast reduction along the range. Clearly additional processing for reconstructing the objects and background true colors and hence the color contrast along the range will further increase the DRI ranges.

Hybrid Video Simulator for Guided Projectile Seeker

Idan Paiss

Israeli Aerospace Industries, Israel

Realistic seeker testing often uses hardware in the loop facilities. The end game is simulated using a dynamic optical scene projector imitating the target image and its surrounding. The simulation setup needs to support a distant optical scene from all possible Line Of Sight (LOS). This requirement can be implemented by a moving optical projection system mounted on a gimbaled platform in front of the seeker. The projector is often required to project a large diameter beam, covering the full seeker field of view. Such projection systems are complex and extremely heavy, requiring an enormous gimbaled system support the projection direction dynamics.

We propose a "hybrid" solution approach that simplifies the simulation setup, reduces the size of the optical system, and enables generation of features not supported by the optical projection system. The method relies on the fact that in a modern seeker systems, there is a distinct separation between the sensor and its processing unit, enabling intervention on the digital video line between the two items.

The solution is based on partly or fully replacing the seeker sensors digital video output of the projected target with synthetic background video that completes the field of view in each frame, generating full format picture and keeping the relevant optical target image intact.

In this paper we describe the main building blocks of the hybrid scene simulator and discusses the implementation methods for optimally combining sensor and synthetic video in real time at high frame rate. We shall also discuss the advantages of such hybrid system compared to conventional scene projectors in test facilities.

Session: Ultrafast Phenomena - Prof. Oren Cohen

Free-Electron Quantum Optics Studied by Ultrafast Transmission Electron Microscopy *

Claus Ropers

University of Göttingen, Germany

Ultrafast Transmission Electron Microscopy (UTEM) is an emerging technique to study structural and electronic dynamics on the nanoscale. Besides its use as an analytical tool with simultaneous femtosecond temporal and nanometer spatial resolution [1], UTEM also provides for a unique test bench to study quantum optics phenomena with free electrons.

This talk will discuss several examples of free-electron beams interacting with optical near-fields at nanostructures, emphasizing quantum coherent phenomena. Specifically, for swift electrons traversing intense optical near-fields [2,3], we observe multilevel Rabi-oscillations on a ladder of quantized free-electron states [4], and implement Ramsey-type dual interactions in polarization-controlled, spatially separated near-fields [5]. Employing phase-locked two-color fields, coherent control of free-electron states is demonstrated [6]. We introduce a scheme to characterize the quantum state of such phase-modulated free-electron states in terms of their density matrix or Wigner function [6].

Finally, we demonstrate various new possibilities in the coherent manipulation of the longitudinal and transverse degrees of freedom of free-electron wave functions, including the optical preparation of attosecond electron pulses.

References

- [1] A. Feist et al., "Ultrafast transmission electron microscopy using a laser-driven field emitter: Femtosecond resolution with a high coherence electron beam", *Ultramicroscopy* (in press, 2016), <http://dx.doi.org/10.1016/j.ultramic.2016.12.005>
- [2] B. Barwick, D. J. Flannigan, and A. H. Zewail, "Photon-induced near-field electron microscopy", *Nature* 462, 902 (2009).
- [3] F.J. García de Abajo, Ana Asenjo-Garcia and Mathieu Kociak, "Multiphoton absorption and emission by interaction of swift electrons with evanescent light fields", *Nano Lett.* 10, 1859 (2010).
- [4] A. Feist, K. E. Echternkamp, J. Schauss, S. V. Yalunin, S. Schäfer, and C. Ropers, "Quantum coherent optical phase modulation in an ultrafast transmission electron microscope", *Nature* 521, 200 (2015).
- [5] K. E. Echternkamp, A. Feist, S. Schäfer, and C. Ropers, "Ramsey-type phase control of free electron beams", *Nature Phys.* 12, 1000 (2016).
- [6] K. E. Priebe et al., unpublished.

Stimulated Radiation Interaction of a Single Electron Quantum Wavepacket

A. Gover, Y. Pan

Tel Aviv University, Israel

We analyze the acceleration and stimulated (emission/absorption) interaction of an electron quantum wavepacket with coherent radiation numerically and using perturbation solution of the "relativistic" Schrodinger equation. The analysis applies to a wide class of radiative interaction schemes, and exemplified for Smith-Purcell radiation. We identify a critical electron drift length away from the cathode zG , which depends on the electron energy and radiation wavelength λ only. We distinguish two different operating regimes: When the drift length is, then linear acceleration/deceleration of the wavepacket is fundamentally impossible because of the wavepacket spread. For such acceleration is possible, with features tending to classical "point particle" acceleration when the standard deviation of the wavepacket spatial distribution is short relative to λ . In second order expansion in the radiation field we emulate the results of FEL theory in the quantum regime [4] and of quantum momentum recoil sidebands in PINEM [5]. We discuss the question of measurability of the quantum wavepacket size.

Reference

- 1. Friedman, A., Gover, A., Kurizki, G., Ruschin, S., & Yariv, A. (1988), "Spontaneous and stimulated emission from quasifree electrons". *Reviews of modern physics*, 60(2), 471.
- 2. Feist, A., Echternkamp, K.E., Schauss, J., Yalunin, S.V., Schäfer, S. and Ropers, C., 2015. Quantum coherent optical phase modulation in an ultrafast transmission electron microscope. *Nature*, 521(7551), 200.

Isolating Strong-Field Dynamics in Molecular Systems

Gal Orenstein, O. Pedatzur, A. July Uza, B.D. Bruner, N. Dudovich

Department of Physics of Complex Systems, Weizmann Institute of Science, Israel

Strong field phenomena involve highly nonlinear light matter interactions in which all internal degrees of freedom can be strongly coupled. High harmonic generation (HHG) spectroscopy exploits the high nonlinearity to reveal a range of electronic processes, combining sub-Angstrom spatial and attosecond temporal resolution. In this self-probing scheme the strong-field tunnel ionization acts as a pump, removing an electron from an atomic or molecular system, thus initiating a hole wavepacket. Driven by the laser field, the liberated electron returns to the parent ion and probes it via radiative recombination, leading to the emission of high-order harmonics of the driving laser field. The heart of HHG spectroscopy lies in the direct link between the pump (ionization) and the probe (recollision), defined by strong field trajectories. This link is assumed to be universal and dictated by the Ponderomotive energy and ionization potential alone. However, so far such a link has been measured and verified for simple atomic systems only. In this work we study one of the most fundamental components in HHG spectroscopy, the intrinsic pump-probe measurement. By adding to the fundamental field a weak perturbative second harmonic we establish its validity in molecular systems. Specifically, we perform a multidimensional measurement of the interaction controlling both the dynamical properties via the two color field, and the structural properties via molecular alignment. Our measurement reveals the universality of the pump probe scheme showing that it is structurally independent. When several orbitals are involved we identify the fingerprint of the transition from the single channel case into multiple channel dynamics-where nontrivial multi-electron phenomena are expected to be observed.

On the Fly Control of High Harmonic Generation using a Structured Pump Beam

Lilya Lobachinsky, Liran Hareli, Yaniv Eliezer, Linor Rapaport, and Alon Bahabad

Department of Physical Electronics, School of Electrical Engineering, Tel Aviv University, Israel

Introduction: We experimentally drive the process of high-harmonic-generation with a structured pump beam made of the interference of a Gaussian beam and a perturbing tunable Bessel. The structured beam is characterized with a periodic standing wave pattern having controlled period, extent and modulation depth. The use of such a structured pump beam allows exerting on-the-fly macroscopic control and enhancement over the emitted high harmonic radiation. Background High Harmonic Generation (HHG) is an extreme nonlinear optical up-conversion process driven with an intense ultra-short laser pulse. Macroscopically, the efficient buildup of each harmonic order is limited to its coherence length which is the distance at which the accumulated phase difference between the pump beam and the harmonic emission is equal to π . Objectives By superposing coaxially a Gaussian and a Bessel beams, a periodic intensity and phase modulation emerges on axis. The overall modulation can be used to realize an efficient alloptical co-propagating Quasi-Phase-Matching scheme. Methods The output beam of an ultrafast amplifier is split into two unequal parts. The major part retains its Gaussian profile. The second beam, with intensity lower than 10% of the first, undergoes an amplitude modulation using a Spatial Light Modulator (SLM), and acquires a spatial distribution of a ring which is later used in a 2f configuration to form a Bessel profile. Both beams are combined and focused together at the output of a Semi-Infinite-Gas-Cell (SIGC), generating high harmonics. The exact parameters of the modulation are easily controlled by the SLM. Results With the described scheme we experimentally demonstrate tunable QPM of harmonic orders 25 to 39, with enhancement of up to 30 fold. Conclusions We present an all-optical co-propagating scheme for QPM of HHG, allowing a nonmechanical, on-the-fly control and enhancement of the high harmonics emission.

Keywords: ultrafast optics, nonlinear optics, high harmonic generation

Optical Access to Topological Insulator Spin Dynamics

Dmitry Panna¹, Raja Marjeh¹, Evyatar Sabag¹, Leonid Rybak¹, Amit Ribak², Amit Kanigel² and Alex Hayat¹

1. Department of Electrical Engineering, Technion, Israel

2. Department of Physics, Technion, Israel

Introduction: We demonstrate all-optical access to topological-insulator ultrafast spin dynamics using transientreflectivity measurements by controlling photon energy and polarization. Our approach distinguishes bulk and surface state responses, providing a practical tool for studying topological insulator dynamics.

Background: Topological insulators (TIs) have been of great interest in condensed matter physics in recent years. Since the surface states of TIs are often overshadowed by doping in the material in electrical transport measurements, optical access to the surface states via light-matter interaction is gaining a great deal of interest lately.

Methods: We performed ultrafast spectroscopy using 35fs pulsed laser with a tunable wavelength at the room temperature.

Results: Here, we demonstrate all-optical access to TI ultrafast spin dynamics using time-resolved transient reflectivity measurements. We exploit the interplay between co- and anti-circular pump-probe polarizations. This is done at two characteristic pump wavelengths of 720nm (1.7eV) and 620nm (2eV) accounting for Dirac cone to Dirac cone and bulk-to-bulk transitions, and a supercontinuum probe. In the bulk-to-bulk case, the strongest change in differential reflectivity $R - R_0$ results from the normal to surface components of the photon and electron spins. On the other hand, for surface states, the strongest change in $R - R_0$ is for opposite pump and probe circular polarization. In this case, $R - R_0$ stems mainly from the parallel components of photon spin, so that pump and probe must have opposite circular polarization in order to interact with the same spin population. We find that the effect of the polarized pump on the surface states is stronger than in the bulk case.

Conclusions: We have demonstrated all-optical access to topological-insulator ultrafast spin dynamics by controlling photon energy and polarization in ultrafast transient reflectivity pump-probe experiments. The presented approach separates the bulk and surface responses yielding a powerful tool for studying the intricate dynamics of topological insulators.

Session: Micro and Nano Optics - Prof. Jacob Scheuer

Extreme Photonics *

Nader Engheta

University of Pennsylvania Philadelphia, USA

The ability to tailor the material parameters at will is at the heart of the field of metamaterials. This paradigm provides exciting avenues for sculpting and manipulating waves and fields at various length scales, leading to novel phenomena in light-matter interaction. Nanotechnology, nanoscience and materials science and engineering have witnessed tremendous advancement in recent years, and consequently scientists and engineers can now construct structures with unprecedented wave-based and quantumbased characteristics. In my group, we are exploring a variety of projects related to the wave-matter interaction in platforms with extreme scenarios, such as near-zero relative permittivity and near-zero relative permeability, and with extreme features, e.g., very high phase velocity, very low energy velocity, nonreciprocal vortices at subwavelength scales, large anisotropy and nonlinearity, “low-index” photonics, nanoscale computation with optical metatronics, and more. Such “extreme photonics” is a novel platform with exciting features and functionalities for quantum-based and wave-based paradigms such as near-zero optics, acoustics and thermodynamics. In this talk, I will give an overview of some of our ongoing work in these areas and will forecast some future directions and possibilities.

Laser Beam Shaping with Intra-Cavity Gradient Metasurfaces

Ronen Chriki^{1*}, Elhanan Maguid^{2*}, Asher A. Friesem¹, Erez Hasman² and Nir Davidson¹

1. Department of Physics of Complex Systems, Weizmann Institute of Science, Israel

2. Micro and Nano optics Laboratory, Faculty of Mechanical Engineering and Russell Berrie Nanotechnology Institute, Technion- Israel Institute of Technology, Israel

Gradient phase metasurfaces (GPM) elements are two dimensional space variant gradient structures, which have interesting properties and enable exotic light manipulation. Such structures consist of a dense assembly of resonant optical antennas, with subwavelength size scales. The structures are characterized by continuous spatial variations, thus enabling control of local light-matter interactions and local light scattering properties. They have been used in a number of applications, including formation of flat optical elements with unique features [1], polarization control [2], and spectro-polarimetric devices [3].

Here we demonstrate, for the first time, integration of GPM elements into laser cavities. We exploited recent developments in design and fabrication of metasurfaces to form efficient and robust GPM elements that can be inserted into laser cavities for controlled output beam shaping. In our investigations, the GPM elements were placed inside a modified degenerate cavity laser [4,5], so as to obtain greater flexibility when handling small-area elements and enable better control of the spatial coherence properties of the output light. Specifically, the GPM elements interact with the laser cavity, and generate output beams with unique and well-controlled properties, such as coherent and partially coherent helical distributions, multiple helical distributions and radial and azimuthal polarized beams. Details of our arrangement and results will be presented.

References

- [1] D. Lin, P. Fan, E. Hasman, and M. L. Brongersma, *Science* 345, 298 (2014).
- [2] Z. Bomzon, G. Biener, V. Kleiner, and E. Hasman, *Opt. Lett.* 27, 285 (2002).
- [3] E. Maguid, I. Yulevich, D. Veksler, V. Kleiner, M. L. Brongersma, and E. Hasman, *Science* 352, 1202 (2016).
- [4] M. Nixon, O. Katz, E. Small, Y. Bromberg, A. A. Friesem, Y. Silberberg, and N. Davidson, *Nat. Photonics* 7, 919 (2013).
- [5] R. Chriki, M. Nixon, V. Pal, C. Tradonsky, G. Barach, A. a. Friesem, and N. Davidson, *Opt. Express* 23, 12989 (2015).

Topological Defects in Coupled Laser Networks

Vishwa Pal, Chene Tradonsky, Ronen Chriki, Gilad Barach, Asher A. Friesem and Nir Davidson

Department of Physics of Complex Systems, Weizmann Institute of Science, Israel

Topological defects have attracted considerable interest in various fields such as cosmology, spin systems and optics. The underlying physical mechanism of their origin and control is becoming an increasingly important and fascinating field of research. Topological defects arise as a result of spontaneous symmetry breaking, whereby a system undergoes a transition from a complex disordered phase state to an ordered phase state.

We investigated dissipative topological defects in a one-dimensional ring network of coupled lasers, and show how they are linked to the Kibble-Zurek mechanism. In this mechanism the approach to explain the formation of defects relies on the notion of competing time scales in the system, and density of defects follows a power-law behavior with respect to the rate at which the phase transition is crossed. These defects may be topologically protected, depending on the size and geometry of the system, preventing it from reaching a perfect ordered state. We experimentally found that the probability of topological defects increases as the number of lasers increases. Also, it strongly depends on the pump strength, where the probability is smaller when the lasers are operated at low pump strength, and increases when the pump strengths are increased. We confirmed that the formation of topological defects depends on two competing time scales, namely phase locking time and synchronization time of lasers amplitude fluctuations. More specifically, when the phase locking time is smaller than the synchronization time, the probability for topological defects formation is zero. Whereas, when the phase locking time exceeds the synchronization time, the probability for topological defects formation is finite.

The details of the experimental arrangement, procedures and results, as well as supporting theoretical results will be presented.

Keywords: Coupled laser network, Phase locking, Kibble-Zurek mechanism, Quantum Optics

Advanced Optical 3D-Microstructures Elements Made of Sol-gel Derived Hybrids Prepared by Nano-imprint Lithography (NIL)

Raz Gvishi¹, Shlomi Lightman^{1,2}, Ofer Bar-On², Jacob Scheuer², Ady Arie²
Philipp Brenner³, Tobias Siegle³, Carsten Eschenbaum³, Heinz Kalt³, Uli Lemmer³

1. Applied Physics Division, Soreq NRC, Israel

2. School of Electrical Engineering, Tel Aviv University, Israel

3. Karlsruhe Institute of Technology, Germany

In photonic applications there is a need for inexpensive 3D-microstructures optical elements. Sol-gel process can be used as a “tool-kit” for production of optical glassy materials which are appropriate for photonic applications in terms of optical quality, thermal and environmental stability. Recently, using a fast sol-gel process a thermal/UV-curable sol-gel hybrid material was developed and applied for bonding of optical components. The obtained sol-gel material is an inorganic-organic hybrid with less than 30% organic residues and negligible porosity. These hybrids possess high thermal and optical power stability and low optical loss in the visible range. In addition, specific properties can be tailored by adding appropriate additives.

In the current work we demonstrated the use of such sol-gel hybrids for fabrication of advanced 3D-microstructures optical elements prepared by nano-imprint lithography (NIL). NIL technology allows mass production of elements with nano-scale resolution and can utilize any thermal/photo-resists. Most of the commercial resists are based on organic polymers which are limited by their optical and mechanical properties. In the current work we used the fast sol-gel derived hybrids in either thermal or UV-curing for NIL process.

We demonstrated fabrication of 3D-microstructures with improved optical and mechanical properties, using NIL technology of two classes of optical elements: phase optical filters which can convert light beam modes and optical ring-resonator which can be used as micro-lasers. For the phase optical filters, we demonstrated optical quality conversion of a zero-order Hermite-Gaussian (HG_{00}) mode into higher-order modes (HG_{10} , HG_{01} , HG_{20} , and HG_{02}). For the optical passive ring-resonator we demonstrated high Q-factors as high as 8.8×10^4 at a wavelength of 635 nm. For active ring resonator we demonstrated lasing performance with low thresholds in the order of 15 kW/cm² under pulsed excitation. In all cases the elements possess high optical quality and environmental stability.

Water-Walled Optofluidics and WaterWave Lasers *

Tal Carmon

Faculty of Mechanical Engineering, Technion, Israel

We fabricate a new type of optofluidic micro-device that is having its walls made strictly of water. Our water-walled devices can therefore co-host water waves and light waves and enable energy exchange between electromagnetic and capillary resonances.

Using our opto-capillary cavity, while operating at its non-resolved sideband, we experimentally demonstrate enhancement of the redder (Stokes) scattering of light from water waves; which allows excitation of water wave laser. This laser is similar to Brillouin lasers; but it relies on water waves instead of sound.

Going to the opposite sideband enables ripplon annihilation and (anti-Stokes) optical cooling of water waves. Except for extending Raman-lasers and -coolers to rely also on water waves, transforming the walls of devices to interfaces made of the liquid phase of matter makes water-walled devices a million times softer when compared to what current solid-based technology allows. This softness implies a giant optical controllability and coolability that might, one day, allow optically cooling such devices toward their quantum ground state from room temperature.

Session: IFLA, High Power Fiber Lasers - Dr. Boaz Lissak

Keynote Lecture: Coherent Time-Domain Combining of Femtosecond Pulses for the Next Generation of Power Scalable Fiber Lasers

Almantas Galvanauskas

EECS Department/CUOS, University of Michigan, USA

Fiber lasers have a unique technological advantage compared to other gain media due to their possible integration into compact circuit-like subsystems, which can be aggregated into more complex but portable electronic-rack type laser units, whose overall power and energy scalability is no longer limited by each individual sub-unit. Essentially, this enables a new technological “dimension” for the power scaling, which is utilized in compact high-power systems based on various coherent and incoherent spatial beam combining techniques for industrial and directed energy applications, with produced average powers from 10kW to more than 100kW. However, spatial beam combining is not sufficient for scaling up ultrashort pulse energies from fiber lasers, where pulse energies achievable even with the chirped pulse amplification (CPA) are nearly two orders of magnitude below the stored energy. This means that ultrashort pulse fiber laser arrays for energy scaling should be correspondingly two orders of magnitude larger than those for average power scaling.

Solution of this problem necessitated extending coherent combining into the time-domain dimension. We are developing a so-called coherent pulse stacking amplification (CPSA) technique, based on generating a prescribed-phase and preshaped-amplitude modulated multiple-pulse burst directly from an output of a mode-locked laser, amplifying it in a fiber CPA system close to the stored-energy limit, and then stacking it into a single pulse at the system output in a compact arrangement of completely reflecting GTI-type resonant cavities. Pulse burst pre-shaping enables complete compensation of very strong energy saturation effects at the stored-energy extraction limit. Coherent combining in the time domain is implemented by active stabilization of the stacking cavity phases, locked to the phases of the incoming stacking pulse burst. Time-domain combining and then compression of up to 81 pulses has been achieved so far, which is equivalent to compressing a ~80ns long pulse down to 300fs - a two order of magnitude stretched-pulse duration increase over a typical CPA. With the state-of-the art 85 μm core Yb-doped CCC fiber amplifiers this enabled demonstration of more than 5mJ ultrashort-pulse energy extraction per single fiber-amplification channel. Such time-domain combining techniques are enabling high power ultrashort-pulse laser systems, necessary for a wide range of novel high-intensity applications ranging from fundamental studies to industry.

250 W Average Power Inner-Cladding Pump Raman Fiber Laser***Yariv Shamir, Yaakov Glick, Matitya Aviel, Avital Attias and Shaul Pearl***Applied Physics division, Soreq NRC, Israel*

Stimulated Raman Scattering (SRS) [1] can be excited in optical fibers by interaction between intense laser beam and the host molecules. In Fused Silica fibers a -13.2 THz 1 st Stokes shift around $\lambda=1\text{ }\mu\text{m}$ enables to harness the process for, e.g., obtaining optical frequencies that may be difficult to reach by common fiber laser ions. For average power scaling, SRS can be advantageous since it might be well immune to modal instabilities, attributed to longitudinal thermal grating [2], at the expense of small thermal loss. Recent FL SRS reports included 80–150 W from direct diode pumping of gradient index fiber [3,4] or 100 W inner-clad in 2010 [5]. Our objective is to examine SRS power scalability with new LMA triple clad fiber architecture, deployed as an oscillator with fiber of 25 μm core / 45 μm inner-clad / 250 μm outer clad diameters. The low Germania doped core has a slightly higher Raman gain that becomes pronounced under oscillations. The experimental scheme included 4×150 W 1030 nm fiber lasers coupled into the TCF via in-house fused combiner [6,7]. Two specialty designed Bragg gratings burned into the TCF fiber for 1079 nm Stokes reflection were connected to the ends of the 160 m TCF, terminated by a cooled angle cleaved end-cap. The 1 st 1079 nm Stokes threshold was around ~30 Watt of pump. Separation between the pump, the 1 st and 2nd Stokes (1120 nm) was handled via long pass 1050 nm and 1100 nm cut-off filters. Power ramping from 50 W on showed gradual M^2 ascending from ~1.7 to ~3. The highest power was 250 W, which is to our knowledge, the highest reported with such inner clad scheme. Counter intuitively, tight coiling did not show significant effect on the results. We achieved ~×2.5 power scaling and ~×4 brightness enhancement factors over the pump laser beam.

Keywords: Stimulated Raman Scattering, high power fiber laser, Multi clad fiber, Stokes beam, Fiber Bragg grating.

References

- [1] N. Bloembergen, Amer. J. Phys., V.35, N.11, 989 (1967).
- [2] C. Jauregui et-al, Opt. Exp., V.19, N.4, 3258, (2011).
- [3] Y. Glick et-al, Laser Phys. Lett., V.13, N.6, 065101, (2016).
- [4] Y. Glick et- al Appl. Opt. V. 56, N.3, 90-102 (2017).
- [5] J. Ji et-al, Opt. Fiber Tech., V.16, N.6, 428–441(2010).
- [6] Y. Shamir et-al, Opt. Lett., V.36, N.15, 2874–2876 (2011).
- [7] Y. Shamir et-al, Opt. Lett., V. 37, N.9 1412–1414 (2012).

kW-Cclass Lasers based on Coherent Beam Combining ***Yaniv Vidne, Benayahu Urbach, Avisar Shapira, Shira Gruner and Eyal Shekel***Civan Advanced Technologies Ltd., Israel*

The advantages of Fiber lasers over conventional solid-state and chemical lasers are well recognized in today's laser industry. These advantages include compactness, near diffraction-limited (Single-mode) beam quality, superior thermal-optical properties, and improved output efficiencies. The primary factors limiting scalability in single mode fiber output power levels are both thermal loads and nonlinear optical effects. Output power levels of 2kW per single mode fiber is the industry benchmark, with some reporting up to 3kW Single mode modules in their laser products. Above this threshold, system cost and robustness levels become either extremely or prohibitively difficult with today's Fiber laser technologies and componentry. At the high power extreme, Single-mode fiber lasers are expected to soon reach their physical limits of maximum broadband powers of ~10–15 kW. Coherent beam combining (CBC) is a most promising method toward combining multiple fiber modules into one single .mode beam that is scalable in output power levels We report kW scale CBC of fiber amplifiers in the near field using a diffractive optical element (DOE). Narrow bandwidth, SBS suppressive CBC of 11 X 140W fiber amplifiers with 1.3 kW total single mode output power is presented. In addition, prospective output power scale-up methods with CBC is presented.

Session: Quantum Optics - Prof. Barak Dayan

Optical Homodyne with Optical Bandwidth

Yaakov Shaked*, Yoad Michael, Rafi Vered, Michael Rosenbluh and Avi Pe'er

Department of Physics and BINA Center of Nano-Technology, Bar-Ilan University, Israel

Homodyne measurement is a corner-stone of quantum optics. It is the main method for measuring the quadratures of light – the cosine-wave and sine-wave components of an optical field, which constitute the quantum optical analog of position and momentum. The quadratures obey quantum uncertainty, indicating the inherent inability to measure both simultaneously. Homodyne measurement – that extracts the quadrature amplitudes by correlating the optical field against an external quadrature reference (local-oscillator-LO), is a critical tool for quantum information: Homodyne can reveal non-classical phenomena, such as squeezing of the quadrature uncertainty; It is used in tomography to fully characterize quantum states of light; Homodyne detection can generate non-classical states, provide local measurements for teleportation and serve as a major detector for quantum key distribution (QKD) and quantum computing.

Yet, standard homodyne suffers from a severe bandwidth limitation. While the bandwidth of optical states can easily span many THz, standard homodyne detection is inherently limited to the electronically accessible, MHz to GHz range, leaving a dramatic gap between the measurement capability and the relevant quantum phenomena. This gap is critical for quantum computation, QKD and other applications of quantum squeezed light. The limited detection bandwidth impedes effective utilization of the huge bandwidth resource of squeezing and prevents the potential enhancement of the information throughput by several orders of magnitude with parallel quantum processing.

We demonstrate a fully parallel optical homodyne measurement across an arbitrary optical bandwidth, effectively lifting the bandwidth limitation completely. Using optical parametric amplification, which amplifies one quadrature of the light but attenuates the other, we measure two-mode quadrature squeezing of $\sim 1.5\text{dB}$ below the vacuum level simultaneously across a spectral bandwidth of 55THz using just a single local oscillator – the pump. This broadband parametric homodyne measurement opens a wide window for parallel processing of quantum information.

Quantum Correlations Enhanced SuperResolution Localization Microscopy

Yonatan Israel, Ron Tenne, Dan Oron, and Yaron Silberberg

Department of Physics of Complex Systems, Weizmann Institute of Science, Israel

We present a method that utilizes quantum correlation measurements for multi-emitter sub-diffraction localization in a time-dependent scene. This is demonstrated using a newly developed imaging configuration based on fiber bundle coupled single-photon avalanche detectors.

In the past two decades, several successful schemes to overcome the diffraction limit in microscopy were developed. Many of these utilize the concept of precise localization of a single emitter in a time series of sparse frames. One inherent problem of these methods is the sparsity requirement, i.e. at most a single emitter per diffraction limited spot per frame, slowing down the acquisition of super-resolved images. In our scheme, a key ingredient to alleviate this problem lies in utilizing information on the number of active emitters. By measuring continuously the quantum correlation $g^{(2)}(0)$, the number of active emitters can be found at any time. In particular, such measurements can help determine intervals of time when only a single emitter is switched 'on' in the detection volume and apply a localization algorithm to localize the emitters, using the precise number of emitters in the image.

Realizing such a scheme requires a fast, low-noise, single-photon sensitive imaging detector. Our novel imaging device, the single-photon fiber bundle camera (SPFICAM), is an ultrafast low pixel-number camera, constructed from a fiber bundle, in which each fiber acts as a 'pixel' and guides photons to a single-photon avalanche photo detector (SPAD), as shown in Fig. 1a. It combines a large fill factor, high quantum efficiency, low noise and a scalable architecture.

References

- 1 Y. Israel, R. Tenne, D. Oron, Y. Silberberg, "Quantum correlations enhanced super-resolution localization microscopy", arXiv preprint arXiv:1609.00312, 2016.

Measuring Incompatible Observables of a Single Photon

Eliahu Cohen

H. H. Wills Physics Laboratory, University of Bristol, UK

Background: One of the most intriguing aspects of quantum mechanics is the impossibility of measuring at the same time observables corresponding to noncommuting operators due to quantum uncertainty. This impossibility can be partially relaxed when sequential weak value evaluation over a large ensemble.

Introduction: Weak measurements [1-4] have been a breakthrough in the quantum measurement framework that is of great interest from both theoretical and applicative points of view. Weak measurements allow to gather information about the quantum system without collapsing it. They gain their power when repeated over a large ensemble of particles.

Objective: I will describe how we realized for the first time a sequential weak value evaluation of two non-commuting operators, i.e. two incompatible polarizations, using a genuine single-photon experiment [5].

Method: We used a heralded single-photon source based on pulsed parametric down-conversion, exploiting a 796 nm mode-locked Ti:Sapphire laser. The signal photon was prepared with a welldefined linear polarization and then traversed two birefringent crystals with different optical axes. These two coupled the two transverse momenta of the photon to two incompatible polarization axes, but crucially, the coupling was weak enough and enabled to avoid decoherence. Finally, the polarization of the photon was post-selected and the photon was detected by a unique array of 32x32 Silicon single-photon avalanche detectors. When collecting the statistics of many such single-photon runs, we were able to accurately infer the two polarization values from the average spatial displacements.

Conclusions: The measured (sometimes anomalous) weak values revealed the single-operator weak values, as well as the local correlation between them known as the sequential weak value. In addition to the conceptual advance made possible through this experiment, it enables to perform process tomography and to test counterfactual communication/computation protocols. It also paved the way for our recent demonstration of protective measurements [6].

Keywords: Quantum optics, single-photon experiments, weak measurements, sequential weak values, quantum uncertainty.

References

- [1] Y. Aharonov, D.Z. Albert, L. Vaidman, How the result of a measurement of a component of the spin of a spin-1/2 particle can turn out to be 100, Phys. Rev. Lett. 60, 1351 (1988). [2] Y. Aharonov, E. Cohen, A.C. Elitzur, Foundations and applications of weak quantum measurements, Phys. Rev. A 89, 052105 (2014). [3] A. Brodutch, E. Cohen, Weak measurements via quantum erasure, Phys. Rev. Lett. 116, 070404 (2016). [4] A.N. Jordan, J. Martinez-Rincon, J.C. Howell, Phys. Rev. X 4, 011031 (2014). [5] F. Piacentini, M.P. Levi, A. Avella, E. Cohen, R. Lussana, F. Villa, A. Tosi, F. Zappa, M. Gramegna, G. Brida, I.P. Degiovanni, M. Genovese, Measuring incompatible observables of a single photon, Phys. Rev. Lett. 117, 170402 (2016). [6] F. Piacentini, A. Avella, R. Lussana, F. Villa, A. Tosi, F. Zappa, M. Gramegna, G. Brida, E. Cohen, L. Vaidman, I.P. Degiovanni, M. Genovese, Determining the quantum expectation value by measuring a single photon, forthcoming.

Simulating Spatial Distribution of Spontaneously Down Converted Photon Pairs in Nonlinear Crystals

Sivan Trajtenberg-Mills¹, Noa Voloch-Bloch², Hagai Eisenberg², and Ady Arie¹

- 1. Faculty of Engineering, School of Electrical Engineering, Israel
- 2. Racah Institute of Physics, Hebrew University of Jerusalem, Israel

Introduction: Spontaneous parametric down conversion (SPDC), where one photon is spontaneously split into two photons through interaction with a non linear media, is today one of the leading technologies for creating non-classical light for various quantum applications. The created photons are naturally entangled in many degrees of freedom, making them useful for quantum computation, quantum cryptography quantum communication and more.

Background: SPDC was first achieved in birefringently phase matched processes [1]. Later, new and sophisticated crystal configurations were proposed in order to shape the spatial properties of the bi-photons, a desirable trait for improving the efficiency of the process as well as controlling different degrees of entanglement and tailoring different states. SPDC was also studied with structured light beams, and OAM conservation in SPDC was shown experimentally, enabling the creation of higher dimensional entanglement [2]. Until now, no simulation tool was available for predicting the spatial distribution of these bi-photons. Predictions and designs were made using wave-vector calculations only, limiting the type of crystals that can be designed to crystals which have simple and well defined reciprocal lattice vectors.

Results and Conclusions: We present an algorithm for calculating the spatial distribution of the output state. The algorithm is based on the classical non linear coupled-wave equations with a seed signal beam having a wide distribution of wave-vectors, simulating the quantum noise. The algorithm correctly reproduces the spatial distribution as measured in different experiments and with different nonlinear crystals, among them one-dimensional and two-dimensional periodically poled crystals and birefringently phase matched crystals [1-3]. Furthermore, SPDC with special structured beams such as vortex beams that carry orbital angular momentum can be also accurately calculated. We believe that this tool will open new possibilities in designing sophisticated nonlinear photonic crystals for quantum optics applications.

References

- 1. P.G. Kwiat, K. Mattle, H. Weinfurter, A. Zeilinger, A.V. Sergienko, and Y. Shih, Phys. Rev. Lett. 75, 4337-4341 (1995).
- 2. A. Mair, A. Vaziri, G. Weihs, and A. Zeilinger, Nature 412, 313-6 (2001).
- 3. E. Megidish, A. Halevy, H.S. Eisenberg, A. Ganany-Padowicz, N. Habshoosh, and A. Arie, Opt. Express 21, 6689-96 (2013).

Diffusion-Free Beams

Slava Smartsev, Ronen Chriki, David Eger, Ofer Firstenberg, and Nir Davidson

Department of Physics of Complex Systems, Weizmann Institute of Science, Israel

Bessel beams are well known for their unique immunity to diffraction [1]. Here we show for the first time that Bessel beams are also immune to diffusion. To experimentally demonstrate this, we shaped the atomic coherence as Bessel beams, mapping phase and amplitude of the light on to the Rb atomic vapor. The frequent collisions of the atoms, induced the diffusion and diffraction on the coherence [2]. We continuously retrieved light from the coherence, with motional-induced diffusion and diffraction signature, controlling the relative strength and the balance between induced diffusion and diffraction [3]. For comparison, we examined different beams which are non-immune to diffusion and diffraction, under similar conditions. Furthermore we examined the random superposition of different orders of Bessel beams, which are also diffusion-free.

References

- [1] J. Durnin, J. J. Miceli, and J. H. Eberly, "Diffraction-free beams," *Phys. Rev. Lett.* 58, 1499 (1987).
- [2] O. Firstenberg, M. Shuker, A. Ron, and N. Davidson, "Coherent diffusion of polaritons in atomic media", *Rev. Mod. Phys.* 85, 941 (2013).
- [3] S. Smartsev, D. Eger, N. Davidson, and O. Firstenberg, "Continuous retrieval of delayed Raman polaritons," *ArXiv e-prints* (2016).

Demonstration of a Bit-Flip Correction for Enhanced Sensitivity Measurements

Lior Cohen, Yehuda Pilnyak, Daniel Istrati, Alex Retzker, Hagai Eisenberg

Racah Institute of Physics, Hebrew University of Jerusalem, Israel

The sensitivity of classical and quantum sensing is impaired in a noisy environment. Thus, one of the main challenges facing sensing protocols is to reduce the noise while preserving the signal. Recently, a proposal to use a quantum error correction protocol to recover sensitivity in the presence of a bit-flipping noise was published [1]. The main idea is to use a protected entangled qubit to correct the bit-flip. Here, we will present a linear optics implementation of this protocol on the polarization degree of freedom of photons and its experimental demonstration [2]. A pair of entangled photons is generated using non-collinear type II spontaneous parametric down conversion. One photon measures a birefringence phase and is vulnerable to a bit flip, while its pair is protected and used for the correction. The error correction is performed by polarization rotations and a projection on a polarizing beam splitter. Our proof of principle demonstration is a novel solution in case of short correlation time bit-flip. The results show a significant recovery of the interference oscillations and about 87% of the sensitivity, independent of the noise rate. Additionally, we will discuss how our scheme can be generalized to an arbitrary number of N photon pairs. In this case, the sensitivity is increased in principle by a factor of \sqrt{N} compared to the shot noise limit, the limit of classical measurements, despite of the existing noise.

References

- [1] G. Arrad, Y. Vinkler, D. Aharonov and A. Retzker, "Increasing sensing resolution with error correction." *Phys. Rev. Lett.* 112, 150801 (2014)..
- [2] L. Cohen, Y. Pilnyak, D. Istrati, A. Retzker, and H. S. Eisenberg, "Demonstration of a quantum error correction for enhanced sensitivity of photonic measurements." *Phys. Rev. A* 94, 012324 (2016).

Session: Electro Optics in Industry - Dr. Michael Berger

Automated Assembly and Testing of Photonics Devices: Addressing the Needs of Growing Production Volumes

Ignazio Piacentini

ficonTEC Service GmbH, Germany

In previous conferences and workshops the comparison between the packaging costs of conventional Integrated Circuits (typically 10-12 %) and that of Photonic Integrated Circuits (that can reach the staggering figure of 80 %) has been discussed and identified, indicating a clear need of advanced assembly automation techniques. Recognition of this need has also led to government-level initiatives in Europe and USA. In the late 90ies / early 2000 'bubble', photonics was targeting primarily telecom, with massive projects like the FTTH (Fibre To The Home), but is today seen as an 'enabling technology', not only covering the needs of data centres, but ranging also in many different application fields from biomedical and life-sciences all the way to aerospace and defence. Automation in photonics - like in many other industrial areas - is linked to production volumes. ficonTEC is a machine manufacturer that has focus entirely on photonics and micro-assembly technologies and that is currently witnessing and monitoring the growth of the photonics market place. The presentation will present the major 'ingredients' and technologies that form the basis of automated equipment for PIC manufacturing, discussing also key concepts privileging flexibility or speed, and what will be the likely trends dictated by growing production volumes. Conclusive remarks will address topics like automated testing, wafer level assembly, the need of standards and design rules taking into account automated assembly and testing, and a brief discussion on how to address the emerging debate on cost-per-part.

Wave-Front Reconstruction for Wafer and Mask Inspection Sensitivity Enhancement

Yinnon Glickman, Boris Golberg, Amir Sagiv

Applied Materials, Israel

Chip manufacturers keep pushing Moore's law by shrinking the design rules. In correspondence, the fabrication-process metrology and inspection tools are required to increase their sensitivity to maintain a reliable defects detection-rate. This requires inspection microscopes with state of the art diffraction limited optics as their point-spread-function [PSF] and the wavefront distortion, respectively, is key factor in the gathered data signal-to-noise ratio [SNR]. It is valid for both the substrate illumination optical path in a scanning spot microscope and the light collection module of a flood illumination microscope.

In optical tools this is the motivation for minimizing the wavefront distortion. Hence, to compensate for optical components manufacturing, assembly and calibration tolerances. The key for correction, either by modules regauging or by adaptive deforming surfaces, is an accurate and stable wavefront sensing instrument such as the Shack-Hartman sensor [SHS]. Here, we will describe a unique technique of embedding in-situs apertures that mimic the SHS operation. These have become unique diagnostics measures for monitoring and issuing aberrations pareto within the tools optics field-of-view [FOV], to a few mLambda accuracy for each Zernike component while inherently overcoming the tool's mechanical vibrations.

A New Automated Optical 3D-Shaping Machine for Printed Circuit Boards

Oded Mor

Orbotech, Israel

Printed Circuit Boards (PCBs) are susceptible to production defects, which can be due to excess (shorts) or missing (opens) copper conductors. We describe an automatic process called 3D-shaping which uses Orbotech's innovative Precise-800 system that improves the PCB production yield; short defects are removed by laser ablation, whereas open defects require 3D-shaping. This disruptive application relies on a combination of 3D-based ablation and copper deposition via a LIFT (Laser Induced Forward Transfer) process.

Challenges of New Product Introduction for the Semi-Conductor Industry

Adam Baer

KLA-Tencor, Israel

The production of any factory is either nearby the design engineering (DE) team or in a remote location, where the selection is typically driven by cost considerations. The technical support for a mature product line, where most design issues have already been resolved, is usually owned by the Manufacturing Design Engineering (MDE) team, assigned to resolve any technical issues related to the production, whether it be product integration issues or supply chain, i.e. vendors, technical support.

In the development and production of complex systems for the semi-conductor industry, the rate of product change is high and continues into the product ramp phase prolonging the period it takes to mature. The high rate of change is due to short time-to-market, driven by the aggressive competition on one hand and evolving customer needs on the other. In such an environment significant involvement of MDE is required already in the New-Product-Introduction (NPI) phase to enable the fast ramp of the new products. Typically the rate of new products release is between every 1.5 to 3 years, while the production volume can vary from a few tens to more than a couple of hundreds annually.

In KLA-Tencor Israel (KTI) we support two product lines. The DE of the first product line is in KTI, while for the second product line DE is in Milpitas California, USA. It may seem that the geographical differences between the two divisions will introduce different challenges, where in fact the NPI process in both cases is quite similar. In order to address the NPI challenges we have structured our teams to support our unique NPI process and developed new methods.

In the following presentation I will describe the challenges and solution of the NPI process for an ever-changing product line in both cases.

MTF Measurement of IR Optics

Hannes Duncker

Trioptics Inc., Germany

Infrared (IR) optical systems are the core of many military, civilian and manufacturing applications. In order to reliably fulfill the demanding requirements imposed on these IR optics, highly accurate, reproducible and fast lens testing is of crucial importance. The MTF (Modulation Transfer Function) test bench presented in this contribution is a turn-key device to precisely measure a wide range of optical parameters of mid- and long-wave IR optics with focal lengths between 10mm and 300mm and clear apertures up to 100mm. Main feature of this instrument is the measurement of the MTF both on- and off-axis (up to 70° field angle) as well as the determination of focal length, distortion, field curvature and chromatic aberration to name a few. The Measurement system is set up in vertical configuration allowing for robust and highly reproducible sample mounting in an air-bearing based sample holder in combination with a small foot print. To achieve highest MTF measurement accuracy we use a highly corrected relay lens exclusively designed for the instrument. We specify an absolute accuracy of +/- 3% MTF which is validated by the measurement of internationally traceable reference optics. By integrating an IR camera we avoid time consuming and high maintenance detection schemes such as the scanning slit method with liquid nitrogen cooled detectors. Together with a sophisticated and intuitive software solution, this makes our instrument a turn-key device providing state-of-the-art optical testing. As an outlook, we introduce the ImageMaster® HR IR with integrated thermal chamber which allows for temperature dependend measurements in the range of -40°C to 100°C which is highly relevant for the application of IR optics in aerospace or vehicles operating in harsh environments.

Smart Thermal Imaging Platforms for the Widest Range of Applications

Frédéric Mathieu, Daravan LY

Device-Alab, France

From Smart Building market to Defense market, thermal imaging applications are more and more demanding and need disruptive technical developments in terms of optics, integration and embedded processing.

This paper covers those challenges and tradeoffs able to address a wide range of applications: from low resolution to high performance thermal vision. It details which improvements have been achieved. Key Electro-Optical performances will be presented. Innovative shutter-less approach aiming to provide major advantage to system integrators will also be discussed.

Keywords: LWIR, EO performances, uncooled micro-bolometer, NUC, shutter-less

Session: Ultrafast Optics - Prof. Oren Cohen

Ultrafast Adiabatic Second Harmonic Generation by Aperiodically Poled Nonlinear Crystal

Asaf Dahan¹, Assaf Levanon¹, Mordechai Katz^{1,2} and Haim Suchowski^{1,3}

1. Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Israel

2. Solid State Physics Department, Electro-Optics Division, Soreq NRC, Israel

3. The center of Light-Matter Interaction, Tel Aviv University, Israel

We introduce a generalization of the adiabatic frequency conversion method for an efficient conversion of ultrashort pulses in the full nonlinear regime. Our analysis takes into account dispersion as well as two photon processes and Kerr effect, allowing complete analysis of any three waves with arbitrary phase mismatched design and any nonlinear optical process. We use this analysis to design an efficient and robust second harmonic generation structure for fundamental wave at the range of 980–1070-nm. We experimentally show that such design not only allows for very efficient conversion of various of ultrashort pulses, but is also very robust to variations in the parameters of both the nonlinear crystal and of the incoming light. These include variation of more than 140°C in the crystal temperature and a wide bandwidth of up to 75nm. Also, we show the dependency of the adiabatic second harmonic generation design on the pump intensity and the crystal length. Our study shows that two-photon absorption plays critical role in such high influence nonlinear dynamics when quasi-phase-matching aperiodically poled KTP is used as the nonlinear crystal.

We have experimentally demonstrated a robust and efficient SHG of ultrashort pulses based on adiabatic frequency conversion with a chirp variation of 200fs to 3.5ps of the incoming pulse. We obtain conversion efficiency over 50% and over 80% pump depletion. Measurements of second-harmonic generation and pump depletion agree with results from analytic predictions.

We have shown that the conversion from near-IR to visible in a SHG process is not sensitive to the bandwidth of the fundamental pulse and to the temperature of the nonlinear crystal.

Keywords: Nonlinear optics, Ultrafast phenomena, adiabatic processes, frequency conversion

Leakage Imaging and Tracking of Ultrafast Surface Plasmon Pulses

Y. Gorodetski^{1*}, T. Chervy², S. Wang², J. A. Hutchison², A. Drezet³, C. Genet², T. W. Ebbesen²

1. Electrical Engineering and Electronics Department, Ariel University, Israel

2. ISIS & icFRC, Université de Strasbourg and CNRS (UMR 7006), France

Institut Néel, CNRS and Université Joseph-Fourier (UPR 2940), France

Among the different surface-plasmon (SP) imaging techniques, leakage radiation (LR) microscopy is a powerful method for imaging SP modes propagating on metal-dielectric interfaces [1–3]. This method has been implemented in a great variety of plasmonic systems, from surface plasmon circuitry [4,5] to near-field weak measurements [6], at the classical and quantum levels [7]. Recently, this technique was combined with interference microscopy, providing also the phase of the leakage signal [8].

Here we develop a system for time-resolved imaging of SP ultra-fast signals with 10 femto seconds (fs) resolution by using a heterodyne interference system combined with LR microscopy [9]. The simplicity of our all-optical method, that does not involve raster-scanned local probe nor non-linear detection processes, presents a clear advantage with respect to the sophistication of recently proposed near-field pulse tracking techniques based on scanning tunneling microscopy [10], two-photon photoemission electron microscopy [11,12] or far-field SP scattering interference imaging [13].

Our experimental scheme consists of an LR microscope within a Mach-Zehnder interferometer. Ultrafast laser pulse (120fs, 800nm) is splitted into two arms. One is used to generate a leakage plasmonic signal from our sample, while the second serves as a reference. Our camera captures the interference of the resulting pulses. The time-delay is varied by movable mirrors in the reference arm. The visibility of the interference fringes corresponds to the overlap of the pulses in time and space. We monitor the imaged interferograms visibility as a function of the delay time between the two pulses. Using the captured and filtered images, the propagation and spatial distribution of the pulse are derived which enables to precisely measure the group and phase velocity of the pulse.

In conclusion we have demonstrated a unique combination of LR microscopy with spatial heterodyne interference technique providing an access to the time-resolved plasmonic imaging.

References

- (1). B. Hecht, H. Bielefeldt, L. Novotny, Y. Inouye, and D. W. Pohl, Phys. Rev. Lett 77, 1889 (1996).
- (2). A. Drezet, et al. Mat. Sci. and Eng. B, 149, 220 (2008).
- (3). A. Hohenau, et al. Opt. Exp. 19, 25749 (2011).
- (4). A.-L. Baudrion, et al. Opt. Express 16, 3420 (2008).
- (5). B. Stein, J.-Y. Laluet, E. Devaux, C. Genet, and T. W. Ebbesen, Phys. Rev. Lett. 105, 266804 (2010).
- (6). Y. Gorodetski, K. Y. Bliokh, B. Stein, C. Genet, N. Shitrit, V. Kleiner, E. Hasman, and T. W. Ebbesen, Phys. Rev. Lett. 109, 013901 (2012).
- (7). A. Cuche, O. Mollet, A. Drezet, and S. Huant, Nano Lett. 10, 4566 (2010).
- (8). E. Descrovi, et al. Opt. Lett. 38, 3374 (2013).
- (9). Y. Gorodetski, T. Chervy, S. Wang, J. A. Hutchison, A. Drezet, C. Genet, and T.W. Ebbesen, Optica, 3,48 (2016).
- (10). M.L.M. Balistreri, H. Gersen, J.P. Korterik, L. Kuipers, and N.F. van Hulst, Science, 294, 1080 (2001).
- (11). A. Kubo, K. Onda, H. Petek, Z. Sun, Y.S. Jung, and H.K. Kim, Nano Lett. 5, 1123 (2005).
- (12). C. Lemke, et al, Nano Lett. 13, 1053 (2013).
- (13). R. Rokitski, K. A. Tetz, and Y. Fainman, Phys. Rev. Lett. 95, 177401 (2005).

Giant AC Stark Effect in a Strongly-Coupled Light-Matter System

Nadav Landau¹, D. Panna¹, S. Bouscher¹, L. Rybak¹, S. Tsess¹, G. Adler¹, S. Brodbeck², C. Schneider², S. Hoebling² and A. Hayat¹

1. Department of Electrical Engineering, Technion - Israel Institute of Technology, Israel

2. Technische Physik, Physikalisches Institut and Wilhelm Conrad Röntgen Research Center for Complex Material Systems, Universität Würzburg, Germany

Introduction: In our experiment we demonstrate for the first time modulation of a strongly coupled light matter system bigger than a Rabi splitting. We observed a non-resonant AC Stark shift in the exciton-polariton spectrum. The shift was measured as a function of pump intensity and for set of temperatures on a femtosecond time scale.

Background: The light-matter interaction between excitons and photons in semiconductor microcavities has been of great interest during the last decade. Numerous of exciting and intricate phenomena have been observed in the strong light-matter coupling regime which manifests new dressed eigenstates for the system - exciton-polaritons - and these include, amongst others, strong parametric scattering and high temperature Bose-Einstein condensation, which exhibits Bogolubov excitations and superfluid behavior.

Methods: Using pump-probe spectroscopy on a specially fabricated semiconductor planar microcavity we probed ultrafast exciton-polariton dynamics in the strong coupling regime.

Results: For high enough pump intensities, we observed a Stark shift comparable to the polariton Rabi splitting. In previous experiments the energy shift of the polaritons levels was treated perturbatively assuming a small energy shift of the exciton levels alone. In our case this assumption was no longer valid, therefore full Hamiltonian diagonalization has been performed. The measured energy shift showed good agreement with the theoretically calculated value. The Stark shifts remains observable even for a wide range of temperatures.

Conclusions: In conclusion, we demonstrated a giant non-resonant AC Stark shift in strongly coupled semiconductor microcavity exciton-polaritons. In the high intensity regime, we obtained a shift in the polariton energy levels comparable to their Rabi splitting. Our results are important for further understanding of polariton dynamics in the strongly coupled regime and can have a range of potential applications, including implementation of an all-optical polaritonic switch utilizing a much broader range of energy shifts and detunings.

Nonlocal Nature of the Ultrafast Nonlinear Response of Metals

Marat Spector¹, Yonatan Sivan²

1. Department of Physics, Ben-Gurion University, Israel

2. Unit of Electro-Optic Engineering, Ben-Gurion University, Israel

Introduction: The ultrafast nonlinear response of metals has been well studied theoretically and experimentally. The response is usually described within the framework of the Two Temperature model, which accounts for the dynamics of the electron and lattice temperatures due to photon absorption [1]. A popular approximation accounts only for the leading order, which is linear with intensity of optical illumination, which gives rise to a local, Kerr-like (i.e., cubic) optical nonlinearity [2]. However, all these studies were limited either to small particles or to uniform excitations of flat interfaces, in which case the field within the metal is uniform, at least to leading order.

Non Uniform Illumination: In this work, we study cases of highly non-uniform (specifically, spatially periodic) illumination of thin metal films which gives rise to temperature gratings. We focus on the dominant role of heat diffusion which causes a self-erasure of the grating contrast on deep sub-picosecond time scales. Thus, the optical functionality of the grating, i.e., the reflectivity, is turned off even if the system does not return to equilibrium. This reveals the strong non-local nature of the ultrafast nonlinear optical response of metals, and shows that the simple local Kerr-like description is invalid for interpretation of many experimental scenarios, such as typical four-wave mixing from metal surfaces. On the practical level, this shows how to construct an ultrafast thermal modulator, which turns on and off at deep sub-picosecond time scales, a task which is usually dimmed impossible and to the breaking of the speed barrier on switching based on free-carrier excitation. We demonstrate the concept in a variety of geometries and scenarios, such as short pulse generation [3], ultrafast switching [4] and time reversal of short pulses [5].

References

- [1]. T. Stoll and P. Maoli and A. Crut and N. Del-Fatti and F. Valle, "Advances in femto-nano-optics: ultrafast nonlinearity of metal nanoparticles." Eur. Phys. Jour. B 87 (2014). [2]. F. Hache and D. Ricard and C. Flytzanis and U. Kreibig, "The Optical Kerr Effect in Small Metal Particles and Metal Colloids: The Case of Gold." Appl. Phys. A 47 (1988). [3]. Y. Sivan and S. Rozenberg and A. Halstuch and A.A. Ishaaya, "Nonlinear wave interactions between short pulses of different spatio-temporal extents" Sci. Rep. 6, (2016). [4]. PT Shen and Y. Sivan and CW Lin and HL Lui and CW Chang and SW Chu, "Temperature- and -roughness dependent permittivity of annealed/unannealed gold films." Opt. Express 24 (2016). [5]. Y. Sivan and J. B. Pendry, "Broadband time-reversal of optical pulses using a switchable photonic-crystal mirror." Opt. Express 19 (2011).

High-Speed Holography of the Retina

Michael Atlan

CNRS, France

Retinal blood flow plays a central role in the pathophysiology of many eye diseases like diabetic retinopathy or glaucoma, either through capillary occlusion, global hypoperfusion or altered flow distribution. In most cases, fluorescein angiography is used for the evaluation of the circulation of the retina, which involves the injection of a fluorescent dye into the circulation, and capturing the fluorescent green light emitted by the retina illuminated with blue light. Quantitative monitoring of hemodynamic signals down to capillaries without contrast agent remains a challenging task.

Typical wide-field coherent light imaging approaches of superficial microcirculation are limited in terms of sensitivity, range of assessed flows, spatial and temporal resolution, and lateral field of view. The required specifications for retinal blood flow monitoring techniques include: high temporal resolution to assess flow dynamics and circumvent rapid eye motion issues, high spatial resolution to observe capillaries, high sensitivity in low light to be compliant with the guidelines for exposure of the eye to optical radiation, and the ability to perform quantitative flow measurements. We developed a holographic laser Doppler ophthalmoscope for non-invasive and non-ionizing retinal blood flow imaging with a high throughput camera at extremely low irradiance levels complying with clinical safety limits. In particular, we demonstrated the measurement of blood flow contrasts in the vascular tree surrounding the optic nerve head in the retina of a pigmented rat by recording holographic interferograms at a sampling rate of 39 kHz; tissue exposure was limited to 1.6 mW of continuous wave, near-infrared laser radiation. The three first moments of the envelope of the short-time Fourier transform of the holograms enabled robust, high spatial and temporal resolution mapping of Doppler contrasts arising from arterial and venous blood flow velocities. Observation of pulsatile retinal blood flow contrasts over 400 by 400 pixels with a spatial resolution of 8 microns and a temporal resolution of 6.5 millisecond was achieved.

Session: Electro-Optic Devices - Prof. Dan Marom

Harnessing Photonic Integrated Circuits *

Andrea Melloni

Politecnico di Milano, Italy

The complexity scaling of photonics circuits is raising novel needs related to control. Reconfigurable architectures need fast, accurate and robust procedures for the tuning and stabilization of their working point, counteracting temperature drifts originated by environmental fluctuations and mutual thermal crosstalk from surrounding integrated devices. Possibly, dynamic and adaptive techniques suitable to follow continuously the variations of the communication link and modulation formats would sustain Software Defined Networks with reconfigurable devices. In this contribution, we report on our recent achievements on the automated tuning, control and stabilization of photonics integrated architectures. The proposed control strategy exploits two key concepts, i) transparent integrated detectors to monitor non-invasively the light propagating in the silicon waveguides in key spots of the circuit and ii) use of pilot tones to label the desired channel multiplexed in wavelength, polarization or spatial mode. Pilot tone selective local monitoring enables the recognition of the channel and the partitioning of complex architectures in small photonic cells that can be easily tuned and controlled, with need for neither preliminary circuit calibration nor global optimization algorithms.

Several examples of applications are presented that include the automatic reconfiguration and feedback controlled stabilization of an 8×8 switch fabric based on Mach-Zehnder interferometers (MZIs); the realization of a wavelength locking platform enabling feedback-control of silicon microring resonators for the realization of a 4×10 Gbit/s wavelength-division-multiplexing transmitter; on-chip all-optical reconstruction and unscrambling of mixed spatial modes by using a self-configuring mesh of silicon photonics MZIs. The effectiveness and the robustness of the proposed approach for tuning and stabilization of the presented architectures is demonstrated by showing that no significant performance degradation is observed even under uncooled operation for the silicon chip.

Induced Mode Mixing via Spatial Phase Masks Directly Printed on Fiber Facet

Miri Blau and Dan M. Marom

Applied Physics Department, The Hebrew University, Israel

We introduce a wavelength demultiplexer operating with multimode waveguides of rectangular geometry matching rectangular fibers. This eliminates the spatial-spectral mixing at output waveguide coupling. Performance is stretched between the need to separate wavelengths and modes. We propose a multimode waveguide grating router (WGR) design with rectangular waveguides constrained to be single mode in one direction (width, defined in lithography) and multi-moded in height. This waveguide configuration matches the mode structure of rectangular core fibers, and allows for direct interface to this SDM fiber variant and realization of an SDM demultiplexer. By dispersing the signals in the WGR plane, where the mode structure is single mode, the coupling to the demultiplexed output waveguides is devoid of spatial structure which can lead to ill-shaped passbands and modal crosstalk. However, due to different mode propagation constants within the WGR, modal dependency still arises. We analyze this form of WGR demultiplexer, establish its performance bounds, and suggest realizations to make it feasible as a wavelength demultiplexer. The existence of multiple modes (which should be routed together) leads to mode-dependent-spatialshifts and as an outcome, to a significant reduction in resolution in standard WGR devices. We propose adjusting the FSR to overlap diffraction orders and generate noncontinuous demultiplexing. For example, for a waveguide supporting 3 spatial modes, if we increase the FSR to obtain two overlapping diffraction orders on the output plane, we can couple the light of the spectral channels using both diffraction orders. This way we don't use neighboring spectral channels and eliminate spectral and mode mixing. Our solution, based on noncontinuous demultiplexing, can lead the way to SDM-WDM devices on chip.

OCIS codes: (060.0060) Fiber optics and optical communications; (130.3120) Integrated optics devices; (060.6718) Switching, circuit

Optimized Depth of Field Methodology using Annular Liquid Crystal Spatial Light Modulator assisted by Image Processing

Naama Shukrun¹, Asi Solodar¹, Amir Aizen¹, Isaac August¹, Iftach Klapp², Yitzhak Yitzhaky¹, Ibrahim Abdulhalim¹

1. Department of Electrooptic Engineering and the Ilse Katz Center for Nanoscale Science and Technology, Ben Gurion University, Israel

2. Department of Sensing, Information and Mechanization Engineering, Agricultural Research Organization - the Volcani Center, Israel

Imaging system's quality is defined by several parameters among which the resolution and depth of field are of high importance. The depth of field (DOF) defines an axial range in which an optical imaging system is capable of high lateral resolution. Both sharpness and, large DOF are controlled by the optical imaging system's numerical aperture (NA). Increasing the NA improves the system's resolution, however, at the cost of lowering the DOF. We present an optical-digital tunable extended depth of field (EDOF) methodology which enables DOF extension along with minimal loss of resolution [1-3]. The new suggested methodology [4] extracts regions of interest (ROIs) in an image, selects the sharpest ROIs out of a set of source images (at different phase masks), based on edge statistics (the mean gradient profile width criterion) and forms a fused image which contains the maximal information. Each phase mask, which contains a different degree of DOF extension, is implemented using an annular liquid crystal spatial light modulator (ASLM) that consists of 16 ring electrodes positioned in the pupil plane of an imaging system. Through a calibration procedure conducted for characterizing the phase retardation accumulation versus voltage, the phase profiles were converted enabling different degree of DOF extension into voltage profiles. Two known phase masks were used and a newly derived one from an optimization of the Binary phase mask for maximal DOF extension. Applying those voltage profiles to the ASLM enables tuning the DOF without mechanical adjustments of the optical set up. Experimental results were investigated both qualitatively and quantitatively and the efficiency of our EDOF methodology was demonstrated [4]. In addition, the results are compared with those of some well-known fusion algorithms and proved its supremacy [4].

Keywords: Liquid crystal devices; Extended depth of field; Image fusion; Pupil engineering; Annular phase mask.

References

- I. Klapp, A. Solodar, and I. Abdulhalim, "Tunable extended depth of field using a liquid crystal annular spatial filter," Opt. Lett. 39, 1414-1417 (2014).
- I. Klapp, A. Solodar, and I. Abdulhalim, "Extended depth of field using a liquid crystal annular spatial light modulator," Appl. Opt. 53, 4301-4312 (2014).
- A. Solodar, I. Klapp, and I. Abdulhalim, "Annular liquid crystal spatial light modulator for beam shaping and extended depth of focus," Opt. Commun. 323, 167-173 (2014).
- Naama Shukrun et.al. "Optimized depth of field methodology using annular liquid crystal spatial light modulator assisted by image processing" to be published 2017.

Hybrid Combination of InP and Silicon Nitride based TriPleX™ Waveguides for a Broad Application Range *

Arne Leinse

LioniX International, Netherlands

In Photonic Integrated Circuit (PIC) technology the mature platforms InP, Silicon on Insulator (SOI) and the silicon nitride based TriPleX™ platform offer user access via Multi Project Wafer (MPW) runs. The TriPleX platform is based on Low Pressure Chemical Vapor (LPCVD) deposition of silicon nitride and silicon oxide. This process is extremely suitable for volume production of PICs creating low loss waveguides which are transparent from 405 nm to 2350 nm. The availability of Photonic Design Kits (PDK) in these platforms also allows design in multiple platforms simultaneously creating new functionality for a variety of applications. By combining an active platform like InP and TriPleX for instance tunable lasers can be realized with very narrowband performance. A big challenge in this hybrid combination however is the large difference in optical mode field diameters of the different platforms and the high confinement with small mode field diameters in the high contrast technologies. These small mode profiles require a high alignment accuracy when two waveguides are hybirdly combined. The ability to integrate spot size converters in the nitride layers allows a low loss transition from the outside world/fibers to the high index contrasts of InP and SOI. The mode profile dimensions in the order of 1 μm require an accurate control of the mode profiles and also an alignment accuracy of 100-200 nm is required for low loss chip to chip coupling. In the presentation the basics of the technology and the challenges of the hybrid alignment of InP and TriPleX are shown, where the state of the art measurements on the combination are presented.

Session: IFLA, Optical Fiber Technology - Dr. Ariel Bruner

Keynote Lecture: Realizing a Moore's Law for Fibers

Yoel Fink

Massachusetts Institute of Technology, USA

Since the dawn of civilization, fibers and fabrics have comprised some of our most essential crafts and manufactured products, including clothing, tapestries, blankets, bandages, and shelters. The technological function of these fibers and fabrics has advanced very slowly over thousands of years, especially when compared with other fields such as communications and electronics. Recently, a new family of fibers composed of conductors, semiconductors and insulators has emerged. These fibers can achieve similar basic device attributes as their modern wafer-based electronic and optoelectronic counterparts, yet are fabricated using preform-based fiber-processing methods, yielding kilometers of functional fiber devices. Here we will describe both the integration of a multiplicity of functional components into one fiber, and on the multiple-fiber level, the assembly of large-scale two- and three-dimensional geometric constructs made of many fibers. These emerging fiber technologies formed the basis for Advanced Functional Fabrics of America (AFFOA), a broad new collaboration between industry, academia and government. The goal of AFFOA is to enable the transformation of fiber and fabric materials into highly functional devices and systems that will see, hear, sense and communicate, store and convert energy and change color.

Silica Fibre Fabrication at the Photonics Institute in Nanyang Technological University *

Seongwoo Yoo*, R. Sidharthan, Daryl Ho, Xiaosheng Huang, Nan Xia, Wenliang Qi, David Yue and Swee Chuan Tjin

The Photonics Institute, School of Electrical and Electronic Engineering, Nanyang Technological University, Singapore

This talk will present recent activities on silica fibre fabrication in The Photonics Institute with an emphasis on fabrication and design considerations of high nonlinearity fibres and high power laser fibres. A stretched core fibre is discussed as a bendable large mode area (LMA) fiber design. Detrimental bending effects can be avoided when the fibre is bent in the short axis plane while the mode scalability is achieved by stretching the other axis. Its mode area scalability, bending performance and lab demonstration are presented. Mode instability is also studied in the stretched core design to understand benefits of better heat dissipation anticipated from the stretched core. High GeO₂ fibre offers high nonlinearity and better transmission than a telecomm fibre beyond 2 μm , hence making itself suitable for mid IR supercontinuum generation. We discuss a fabrication route to realise high GeO₂ fiber and supercontinuum demonstration. In addition, a double layer split cladding air core fibre will be discussed as an additional design of anti-resonant waveguides.

Keywords: Fibre lasers, fibre fabrication, fibre devices

Fluoride Glass Fibers for Active Applications *

Robert M. Pafchek and Mohammed Saad

Thorlabs Inc, USA

The first fiber laser was demonstrated in 1964 by Snitzer et al. using a rare-earth doped silicate fiber. Since then fiber lasers have experienced extraordinary development due to the significant advantages they exhibit. Compared to other technologies such as semiconductor, gas and solid state lasers, fiber lasers are compact and have high efficiency, excellent beam quality and display good heat dissipation. They are currently used in many industrial and high tech applications, such as defense and aerospace, medicine, spectroscopy and sensing. High power output fiber lasers have been already demonstrated using silica doped fiber and achieved output power in the kilo watt range. These fiber lasers are already being used in many industrial applications. Intensive investigation of other glass hosts is currently underway to extend the delivery of new wavelengths that build upon the success demonstrated by silica fiber lasers.

Silica and fluoride glasses are both attractive hosts since they combine many of these attributes. However, fluoride glass has a lower phonon energy, and consequently a wider transmission window than silica glass. In addition fluorides have a higher solubility of rare-earth ions. So far, many fiber lasers have been demonstrated using rare earth doped fluoride fiber with emissions extending from the ultra-violet out to 4 microns in the mid-infrared.

The mechanical strength of fluoride fibers has also been dramatically improved allowing the integration of fluoride fiber into optical devices. The ability to obtain high quality cleaves and fusion splice directly to fluoride or silica fibers further enables this integration.

This presentation will focus on the technological developments associated with fluoride fiber fabrication. We will also highlight significant achievements in rare-earth doped fluoride fiber amplifiers and fiber lasers.

Advances in Phosphate Glass Optical Fibers for Lasers and Optical Amplifiers *

Daniel Milanese

Politecnico di Torino - DISAT, Italy

Short-pulse fiber lasers are of great interest for remote sensing and materials processing. The fiber format offers the possibility of increasing efficiency, while reducing thermal stress and providing high beam quality in single-mode regime. The main limit, however, is due to the nonlinear effects that are cause of pulse distortion and reduce the performance of the source: they occur because of the combination of high optical intensity in the single-mode fiber and long fiber amplifier lengths.

Compact optical sources made of a seed laser and a short booster amplifier are a solution to obtain devices free of nonlinear effects. For this type of devices, the inherent properties of silica glass consist in a technological bottleneck. Actually, they can only incorporate a limited concentration of rare earth ions, thus resulting in meters long amplifier sections. Phosphate glasses represent an interesting alternative for the fiber material [1]: thanks to their high rare-earth ions solubility, phosphate glasses have the potential to outperform silica fibers for the development of compact booster fiber amplifiers for short pulse amplification.

We report a series of rare earth doped optical fiber configurations suitable for the fabrication of power amplifiers operating in the near infrared wavelength region. Two cases have been studied, corresponding to the use of Nd³⁺ and Er³⁺ ions, operating at 1 and 1.5 mm respectively. Ongoing activities and recent results will be reported for both applications.

Session: Nano and Quantum Optics - Prof. Jacob Scheuer

The Quantum Knitting Machine: A Deterministic Route for Producing Large Scale Entanglement *

David Gershoni

The Physics Department and the Solid State Institute, Technion, Israel

Photonic cluster states are a resource for quantum computation based solely on single-photon measurements. We use semiconductor quantum dots to deterministically generate long strings of polarization-entangled photons in a cluster state by periodic timed excitation of a precessing matter qubit. In each period, an entangled photon is added to the cluster state formed by the matter qubit and the previously emitted photons. In our prototype device, the qubit is the confined dark exciton, and it produces strings of hundreds of photons in which the entanglement persists over five sequential photons.

The measured process map characterizing the device has a fidelity of 0.81 with that of an ideal device. Further feasible improvements of this device may reduce the resources needed for optical quantum information processing.

*Work done in collaboration with Ido Schwartz, Dan Cogan, Emma Schmidgall, Yaroslav Don, Liron Gantz, and Oded Kenneth [Schwartz et al Science 354, 434, (2016) featured by Briegel H.J, Science 354, 416 (2016)]

Directing Single Photons: A Highly Directional Room-Temperature Single Photon Device

Nitzan Livneh¹, Moshe G. Harats², Hamza Abudayyeh², Boaz Lubotzky², Daniel Istrati², Hagai Eisenberg², and Ronen Rapaport^{1,2}

1. Applied Physics Department, The Hebrew University of Jerusalem, Israel

2. Racah Institute for Physics, The Hebrew University of Jerusalem, Israel

One of the most important challenges in modern quantum optical applications is the demonstration of efficient, scalable, on-chip single photon sources, which can operate at room temperature. In this talk we demonstrate an efficient and scalable room-temperature single-photon source [1] based on a single colloidal nanocrystal quantum dot positioned inside a circular bulls-eye shaped [2] hybrid metal-dielectric nanoantenna [3]. Experimental results show that 20% of the photons are emitted into a very low numerical aperture ($NA < 0.25$), a 20-fold improvement over a free standing quantum dot, and with a probability of more than 70% for a single photon emission. With an $NA = 0.65$ more than 35% of the single photon emission is collected. The single photon purity is limited only by emission from the metal. We show that the design of this device can be further optimized so to reach a collection efficiency of over 70% into an NA of a multi mode fiber without the need of any additional optics, with a very high single photon purity. The concept presented here can be extended to many other types of quantum emitters. Such a device paves a promising route for a high purity, high efficiency, on-chip single photon source operating at room temperature.

References

- [1] Nitzan Livneh, Moshe G. Harats, Daniel Istrati, Hagai Eisenberg, and Ronen Rapaport, A highly directional room temperature single photon device, *Nano Lett.*, 16, 2527 (2016)
- [2] Moshe G. Harats, Nitzan Livneh, Gary Zaiats, Shira Yochelis, Yossi Paltiel, Efrat Lifshitz, and Ronen Rapaport, Full Spectral and Angular Characterization of Highly Directional Emission from Nanocrystal Quantum Dots Positioned on Circular Plasmonic Lenses, *Nano Lett.*, 14, 5766, 2014,
- [3] Nitzan Livneh, Moshe G. Harats, Shira Yochelis, Yossi Paltiel, and Ronen Rapaport, Efficient Collection of Light from Colloidal Quantum Dots with a Hybrid Metal-Dielectric Nanoantenna, *ACS Photonics*, 2, 1669 (2015).

Enhanced Nitrogen-Vacancy Concentration in Diamond through Optimized Electron Irradiation

Demitry Farfurnik^{1,2}, N. Alfasi³, S. Masis³, Y. Kauffmann⁴, E. Farchi⁵, E. Buks³, and N. Bar-Gill^{1,2,5}

1. Racah Institute of Physics, Hebrew University, Israel

2. The Center for Nanoscience and Nanotechnology, Hebrew University, Israel

3. Andrew and Erna Viterbi Department of Electrical Engineering, Technion, Israel

4. Department of Materials Science and Engineering, Technion, Israel

5. Department of Applied Physics, Rachel and Selim School of Engineering, Hebrew University, Israel

The unique optical properties and long room-temperature coherence times of nitrogen-vacancy (NV) centers in diamond position them as leading candidates for ultra-sensitive magnetic sensing and applications in quantum information and computation. A long standing goal in the field is to increase the conversion efficiency from N defects to NV defects, thus increasing the NV concentration without reducing the coherence times. In this work, we use electron irradiation on various types of HPHT and CVD diamond samples, to increase the NV concentration by an order of magnitude up to $\sim 10^{10}$ Nv/cm². We achieve about 5% conversion efficiency from N defects to NV centers in the diamond. Improvement in the fluorescence signal, with no degradation of the coherence properties of the NV spin, paves the way toward improved sensitivity of DC and AC magnetometry, as well as the study of many body physics of NV ensembles.

Plasmonic “Templar Cross” Antennas for Subwavelength Addressing of Spin States in Diamonds

Tzach Jaffe¹, Ofir Sorias¹, Lior Gal¹, Rafi Kalish² and Meir Orenstein¹

1. Department of Electrical Engineering, Technion - Israel Institute of Technology, Israel

2. Solid State Institute and Physics Department, Technion - Israel Institute of Technology, Israel

We propose and experimentally demonstrate a selective and spatially localized method for addressing the nitrogen vacancy (NV) center spin state by a polarized doubly resonant plasmonic antenna tuned to the NV's phonon side band peak transition in red and the narrowband NIR transition.

Key Words: Surface plasmons; Defect-center materials; Plasmonics; Diamonds; Introduction and motivation
he negatively charged NV center in diamond is an important physical system for emergent quantum technologies and sensing at room temperature. The NV center is a localized multi-electron system which allows us to address its spin state with light, providing a control over initialization and readout of its spin state. Different methods for addressing and controlling the spin states of NV centers have been thoroughly investigated in recent years, but currently there is no efficient way to selectively address single NV centers in regular bulk diamonds with high efficiency. This control is essential for realizing a device containing scaled arrays of atom-like systems, which are decoupled from their surrounding area and background noise for sensing and quantum circuitry applications. In order to achieve that, we have to overcome the inherent mismatch between the effective length scale of light (~wavelength) and the dimensions of the NV center, and at the same time to increase its photonic density of states for enhanced light-matter interaction at a specific localized spot. We investigated theoretically and experimentally a specific plasmonic antenna family, denoted here as the “Templar Cross” Antenna (TCA), comprised of two vertical antennas made of gold - each can be tuned to different resonance frequency with a polarization dependency. The gold antennas were deposited on top of a 1b diamond that was implanted with low energy Argon atoms beam in order to promote shallow NV centers formation at the surface vicinity ($\sim 20\text{-}30\text{nm}$ deep) and within the range of a significant overlap with the plasmonic field distribution. This structure is designed to enhance the light-matter interaction of the NV's zero phonon line and phonon sideband transitions at the visible spectrum and the narrowband NIR transition (1042nm). Experimental

results: We investigated the photoluminescence (PL) and lifetime characteristics of this sample and experimentally demonstrated PL enhancement factor of 50 and 20% lifetime reduction due to enhanced light-matter interaction. Moreover, we emphasized the polarized doubly resonance functionality of the structure by using two perpendicular dimers with different dimensions, realizing two perpendicular channels for addressing the NV center ensembles inside the antenna's feed gap.

High Resolution Trapping using Structured Super-Oscillating Light Beams

Brijesh Kumar Singh¹, Harel Nagar², Yael Roichman², and Ady Arie¹

1. School of Electrical Engineering, Fleischman Faculty of Engineering, Tel-Aviv University, Israel

2. Raymond and Beverly Sackler School of Chemistry, Tel-Aviv University, Israel

Introduction and Objectives: It is well known that an optical lens can focus a plane wave to a diffraction limited spot size of $2\pi N$ (where λ is the optical wavelength and N is the lens numerical aperture) also known as Abbe limit. However, if instead the lens is illuminated by a properly modulated light beam, much smaller focal point is obtained, accompanied by additional rings of light. This is a manifestation of a super oscillating function – a band limited function that oscillates locally faster than its higher Fourier component. Here we present a systematic method for structuring the sub-diffraction lobes of super-oscillating (SO) beams. Different functions, such as Hermite-Gauss, Laguerre-Gauss and Airy, were used to structure these lobes. Furthermore, we utilize these structured light beams for high resolution trapping and manipulation of nanometer-sized particles.

Methods: To realize the structured SO beams we used computer generated holograms (CGHs) to modulate the input beam at the pupil plane of the lens. The CGH is an annular phase mask consisting of two regions with opposite phase, displayed onto a spatial light modulator (SLM) and at the focal plane of Fourier transforming lens super-oscillating structured beams are realized. By changing the inner radius of the mask, the focal spot size of the SO beams can be made arbitrarily small in a tractable manner, although the spot intensity is simultaneously reduced.

Results: First, we realized an SO- Gaussian beam in the aforementioned technique, resulting in a reduction of its lobe size by a factor of 2.6 as compare to a normal Gaussian beam. The SO-Gaussian beam's lobe size was 163nm, which is below the diffraction limit of the laser 532nm. Next we showed the ability of this method to generate sub-diffraction “doughnut” shaped SO-vortex beam having a dark core a factor of 1.3 smaller than the achieved core with a regular diffraction limited beam. Similarly, we were able to produce HG10 and Airy based super-oscillating beams with main lobes smaller than the diffraction limit. Further, we showed that these structured beams can trap sub-micrometer sized polystyrene beads with unprecedented localization. The trapping stiffness was 44 times higher than that achieved by diffraction limited Gaussian beam, despite the lower power of the SO beam. The sub-diffraction spots of the structured beams may be applied for STED microscopy and in lithography. Further, this method can be used in other fields, e.g. nonlinear frequency conversion, plasmonics, structuring light pulses in time domain and for time-dependent focusing.

Keywords: Beam shaping, super-oscillating beams, optical vortex, optical tweezers, diffraction limit

Observation of Anderson Localization in Disordered Nanophotonic Structures

Hanan Herzig Sheinfux¹, Yaakov Lumer¹, Guy Ankonina¹, Azriel Genack², Guy Bartal¹, Mordechai Segev¹

1. Technion, Israel Institute of Technology, Israel

2. Physics Department, Queens College and Graduate Center of CUNY, USA

Anderson localization is an interference effect pivotal to the understanding of waves in disordered media. As with all interference effects, localization is expected to diminish and disappear when the features of the disordered structure are much smaller than the wavelength. Here we demonstrate theory and experiment of light being localized by a disorder whose features are deeply subwavelength. We consider multilayer structures where the layer thickness is ~ 15 nm (~ 40), in experiments and up to ~ 1000 in theory (we provide an analytical scaling relation and extensive numerical calculations). But surprisingly, localization does not disappear; rather it remains a dominant effect when waves are incident in the vicinity of a certain critical angle. This localization regime is shown to be physically rich and display unusual properties such as disorder enhanced transmission, and node-less strongly localized modes. To highlight the sensitivity to deep-subwavelength features exhibited in this regime, we experimentally demonstrate that varying the thickness of a single layer by 2 nm changes the reflection appreciably. This sensitivity, almost down to the atomic scale, is unique in any type of photonic structure and holds the promise of extreme subwavelength sensing.

Multitasking Geometric Phase Metasurfaces

Elhanan Maguid¹, Igor Yulevich¹, Dekel Veksler¹, Michael Yannai¹, Vladimir Kleiner¹, Mark L. Brongersma², Erez Hasman¹

1. Micro and Nano optics Laboratory, Faculty of Mechanical Engineering, and Russell Berrie Nanotechnology Institute, Technion - Israel Institute of Technology, Israel

2. Geballe Laboratory for Advanced Materials, Stanford University, USA

Multifunctional planar systems that perform a number of concurrent tasks in a shared-aperture were recently introduced in the field of phased array antennas for radar applications. The shared-aperture phased antenna array is a promising approach for increased functionality in planar photonics. Metasurfaces consist of subwavelength nanoantennas, capable of manipulating light by controlling the local amplitude and phase of an incident electromagnetic wave. Effective control of the electromagnetic response of the metasurface can be acquired by the geometric phase mechanism which enables spin-controlled phase modulation, where the photon's spin is associated with the intrinsic angular momentum of light. We incorporated the shared-aperture phased antenna array concept and the geometric phase mechanism, utilizing the spin-orbit interaction phenomenon, to implement a multifunctional geometric phase metasurface (GPM).

High efficiency multifunctional GPM was realized, wherein the phase and polarization distributions of each wavefront are independently controlled. We adopted a thinning technique within the shared-aperture synthesis and investigated interleaved sparse nanoantenna matrices and spin-enabled asymmetric harmonic response to achieve spin-controlled multiple structured wavefronts such as vortex beams carrying orbital angular momentum.

We used multiplexed geometric phase profiles to simultaneously measure spectrum characteristics and the polarization state of light, enabling integrated on-chip spectropolarimetric analysis. The spectropolarimeter metasurface was utilized to measure the optical rotary dispersion of L-glucose and D-glucose and thus characterize and differentiate between these two enantiomers.

The alliance between the geometric phase and the shared-aperture antenna arrays technology pave the way for spin-enabled multifunctional wavefront shaping using a single broadband nanooptic device.

• E. Maguid, Y. Yulevich, D. Veksler, V. Kleiner, M. Brongersma, and E. Hasman. Science 352, 1202 (2016).

Session: Electro Optics in Industry - Dr. Michael Berger

Futura Advanced Zoom: An Ultrafast Zoom Lens

Thomas Schaeffler

Qioptiq, Germany

Introduction: Qioptiq introduces Futura+ Advanced Zoom Lens which is an ultra fast zoom lens with 12.5:1 zoom ratio.

Background: Throughput in automated inspection and measurement is the key parameter besides resolution. Futura+ is the perfect solution to increase throughput in systems with variable Field-of-view and resolution Objectives: Creating a reliable and fast zoom component to be integrated in a flexible micro-imaging system for automated inspection.

Methods: A linear rail system is combined with precise position measurement and advanced control algorithms to achieve fast and accurate lens positioning. The universal dovetail mount of the Fusion system enables connectivity to a wide range of optical components including motorized focus options, beam splitters and illumination.

Results: Futura+ travels the complete zoom range of 12.5:1 in less than 1 second in the so called fast mode. In the second mode with adjustable speed continuous zoom is supported for applications that require the object to be in focus while zooming, e.g. when an operator is looking on a screen in parallel. The high precision mechanics in Futura+ also results in a service life of more than 1 Mio zoom cycles. This long life time is very important for unattended operation.

Recommendations &/or Conclusions: Futura+ in connection with the Optem Fusion system enables a modular micro-inspection tool with enormous flexibility and high performance. The high zoom speed is mandatory for high performance inspection and measurement machines that must offer short tact times.

Application of Phase Matching Autofocus in Airborne Long-Range Oblique Photography Camera

Vladimir Petrushevsky, Asaf Guberman

Elbit Systems ElectroOptics - ELOP, Israel

The Condor2 long-range oblique photography (LOROP) camera is mounted in an aerodynamically shaped pod carried by a fast jet aircraft. Large aperture, dual-band (EO/MWIR) camera is equipped with TDI focal plane arrays and provides high-resolution imagery of extended areas at long stand-off ranges, at day and night.

Front Ritchey-Chretien optics is made of highly stable materials. However, the camera temperature varies considerably in flight conditions. Moreover, a composite-material structure of the reflective objective undergoes gradual dehumidification in dry nitrogen atmosphere inside the pod, causing some small decrease of the structure length. The temperature and humidity effects change a distance between the mirrors by just a few microns. The distance change is small but nevertheless it alters the camera's infinity focus setpoint significantly, especially in the EO band.

To realize the optics' resolution potential, the optimal focus shall be constantly maintained. In-flight best focus calibration and temperature-based open-loop focus control give mostly satisfactory performance. To get even better focusing precision, a closed-loop phase-matching autofocus method was developed for the camera. The method makes use of an existing beamsharer prism FPA arrangement where aperture partition exists inherently in an area of overlap between the adjacent detectors. The defocus is proportional to an image phase shift in the area of overlap. Low-pass filtering of raw defocus estimate reduces random errors related to variable scene content. Closed-loop control converges robustly to precise focus position. The algorithm uses the temperature- and range-based focus prediction as an initial guess for the closed-loop phase-matching control.

The autofocus algorithm achieves excellent results and works robustly in various conditions of scene illumination and contrast.

Keywords: Autofocus, phase matching, defocus estimation, beamsharer prism, EO, airborne reconnaissance

4 Decades of Space Optics, Optical Design, in Israel

Aharon Nir

Elbit systems, EL-OP, Israel

El-Op has been engaged in the optical design of space remote sensing optics since the mid-1980s. Our portfolio includes wide spectral region systems from the VUV (Vacuum Ultra Violet) spectral band up to the high end of SWIR spectral region (2.5m). The optical designs are for Pan-chromatic, multi-spectral systems and Hyper-spectral systems, using Catoptric, Catadioptric and Dioptric optics configurations. Several systems are in orbit now or have been in orbit and some of them still await launch.

This presentation will describe, in detail, the heritage and experience in space optic design.

Minimization of Light Power Losses in Diffractive Optics and Computer Generated Holograms

Michael A. Golub

Electrical Engineering- Physical Electronics, Tel Aviv University, Israel

Efficient use of incident beam power and minimization of power losses are critical issues in optics and applications. Light power losses may lead to non-tolerable heating and even damage of high power laser optics, costly cooling arrangements and extra-power batteries in mobile devices, insertion loss and reduction of the non-amplified span length in fiber optic communication. Refractive and reflective optics with smooth optical surfaces already have a bunch of proved solutions for high transmission and but are limited in functionality.

Programmable diffractive optics and computer generated holograms bring tailored functionality to shaping of beam intensity and wavefront for head mounted display, augmented and virtual reality, gesture recognition, 3D sensing. However, DOEs show considerable power losses because of multiple diffraction orders, technological limitations on groove density and high sensitivity to fabrication errors.

In this contribution we address a problem of how to achieve almost lossless diffractive optics system with high diffraction efficiency. First problem is that encoding of required complex transmission function into that of phase-only DOE utilizes only part of beam power, while the rest of the power is sent to ghost diffraction orders and serves as a spatially distributed noise. Another basic problem is how to achieve high local diffraction efficiency of phase only DOE. We analyzed and compared several approaches for high efficient phase-only DOE: kinoform, computer generated holograms, nonparaxial microrelief equations, resonance domain DOEs, map transformation pair of DOEs, micro-DOEs in spherical beam. Computer-simulation results will be presented. We also used available experimental data of our research and literature.

We found out that best solution resorts to a pair of spatially separated DOEs, wherein first of them creates required amplitude distribution by map-transformation geometrical optics design, while second corrects the phase. Each DOE should be either multi-level phase-wrapped structure or a spatially variable resonance domain diffraction grating.

Keywords: Diffractive optics, beam shaping, power losses, diffraction efficiency.

InAs/(GaSb,InAsSb) and HgTe/CdTe Superlattices: Detector Materials with Topological Properties

Philip C. Klipstein

Semiconductor Devices, Israel

Type II superlattices (T2SLs) based on alternating layers of InAs and GaSb exhibit rather unique properties, including a zero bandgap at a critical value of the layer thicknesses. In this respect, T2SLs bear a close relationship to the alloy, $Hg_xCd_{1-x}Te$ ("MCT"), where the bandgap vanishes at a critical value of the composition parameter, x . Recently, a 15 pitch T2SL LWIR array detector was demonstrated by SCD, based on a new XBp barrier architecture and a new and robust passivation process. This detector is made entirely from III-V materials but exhibits performance comparable to high quality MCT detectors.

The SCD T2SL XBp detector contains both an InAs/GaSb active layer (AL) and an InAs/AlSb barrier layer. A $k \cdot p$ simulation method is described which can predict both the QE and dark current with reasonable precision, from a basic definition of the superlattice period and the AL stack thickness. Results are compared with other types of superlattice including HgTe/CdTe. The method introduces a number of novel features including the use of an interface matrix, and a way of calculating the Luttinger parameters from standard reference values.

For layer thicknesses greater than the critical values, both InAs/GaSb and HgTe/CdTe superlattices undergo a transition to a topological insulator phase (TI). Some of the properties of the topological phase will be discussed, including a graphene like dispersion at the TI transition and possible advantages of the TI phase for spintronic and THz devices.

Session: Enhanced Optical Sensing Techniques - Dr. Eyal Agassi

Fast Electrically Switchable IR Notch Filter using Liquid Crystal

Karni Wolowelsky², Amir Gil², Moshe Elkabets², and Carmel Rotschild¹

1. Faculty of Mechanical Engineering, Technion - Israel Institute of Technology, Israel

2. CI-Systems LTD, Israel

Current technologies for gas detection use the following methods: (1) single band-pass filter, which dictate a “man in the loop”; (2) bi-channel sensors that need allocation of half of the detecting area for each band; (3) low rate and/or highly expensive multi/hyperspectral sensors. We suggest a low-cost, high dynamic frequency alternating notch-filter, based on liquid crystal in an IR-transparent cell. This may enable dynamic dual band sensing utilizing the entire detector area.

We utilize fundamental properties of the liquid crystal (LC): its molecular absorption bands are overlapping those of hydrocarbon gaseous, and the absorption strength depends on the orientation of the LC molecules relative to the polarization of the incident light (ordinary vs. extraordinary), and thus when voltage is applied on the LC cell, it affects the molecule orientation, and significantly changes the transmittance in the absorption lines. Also, high frequency response of LC may enable detecting dynamic gas plumes.

We proved the fast electrically switchable IR notch filter concept using custom made Polyamide-coated Germanium cells and a commercial LC, E7. The spectral response shows several absorption lines overlapping those of some hydro-carbonates hazardous and greenhouse gaseous that require monitoring. The absorption difference between E7 ordinary (Voltage off) and extraordinary (Voltage on) states allows up to 3 fold modulation (better alignment of the LC may reach 6 fold modulation), within 20 milliseconds.

Currently, we are performing a feasibility study of gas detection using this method, and the results will be presented in this talk.

Keywords: IR Gas-detection, Liquid-Crystal, Germanium-cell

Plasmon-Waveguide Resonances with Enhanced Figure-of-Merit and their Potential for Unisotropic Bio-Sensing in the Near Infrared Region

Said Mahajna, Michal Neumann, Ofer Eyal, and Atef Shalabney

Physics and optical engineering department, Ort Braude College, Israel

Background: A great deal of interest has been recently shown in optical sensors based on surface plasmon resonances (SPRs). These are obtained when surface plasmon waves (SPWs) are resonantly excited on the interface between thin films, made of noble metals and a dielectric medium. The SPR modes are highly sensitive to the optical properties of the adjacent dielectric medium, making them a powerful tool for bio sensing and molecular detection [1,2].

Objective: The main objective of this work is to modify the conventional SPR configuration to be used for sensing and molecular spectroscopy in the near infrared region (NIR) region. We explore the combination of SPWs with photonic guided modes to achieve large figure of merit (FOM) and enhanced sensitivity that are essential for large biological species detection.

Methods: In the present study, we theoretically investigate the addition of a thick SiO₂ layer on top of the metallic film in the conventional Kretschmann-Raether (KR) configuration to excite both transverse electric (TE) and transverse magnetic (TM) guided modes [3]. These hybrid resonances are probed in the spectral interrogation method and their capability for sensing is extensively examined. Results and conclusions We show that the guided modes have extremely narrow bandwidths, enhanced sensitivity and large FOM with respect to the conventional SPR sensors in the NIR. The extremely high FOM originates from the fact that the guide modes are experience low dissipation as they exist in the SiO₂ core. In addition, the extended tail inside the analyte region makes these resonances very sensitive to tiny variations in the medium to be sensed. The possibility of exciting both TE and TM modes enables anisotropic bio sensing, which makes our structure potential for cell and proteins studies. To conclude, we have shown that coupled waveguide-SPR configurations offer new possibilities for sensing and biodetection in the NIR region, that is inherently limited in standard SPR-based configurations [4].

Keywords: surface plasmon resonance, optical bio sensors, sensitivity.

References

- 1. J. Homola, et al, Sensors and Actuators B: Chemical, 54, 1-2, 3-15, 1999.
- 2. A. Shalabney, et al, Laser & Photonics Rev. 5, 571- 606 (2011).
- 3. Z. Salamon et al, Biophysical Journal, 73, 2791-2797 (1997).
- 4. A. Shalabney et al, Annalen der physik, 524, 11, 680-686, 2012.

Radiometric Imaging by Double Exposure of Blurred and Sharp Thermal Images

Iftach Klapp¹, Shahar Papini^{1,2} and Nir Sochen²

¹. Department of Sensing, Information and Mechanization Engineering, Institute of Agricultural Engineering, Agricultural Research Organization, Volcani Center, Israel

². Department of Mathematics, Tel Aviv University, Israel

Due to their low cost and small size, the un-cooled micro-bolometer based thermal focal plane array are very attractive for radiometry [1].

However being uncooled this systems suffers from temporally and spatially changes in their calibration, thus requires constant calibration. In previous works authors suggest solving this problem by preforming tedious calibration of the camera for different temperatures combinations using black body and environmental chamber [2-3]. In field it was suggested to use the optical shutter with a known temperature as reference object [4-5]. However lab calibration does not compensate for all environmental influence on camera, such as wind load and sun radiation [6]. Flipping semi-transparent shutter may provide multiply information on the object which can save the need in offset calibration. In the suggested approach it was assumed that the gain is calibrated and space invariant [7]. However low cost cameras does not contains shutter and their gain response is typically space variant (SV). In this paper we present a new computational optics approach [8-9] which simplifies the essential calibration of the (SV) gain and offset. First we show that if gain is calibrated, by using two successive images of the object taken with different known blur levels, one can eliminate the object term coming from the image formation equation, resulting with equation for the unknown sensor offset and object radiation also for (SV) gain. Following that the model was extended to an iterative joint estimation of N different objects, The extended model, allows restoring radiometric value of the N objects while both gain and offset are unknown .Simulations of 256X256 images in different kinds of restoration conditions, and Signal to Noise ratio, shows that in the range of 30db and 35db the standard deviation of the restoration error can be as small as 0.2% and 0.1% respectively.

Keywords: Radiometry; Computational imaging; Remote sensing and sensors.

References

1. R.K. Bhan, R.S. Saxena, C.R. Jalwania, and S.K. Lomash , " Uncooled Infrared Microbolometer Arrays and their Characterisation Techniques , " Defence Science Journal, 59, 6, 580-589, (2009).
2. Tempelhahn, H. Budzier, V. Krause, and G. Gerlach," Shutter-less calibration of uncooled infrared cameras," J. Sens. Sens. Syst., 5, 916, (2016).
3. P. W. Nugent, J. A. Shaw , "Calibration of uncooled LWIR microbolometer imagers to enable long-term field deployment," Proc. of SPIE Vol. 9071 90710V,1-10 (2014).
4. P. W. Nugent, J. A. Shaw, N. J. Pust, "Radiometric calibration of infrared imagers using an internal shutter as an equivalent external blackbody," Opt. Eng. 53,12, 123106 (2014).
5. P.W. Nugent, J. A. Shaw, N. J. Pust, Correcting for focal-plane-array temperature dependence in microbolometer infrared cameras lacking thermal stabilization, Opt. Eng. 52, 6, 061304 (2013).
6. K.Kusnerek, A. Korsaeth," Challenges in using an analog uncooled microbolometer thermal camera to measure crop temperature," Int J Agric & Biol Eng. 7,4 60-74 (2014).
7. R. Olbricht, B. Wiecek and G. De Mey, "Thermal drift compensation method for microbolometer thermal Cameras," App. Opt., 51,1788-1794 (2012).
8. I.Klapp." Radiometric imaging by double exposure and gain calibration" in Computational Optical Sensing and Imaging, OSA (2016), paper JT3A.51.
9. S. Papini, I. Klapp and N. Sochen, "Calibrating Uncooled Microbolometer FPA By lenses," in Light, Energy and the Environment, OSA, (2016), paper EW3A.6.

Practical Considerations in MTF Measurement of a Digital Head-Up Display System

Yuval Erez

Elbit Systems ISTAR, Israel

The modulation transfer function (MTF) is a fundamental characteristic of an optical system's design and a main feature in the evaluation of its performance. From a practical engineering point of view it is a very useful measure as not only is it well defined, but there are also several well established methods for its measurement. Furthermore, the MTF of a system is the product of the MTF of its components, and is hence commutative in nature. Owing to the abovementioned qualities, the analysis of a system's MTF might be assumed to be rather straightforward. However, as is often the case in real-life industrial applications, several complications assure that this not always true. In electro-optical products, the optics is most commonly coupled to either a sensor or a display. While this coupling is nontrivial, assessing the performance of an assembled system may be more valuable than rating the optics stand-alone. Here the particular case of a liquid crystal micro-display based Head-Up Display avionic system is discussed, accounting for the many pitfalls along the way of its MTF measurement, potentially drawing the measured numbers apart from the real values if not carefully addressed. In order for these obstacles to be overcome, special attention needs to be given to the parameters of the LCD, the camera and the system setup. These parameters include the LCD and camera sensor Gamma and gain functions, the LCD fill factor, and stray light in the system.

Chromatic Confocal Sensors

Matthieu Desjacques

STIL SA, France

Confocal systems are practically "blind" for all space except for the sharply focused point S'. Light emitted by points located beside, below or above S' cannot reach the detector located behind the filtering pinhole at S''. This property is true both for scattering samples and for specular (polished) samples. When scanned in X,Y directions, the confocal system generates a sharply focused observation plane. This property is called "Optical Sectioning". Points located above or below the sectioning plane are completely out of focus. As a result, image contrast is excellent. Chromatic confocal imaging consists in introducing an optical element with axial chromatism in the setup of a confocal imaging system. For each wavelength the system behaves as a classical confocal system, but the position of the sharply focused point S' depends on the wavelength. When the point source S is polychromatic, the system generates a continuum of sharply focused monochromatic images S(λ_i) corresponding to the spectral content of the point source. The chromatic confocal imaging system is "blind" for all space except for the color-coded segment generated by axial chromatism. We call it the "single line" viewing system.

Improving the Sensitivity of Fluorescence-based Immunoassays by Reducing the Auto-Fluorescence of Magnetic Beads**Amos Danielli**

Bar-Ilan University, Israel

Session: Electro-Optic Devices - Prof. Dan Marom**Integrated Nanophononic Circuits: Harnessing On-Chip Photon-Phonon Interactions**

*

Benjamin J. EggletonCentre for Ultrahigh bandwidth Devices for Optical Systems (CUDOS),
School of Physics, University of Sydney, Australia

On-chip Stimulated Brillouin scattering (SBS) is the focus of current research because of its potential for integration of a variety of important photonic functionalities. Here, we demonstrate record high chip-based SBS of over 50dB net-gain which allows for advanced microwave photonic signal processing applications.

Compared to the almost magical impact of lasers and photonics on our lives, from the Internet to supermarket checkouts, mechanical systems can seem almost quaint. Yet one of the surprises of nonlinear optics – the field of optics with high intensity lasers – is that light may interact strongly with sound, the most mundane of mechanical vibrations. Intense laser light literally “shakes” the glass in optical fibres, exciting acoustic waves (sound) in the fibre. Under the right conditions, it leads to a positive feedback loop between light and sound termed “Stimulated Brillouin Scattering,” or simply SBS. This nonlinear interaction can amplify or filter light waves with extreme precision in frequency (colour) which makes it uniquely suited to solve key problems in the fields of defence, biomedicine and wireless communications amongst others. SBS has been studied in optical fibres for decades; it is usually regarded as a nuisance for telecommunication and laser applications but it can also be harnessed for important applications. We achieved the first demonstration of SBS in compact chip-scale structures, carefully designed so that the optical fields and the acoustic fields are simultaneously confined and guided. This new platform has opened a range of new functionalities that are being applied in communications and defence with superior performance and compactness. This new optical-phononic chip reveals new regimes of light sound interactions at the nanoscale, which has required new theoretical developments. My talk will introduce this new field, review our progress and achievements and some of our recent highlights that point towards a new class of entirely silicon based optical phononic processor that can be manufactured in semiconductor CMOS foundries.

References

- [1] B. J. Eggleton, C. G. Poulton, and R. Pant, “Inducing and harnessing stimulated Brillouin scattering in photonic integrated circuits,” *Adv. Opt. Photonics*, vol. 5, pp. 536–587, 2013.
- [2] R. Pant, C. G. Poulton, D.-Y. Choi, H. Mcfarlane, S. Hile, E. Li, L. Thevenaz, B. Luther-Davies, S. J. Madden, and B. J. Eggleton, “On-chip stimulated Brillouin scattering,” *Opt. Express*, vol. 19, no. 9, pp. 8285–8290, Apr. 2011.
- [3] B. J. Eggleton, B. Luther-Davies, and K. Richardson, “Chalcogenide photonics,” *Nat. Photonics*, vol. 5, no. 12, pp. 141–148, Dec. 2011.

Light-Enhancing Plasmonic-Nanopore Biosensor for Superior Single-Molecule Detection

Ossama N. Assad¹, Tal Gilboa², Joshua Spitzberg² and Amit Meller¹

1. Department of Biomedical Engineering, The Technion - Israel Institute of Technology, Israel and
Department of Biomedical Engineering, Boston University, USA
2. Department of Biomedical Engineering, The Technion - Israel Institute of Technology, Israel

Solid-state nanopores are single-molecule biosensors capable of concentrating and sensing a wide spectrum of charged biomolecules, including nucleic acids and proteins, and are broadly developed for ultra-fast DNA sequencing applications. Here, we combine the molecular focusing feature of a solid-state nanopore with a plasmonic nanowell structure to achieve localized fluorescence enhancement of labeled DNA molecules as they translocate through a sub-5 nm pore. The stacked plasmonic nanowell-nanopore (PNW-NP) biosensor almost entirely suppresses the background fluorescence from bulk and yield net >10 fold enhancement of the fluorescence intensity, offering extremely high S/B ratio for single-molecule detection at extremely low excitation laser intensities while maintaining sub ms resolution detection bandwidth. Finite-difference time-domain (FDTD) simulations of our device agree with the measured enhancement pointing to both local field amplification and increased fluorescence brightness. Additionally, the stacking of the plasmonic nanowell on top of the nanopore induces temporal synchronization between the electrical resistive pulse and the optical emission, highly facilitating the data analysis and nearly eliminating spurious optical spikes from unsuccessful DNA translocations through the pore. These three main features of the PNW-NP sensor make it ideally suited for improved sensing and future nanopore applications including genotyping and DNA sequencing.

Feasibility of using Nano-Columnar PbSe Thin Films Grown by CBD as a SWIR Photodetector

Hadar Manis Levy, Tzvi Templeman¹, Nitzan Maman², Iris Visoly-Fisher², Yuval Golan¹ and Gabby Sarusi

1. Electrooptics Engineering Department, Materials Engineering Department
2. Solar Energy and Environmental Physics Department and Ilse Katz Institute for Nano-Scale Science and Technology, Ben Gurion University of the Negev, Israel

We demonstrate PbSe nano-columnar thin films (~200 nm) grown perpendicular to (100) oriented n-doped (1017–1018 cm⁻³) GaAs substrate by Chemical Bath Deposition (CBD) technique. The advantage of using vertically grown nano-columns is that their spectral response can be tuned based on their diameters where quantum confinement increases oscillator strength and thus the overall absorption, unlike the case of nano-colloid based layers, since high vertical mobility is maintained due to the bulk characteristics of the nano-columns in this direction. Nano-column diameters were around 10–15 nm, well below the Bohr radius of PbSe, thus affected by quantum confinement. PL measurements showed blue shifts of the PL spectra and photo response to the SWIR region (1.3–2.6 μm) was obtained. Analysis of current voltage (I-V) curves carried out in vertical geometry on different mesa sizes (250–2000 μm in diameter) revealed a densely packed film of nano-columns with no apparent pinholes or shunts, confirming the high quality of the deposition. Consequently, this result rules out the concern of possible shunts resulting from thicker nanocolumns that might be present in the thin film. Nanoscale current measurements carried out on the top surface of the nano-columns clearly showed that the current is channeled through the nano-columns that are isolated from one another by grain boundaries. The I-V measurements revealed rectifying curve characteristics that may be caused by the heterojunction between the n-type GaAs substrate and the intrinsic PbSe layer. We show that the relatively high dark current can be attributed to defect states in the nano-column grain boundaries which can be reduced by thermal treatment in an inert atmosphere. Temperature dependence of the vertical I-V measurements taken between 11–300°K showed a decrease in photo-response as a function of temperature apart from the 11–100°K region where tunneling takes place.

High-Speed InAs/InP Quantum Dot Laser with Low Sensitivity to Temperature Change

Ori Eyal^{1,2}, G. Eisenstein^{1,2}, and J. P. Reithmaier³

1. Technion - Isreal Institute of Technology, Electrical Engineering Dept., Israel
2. Technion - Isreal Institute of Technology, Russel Berrie Nanotechnology Institute, Israel
3. University of Kassel, Institute of Nanostructure Technologies and Analytics, Technische Physik, CINSaT, Germany

We report temperature insensitive high speed InAs/InP quantum dot lasers. At 140C–800C, the small-signal bandwidth is respectively 16–13GHz. 25 Gbit/s under constant drive parameters at 14–600C and 35 Gbit/s at 140C were demonstrated. Quantum dot (QD) lasers have several unique properties the most important of which are temperature insensitivity and the potential for high speed modulation capabilities stemming from the delta like density of state function. Many reported QD lasers have previously shown only moderate bandwidths owing to a reduced differential gain which was hampered by the state filling effect. This has changed significantly with recent developments in InAs/InP QD lasers which exhibit a reduced gain inhomogeneity and an extremely high modal gain. The large modal, and differential gain enable record modulation capabilities provided that the epitaxial layer structure is properly designed using a comprehensive spatially resolved model. In this paper we report record modulation capabilities and since these lasers are very insensitive to temperature, they exhibit high speed operation over a wide temperature range. The small signal bandwidth varies from 16 GHz to 8 GHz as the temperature changes from 140C to 800C. Digital modulation at 25 Gbit/s under constant drive conditions is obtainable in the temperature range of 140C to 600C; at temperatures above 600C, modulation requires changes in the bias and digital drive level. The maximum digital modulation at 140C was 34.4 Gbit/s which is a record result for any QD laser. To conclude, we have demonstrated record dynamical properties in InAs/InP QD lasers. The lasers exhibit a high degree of temperature insensitivity of the small signal modulation response and of digital modulation. The results testify to the immense potential of these 1550 nm QD lasers in advanced telecom and data com applications.

Optoelectronic Adventure in 2D Land *

Ilya Goykhman

Cambridge Graphene Centre, Department of Engineering, University of Cambridge, UK

The emerging two-dimensional (2D) materials provides an exciting opportunity to explore new paradigms in photonics and optoelectronics. 2D crystals have rich portfolio of electronic and optical properties, and exceptional capabilities of forming complex functionalities by stacking in van der Waals heterostructures. This can lead to development of novel devices, architectures and systems with capabilities to significantly improve and even outperform current technologies. Despite being atomically thin, 2D materials strongly interact with light, which allow new approaches and designs of advanced optoelectronic functionalities across wide range of electromagnetic spectrum. These include energy efficient optical modulators, broadband photodetectors, light emitters, single photon sources, saturable absorbers, ultrafast lasers and more. In this talk, I will discuss 2D optoelectronic devices and hybrid systems, addressing graphene integration with silicon photonics and exploring van der Waals heterostructures for flexible photodetection and light emission applications. Key aspects related to device physics, material properties, fabrication processes and system performances will be discussed.

Session: IFLA, Fiber Components - Eyal Shekel

Concepts for High Brightness Fiber Coupled Diode Laser Modules for Fiber Laser Pumping and Direct Diode Cutting Applications *

Jörg Neukum

Coherent | DILAS, Germany

It is described how a tailored approach will lead to optimized high brightness fiber coupled pump modules for kW class fiber lasers.

The concept starts with tailored laser diode bars, which take advantage of front facet passivation techniques to enhance output power per emitter width, combined with optimization in the structural chip design to reduce divergence. Such tailored bars, are mounted in an automated process onto a CTE matched sub-mount, and afterwards the bars-on-sub-mount are aligned side by side and are simultaneously mounted on a common cooling platform. Automated alignment of simple micro-optics (FAC / SAC) and other micro-optical parts, leads to very consistent optical beam shaping, reducing fiber coupling losses and keeping consistency of the final modules high.

The beam shaping allows fiber coupling into 100 μ m / NA0.22 fibers for a single cooling platform, but also allows the scalability of power at 976nm up to 2kW-Modules in 400 μ m / NA0.22, by spatial and polarization multiplexing of several cooling platforms into a single module. In all of these power levels the usage of virtual-Bragg-gratings (VBG) allows the spectral stabilization, as well as the spectra narrowing of the emission down to <1nm spectral width, costing only a small amount of absorption losses by the VBGs.

Solutions dedicated to particular application, such as light-weight modules for airborne fiber laser applications have been realized, as well as applications dedicated to display & projection, using 640nm.

The technology can also be adapted to build high brightness direct diode lasers, based on further optimized tailored bars, combined with dense and coarse wavelength multiplexing, resulting in more than 800W out of 100 μ m / NA0.17, allowing thin sheet metal cutting.

The work described in the presentation has been accomplished by various groups at Coherent-DILAS, as well as together with external partners.

Femtosecond Inscription of Bragg Gratings in Various Fibers and Planar Transparent Materials using a Phase Mask *

Avishay Shamir, Zev Montz, Aviran Halstuch, and Amiel A Ishaaya

Department of Electrical and Computer Engineering, Ben-Gurion University of the Negev, Israel

Introduction: Femtosecond lasers have become important tools for processing a variety of materials. The main advantage of using a femtosecond laser source is that its high peak power pulses can deliver energy into materials before thermal diffusion occurs, resulting in high precision and minimal collateral damage.

Background: In the last decade the technique of BG inscription in optical fibers and waveguides with ultrafast lasers and a phase mask has proven to be far more versatile than the standard ns UV-laser grating writing techniques. This led to inscription of BG in various non sensitized transparent materials (fibers and waveguides).

Objectives: The objective of this work is to inscribe BG with fs pulses in various fibers and planar substrate materials. This includes inscription of BG in “new materials” and with “new techniques”.

Methods: Different BGs were inscribed in various materials using an 800 nm Ti:Sapphire femtosecond laser with a 35 fs pulse duration and 1 KHz repetition rate. In addition, we tripled the 800 nm laser and inscribed BGs with 266 nm fs pulses. For both cases we used a phase mask to inscribe BGs of a few mm in length in the fiber core or on the planar surface.

Results: High quality BGs were created in various fibers. We demonstrate how to erase different sections of the BG similar to the annealing process and we show how to “immune” the fiber against fs inscription. We show how to create phase shifted gratings by inscribing 2 “different” BGs on the same section of the fiber. In addition, we manage to inscribe BGs without removing the fiber coating with 2 different approaches. Other results include inscription of BGs on different planar substrates such as sapphire and GaN. Finally, we show transient BG and transient effects (switching) in optical fibers.

Conclusions: High quality BGs were inscribed in different optical fibers and planar materials with NIR and UV fs pulses and a phase mask. In addition, we inscribed BGs through the fiber coating and demonstrated some transient switching effects in optical fibers. These results are an additional step in precision fs processing of fibers and waveguides and towards establishing an ultrafast optical switch in fibers.

Keywords: Femtosecond laser, Bragg gratings (BG), Ultrafast Optics, Fibers, Light Matter Interaction

Fs Lasers for Complex Gratings Integrated Circuits and Beam Shaping with Novel Optical Fibres *

Kyriacos Kalli

Nanophotonics Research Laboratory, Cyprus University of Technology, Cyprus

Summary Femtosecond (fs) lasers are well suited for high-resolution inscription and micromachining in transparent materials of all types. Silica and low loss polymer optical fibres can be readily modified using fs-laser, direct-write methods that offer great flexibility and are often simple and single-step processes. The short temporal duration of fs-laser pulses lead to intensity-dependent, non-linear absorption processes for moderate average laser powers. Multi-photon absorption and avalanche ionization can occur in the focal volume, leading to refractive index changes and/or micro voids; this selective material modification allows for the flexible patterning and prototyping of micro- and nanostructures. We present new opportunities in fibre device design using fs lasers, by inscribing fibre Bragg grating (FBG) structures in optical fibre cores, integrated circuits in the fibre cladding, and Fourier optic and non-diffracting beam devices on the end face of optical fibres. FBGs in multi-core and polymer optical fibres have many applications related to high strain recovery and shape sensing, whereas taking advantage of the fibre cladding allows for new, self-contained optical fibre devices, and finally one may realise 1-D and 2-D grating structures written across the fibre end face, along with Bessel, Airy and vortex beam generators, all using single mode fibres. Moreover, we present gratings in semiconductor-core glass fibres that have emerged recently as an interesting alternative to planar silicon for a variety of optoelectronic applications; this as an important step towards in-fibre photonics. Finally, we demonstrate a method to extend the versatility of existing optical fibre sensors, and focus on the modification of an encapsulated, extrinsic Fabry-Perot interferometer pressure sensor that requires temperature compensation in the measurement process. Applications as diverse as temperature compensated pressure measurements in the organs of the human body, particularly in volume restricted areas (such as the brain or blood vessels), to remote, automated underwater vehicles are discussed.

Very High Power Fiber-to-Fiber Coupled Devices

Zachary S. Sacks

Elbit Systems Elop, Israel

Introduction: Robust high power components for fiber lasers are required in order to enable further penetration to applications. Components should be fiber based or fiber coupled to allow direct integration into the fiber laser monolithic platform. For example fiber coupled optical isolators are required in many fiber laser applications in order to protect the laser from selfdestruction due to light traveling backwards within the fibers, e.g., from backreflections or as isolation between fiber amplifiers. Background: Fiber coupled bulk components, such as isolators and acousto-optic modulators, are essentially bulk components coupled between two fiber collimators. The power is generally lost on coupling of light back into a fiber. This power can lead to loss of isolation and loss of optical power transmission. Typical fiber coupled components are limited to 20W of input power. Objectives: The purpose of this work was to show the proof of principle to make a high power fiber coupled device using existing mechanical and optical platforms. Methods: By changing the fibers to a double clad glass fiber, all light that typical does not make it into the core of the fiber is transmitted down the fiber and removed controllably using a cladding light stripper. This idea was tested by replacing the fibers on an existing isolator platform. Results: More than 70W (source limited) of light was launched into the isolator. More than 50W was transmitted in the core with an additional ~16W in the clad, which was safely stripped. Insertion loss gradually increased but always remained lower than 1.5dB. Recommendations and Conclusions: A straightforward method was shown to make a high power fiber coupled components using the existing lower power platform. Future work will be on improving performance and demonstrating higher power.

Keywords: fiber lasers, fiber components, isolators

Poster Presentations

Monday, 27 February, 2017



Topic: IFLA - Fiber Lasers and Applications - Dr. Yoav Sintov

Affordable Dispersion and Diffraction Compensation using Simple Post-detection Filters

Shalom Bloch, Shmuel Sternclar, Daniel Gotliv and Er'el Granot

Department of Electrical and Electronic Engineering, Ariel University, Israel

Introduction: Optical dispersion and diffraction are major sources of distortion in optical communications and optical imaging respectively. Since these mechanisms act as linear operations on the optical field, they can be mitigated by using optical devices but, in low-cost fiber-optic networks, these solutions are too costly and in x-ray imaging, linear compensating devices, e.g., lenses, don't exist.

Objective and Method: Dispersion and diffraction are related since they are both governed by the Schrödinger equation. Therefore, there is a need for a generic low-cost solution to compensate Schrödinger dynamic distortions. In this work such a solution is presented. The compensation process takes place after the detection took place. Therefore, the compensation occurs in the electrical domain, and can be suitable as a low-cost solution.

The method is based on the fact that when a weakly modulated signal experiences Schrödinger distortion, the distortion effects can be reduced with a proper filter, which operates on the detected electrical signal.

Results: We demonstrate this new method for both dispersion and diffraction mitigation. For the dispersion problem we show that by adding an electronic filter to a low-noise OOK system it is possible to transmit data at bit rates of 50Gb/s to distances at least six-fold larger than its OOK dispersion limit (6km for smf28), i.e., 40km and beyond. For the diffraction problem we demonstrate reconstruction of highly distorted x-ray images.

Conclusion: It is feasible to reconstruct distorted signals and images, which experienced Schrödinger distortion (either dispersion or diffraction) even after ordinary power detection. That is, despite the fact that the distortion took place in the field domain, it is possible to reconstruct the signal by a simple low-cost electronic filter at the power. Since this is a low-cost solution it can be incorporated in either low cost digital/analog networks or low cost imaging systems.

Keywords: Dispersion compensation, Fiber optics communications, diffraction, X-ray imaging, Phase retrieval.

High efficiency, 154 W CW, diode-pumped Raman fiber laser with brightness enhancement

Yaakov Glick^{1,2}, Viktor Fromzel¹, Jun Zhang¹, Nikolay Ter-Gabrielyan¹, and Mark Dubinskii¹

1. U.S. Army Research Lab, USA

2. Soreq Nuclear Research Center, Israel

Fiber lasers based on Raman conversion are a useful scheme for laser power generation at a variety of wavelengths. Besides the conversion to a new wavelength, Stimulated Raman scattering (SRS) in fibers is also known to simultaneously enhance the brightness of the pump source. Raman lasers designed to demonstrate brightness enhancement are often pumped with a laser source of mediocre beam quality which produces a higher beam quality Raman beam. The highest power reported to date in this manner is in ref. [1], where 100 W at 1120 nm was obtained with an efficiency of 63% when a Raman fiber laser was cladding pumped by an Yb. fiber laser. With the maturation of high power, high brightness, laser diodes and laser diode modules, the pumping of Raman fiber lasers with diodes is becoming more attractive and realistic. The ability to improve the laser diode pump's brightness by pumping the Raman fiber laser directly is especially appealing, since this eliminates an additional stage of power conversion and thus loss of efficiency. GRIN fibers have also been pumped with diode pumps, and in ref. [2] an output Raman power of ~4 W at below 1 mm was obtained, while in ref. [3] 20 W of power were reported at 1020 nm. The highest power reported so far from a diode pumped Raman laser is 80 W [4], using a GRIN fiber.

We demonstrate [5] a high power high efficiency Raman fiber laser pumped directly by laser diode modules at 978 nm. 154 Watts of CW power were obtained at a wavelength of 1023 nm with an optical to optical efficiency of 65%. A commercial graded-index (GRIN) core fiber acts as the Raman fiber in a power oscillator configuration which includes spectral selection to prevent generation of the 2nd Stokes. In addition, brightness enhancement of the pump beam by a factor of 8.4 is attained due to the Raman gain distribution profile in the GRIN fiber. To the best of our knowledge this is the highest power and highest efficiency Raman fiber laser demonstrated in any configuration allowing brightness enhancement (i.e., in either cladding pumped configuration or with GRIN fibers, excluding step index core pumped), regardless of pumping scheme (i.e., either diode pumped or fiber laser pumped).

References

1. J. Ji, C. A. Codemard, J. K. Sahu, J. Nilsson, "Design, performance, and limitations of fibers for cladding-pumped Raman lasers", *Optical Fiber Technology* 16, 428–41 (2010).
2. E. A. Zlobina and S. I. Kablukov and M. I. Skvortsov, I. N. Nemov and S. A. Babin, "954 nm Raman fiber laser with multimode laser diode pumping" *Laser Phys. Lett.* 13, 035102 (2016).
3. T. Yao, A. Harish, J. K. Sahu, J. Nilsson, High-Power Continuous-Wave Directly-Diode-Pumped Fiber Raman Lasers, *Appl. Sci.*, 5, 1323–36 (2015).
4. Y. Glick, V. Fromzel, J. Zhang, A. Dahan, N. Ter-Gabrielyan, R. K. Pattnaik and M. Dubinskii, "High power, high efficiency diode pumped Raman fiber laser", HYPERLINK "<http://iopscience.iop.org/journal/1612-202X>" *Laser Phys. Lett.* HYPERLINK "<http://iopscience.iop.org/1612-202X/13>" 13, 065101 (2016).
5. Y. Glick, V. Fromzel, J. Zhang, N. Ter-Gabrielyan, and M. Dubinskii, "High-efficiency, 154 W CW, diode-pumped Raman fiber laser with brightness enhancement," *Appl. Opt.* 56, B97-B102 (2017).

Comparison of LBO Crystals: Measurements and Ramifications

Steven Jackel, Leonid Pascar, Assaf Halevy, Yaniv Vidne, Chanan Rosin, and Eyal Shekel

Civan Advanced Technologies, Israel

Frequency doubling modules are being developed for Civan's family of high-power, single-mode CW lasers. In order to achieve a first phase goal of 50W green @ >30% doubling efficiency, we purchased LBO crystals from several manufacturers and tested them at high power. A multiple-crystal, achromatic relay-imaged doubling system, with inter-crystal phase mismatch correction facilitated measurements as pump and doubled powers increased. Parameters measured were oven temperatures for optimum doubling and normalized doubling efficiencies (P_{2w}/P_{w 2}). For zero absorption, oven temperature should remain constant and P_{2w}/P_{w 2} should drop only due to pump depletion. In the presence of absorption (either wavelength), crystal temperatures will increase. Oven temperature would then have to be reduced. Absorption induced temperature gradients parallel and perpendicular to the optical axis might result in intracrystal phase mismatch and smaller than expected P_{2w}/P_{w 2}. Based on oven temperature measurements, it was found that infrared absorption differed by >20x between the different manufacturers. This did not, however, result in a change in single crystal doubling efficiency (in the absence of substantial green) for input powers up to 140W. Green absorption was higher. The green / IR absorption ratio was 10x and 2.3x in the lowest and highest absorption crystals respectively. We used SNLO simulations to isolate out pump-depletion effects. P_{2w}/P_{w 2} decreased faster than expected in the presence of substantial green power for all crystals. The parameter of importance in comparing crystals is the absorption at the wavelength that produces the most heat. In our case this is in the green not manufacturer measured IR absorption. Further progress should concentrate on reducing this parameter. We note that for a given level of absorption, the system can be designed for shorter crystals and tighter foci to eliminate back-conversion. This will require higher damage threshold AR coatings.

Structural Numerical Simulations of Fused Fiber Components

Avihai Spizzichino^{1,2}, Yuri Feldman², Sharone Goldring¹ and Naama Gloor¹

1. Nuclear Research Center - Soreq, Israel

2. Department of Mechanical Engineering, Ben-Gurion University of the Negev, Israel

Introduction: A variety of optical components are fabricated by thermally fusing optical fibers. A numerical model to simulate the spatial distribution of materials in such components is presented.

Background: Over the years, numerous models were developed to simulate the optical behavior of fused fiber-optic components. These models are inherently dependent upon the accurate information regarding the physical structure of the component that is not always available. A common feature of these components is the fabrication process which includes thermal fusion and tapering. Unfortunately, generic simulation tools predicting the spatial structure of fiber-optic components are not readily available.

The need of a robust structural simulation tool for such components is further emphasized in complex systems which are difficult to fabricate and are optically sensitive to small structural variations.

Objective: The objective is to develop a robust numerical simulation to predict the structure of fiber optic component fabricated by heating and pulling. The output of such a simulation should contain all the required parameters to facilitate accurate optical simulations.

Methods: We developed a novel code based on Immersed Boundary Method specifically designed to simulate flows in the presence of complex geometries and moving boundaries. It solves continuity and Navier Stokes equations implicitly, by using pressure and interface curvature as distributed Lagrange multipliers. At this point it can be used to simulate two phase flows in 2D. For validation, the simulation output is compared to cross-sectional material distribution of a real component fabricated at our lab.

Results and conclusions: A good agreement between the simulations and available benchmark results for two phase flows was observed. A comparison to a real symmetric 2x2 coupler cross-section is presented. Future prospects regarding more complex systems are extensively discussed.

High-Power Laser Diodes with High Polarization Purity

Etai Rosenkrantz, Dan Yanson, Ophir Peleg, Moshe Blonder, Ilya Baskin, Noam Rappaport, and Genady Klumel

SCD - SemiConductor Devices, Israel

Fiber-coupled multi-emitter laser diode modules rely on power scaling for fiber laser pumping. Beam multiplexing techniques such as geometrical, spectral, and polarization beam combining (PBC) are commonly used. For PBC, linear polarization with a high degree of purity is important, as any imperfectly polarized light leads to optical losses and heating inside the module. Furthermore, PBC is typically performed in a collimated portion of the beams, which cancels the angular dependence of the PBC element, e.g., beam-splitter. We have developed TE-polarized high-power single emitters at 9xx nm that exhibit both reduced far-field divergence and high polarization purity. The laser diodes are shown to have a variable degree of polarization, which depends both on the operating current and far-field divergence. We present angle-resolved polarization measurements demonstrating correlation between the polarization purity and the ignition of high-order modes in the slow-axis emission of the emitter. It is demonstrated that the ultimate laser diode brightness includes not only the standard parameters such as power, emitting area and beam divergence, but also the degree of polarization (DoP), which is a strong function of the slow-axis beam quality. Reduced slow-axis divergence, therefore, contributes not only to high spatial brightness, but also to high polarization beam combining efficiency.

Topic: Lasers and Applications - Prof. Amiel Ishaaya

Electromagnetic Wavelength Variation of a Laser Beam Reciprocalation between Moving Carriages

Oren Aharon

Duma Optronicsm, Israel

Introduction: This lecture will discuss a device and a method for changing the wavelength of an electromagnetic or any other source with wavelength propagation characteristics. Wavelength alteration is achieved by reciprocating the original beam between two moving carriages.

Background: The device comprises of two carriages moving along a line towards each other or away from each other and an electromagnetic beam reciprocating in between. The reciprocalation effect is achieved by a reflective element mounted on each carriage. The presented discussion relates to a method of changing the wavelength of a beam by reciprocalation between reflective moving carriages. The beam will change its wavelength each time it is reflected. The reflected beam will have a different wavelength each time it bounces back from a moving reflective surface. The amount of change for each reflection is according to what is commonly known as Doppler Effect.

Objectives: Implementation of such a device or imaginary experiment could affect many aspects of modern physics in several areas such as: · Continuous change in the wavelength of a laser or electromagnetic beam · Delivering energy from a remote source for propulsion purposes · Direct conversion of mechanical energy into light energy This lecture relates generally to the theory and applications of electromagnetic wavelength changes over a wide, almost unlimited bandwidth and also to actively increasing or decreasing the beams' energy by mechanical movement of reflective elements.

Methods: The main methods at this stage are relying on Einstein's gedanken experiment, which will describe this unique approach of wavelengths changing by detailed analysis of light theoretical behavior and the mathematical implications for such a device.

Conclusions: Further analysis is needed to fully understand the implication of the proposed unique physics effect.

Intra-cavity Passive Coherent Combining in a Crossed-Porro Resonator Configuration

Z. Alperovich¹, O. Buchinsky², S. Greenstein², A. A. Ishaaya¹

*1. Department of Electrical and Computer Engineering, Ben-Gurion University, Israel
2. Elbit Systems Electro-optics - Elop Ltd., Israel*

Intra-cavity passive coherent beam combining is a method employed to increase the laser output power while maintaining the beam quality. Until now, intra-cavity coherent combining has only been demonstrated with flat end mirrors and a flat output coupler (e.g. [1]). A plano-plano resonator is known to be highly sensitive to mirror misalignments. One solution to reduce misalignment sensitivity is to use crossed-Porro prisms as the rear mirrors, together with a polarized beam splitter as the output coupler [2]. In more complicated laser resonators, such as coherently combined multi-channel resonators, where interferometric beam combining takes place, the use of a crossed-Porro configuration has not yet been studied. In this work we investigate coherent combining of two multimode Nd:YAG laser channels in a crossed-Porro resonator configuration, and measure the misalignment sensitivity in this configuration. We obtain highly efficient coherent combining in both free-running and pulsed operation, and show that with the crossed-Porro resonator configuration we obtain reduced sensitivity to tilt misalignments, while maintaining the beam quality. To the best of our knowledge, this is the first report of coherent combining in a crossed-Porro configuration. The crossed-Porro resonator consists of two Porro-prisms, two Nd:YAG rods side pumped by laser diodes, a Galilean telescope, and a quarter-wave plate with a polarizing beam splitter for output coupling. The measured nearand far-field intensity distributions are symmetrical and typical of multimode operation. The beam quality is $M^2 = 2.2$, the combining efficiency is 97% and the measured output pulse energy is 57mJ per pulse. The highest tilt sensitivity, defined as the 10% power loss setting, was $\pm 11 \mu\text{rad}$ for the plano-plano configuration, and $\pm 54 \mu\text{rad}$ for the crossed-Porro configuration. We conducted extensive measurements for various elements in the resonators, and compared their misalignment sensitivity to that measured with a single channel resonator (plano-plano and crossedPorro).

References

- [1] D. Sabourdy, V. kermene, A. Desfarges-Berthelemot, M. vamouille, and A. Barthelemy, "Coherent combining of two Nd:YAG lasers in a Vernier-Michelson-type cavity", *Appl. Phys. B* 75, 503-507 (2002).
- [2] N. Hodgson, and H. Weber, "Laser Resonators and Beam Propagation", Springer 108, (2005) chap. 17.

Glint Filtering In Electro-Optical Sensing At Marine Environment

R. Avrahamy, B. Milgrom, S. Hava

Department of Electrical and Computer Engineering, Ben Gurion University, Israel

Glint is a general term for changes in the appearance of brightness or position of the distant light source. These changes are optical phenomena that cause light source to appear flickered.

In marine environment, there is a collection of glints reflected on the water, which changes faster than the eye can discern. Location and timing of these glints depend on many variables. As for Observation and detection systems in the marine environment, these glints may produce severe saturation in some areas of photography. Saturation causes great difficulty for the observers, creating blinding glares and increasing fatigue. In addition, these glints increases marine target detection difficulty. At times, certain objects can hide "behind" these glints making them very hard to detect.

The aim of the study was the reduction in the quantitative relationship between the flashes and the background in the marine environment.

We have examined the glints in the Red-Sea and examined reducing the glints by adding external linear polarizers to the observation camera. Experiments carried out an analysis in a qualitative and quantitative manner, using image processing and comparing with theory. A survey with observers was performed to examine effectiveness of the solution.

References

- D. Lynch, D. Dearborn and J. Lock, "Glitter and glints on water", *Appl. Opt.*, vol. 50, no. 28, p. F39, 2011.
- G. Zhou, W. Xu, C. Niu and H. Zhao, "The polarization patterns of skylight reflected off wave water surface", *Opt. Express*, vol. 21, no. 26, pp. 32549–32564, 2013.
- K. Coulson, *Polarization and intensity of light in the atmosphere*. Hampton, Va., USA: A. Deepak Pub., 1988.
- X. Quan and E. Fry, "Empirical equation for the index of refraction of seawater", *Appl. Opt.*, vol. 34, no. 18, p. 3477, 1995.

Three Mirrors Cavity Resonator Embedding a Metasurface Mirror

G. Ehrlich¹, M. Zohar², M. Auslender¹, and S. Hava¹

1. Department of Electrical and Computer Engineering, Ben Gurion University, Israel

2. Department of Electrical Engineering, Shamoon College of Engineering, Israel

We study a novel arrangement of two flat mirrors and nanograting mirror to couple 1st diffracted order into cavity circulation. The intracavity and combined throughput light power buildup show high sensitivity to the cavity dimensions.

Among metadevices, gratings are well-known metasurface devices capable of performing functions for nonconventional optics. Interferometry utilizes coherent addition of correlated optical waves, traditionally achieved by splitting and recombining a single optical beam, entering through a transparent beam splitter. Standing-wave open Fabry-Perot (FP) cavity with two flat mirrors and a grating beam-splitter-mirror; a ring FP cavity embedding similar constituents was later proposed. No theory was elaborated in the open case, and only schematic treatment was presented in the ring case, but the grating was not optimized for best cavity gain. Our study aims at filling this gap, and this paper is devoted to the ring FP cavity.

We considered an FP cavity consist two identical flat mirrors and M-M is a grating-patterned metasurface, arranged relative to each other as follows. Let light impinge M-M, then by appropriate mirrors mounting and grating structure, one can force the initially diffracted -1st order beam to launch the light circulation, so that after the first round trip the circulation proceeds infinitely with the secondary zero order beam. Simultaneously, the secondary out-of-cavity + 1st order beams diffracted from M-M after each round trip add with the initial zero order beam (as they propagate under the same angle), giving rise to the carrier light read out at the detector port D. The light recirculation gives rise to an intracavity light power gain and a small D-readout if the cavity is tuned, and vice versa if it is detuned. Using ray tracing the circulating resonant light power gain, can be obtain as function of the complex reflection amplitude of m diffracted order at an incidence angle. Using our in-house software, we optimized the structure for a TiO₂-air grating on a multilayer of Si and SiO₂. The procedure results in an extremely narrow Fano-like spectrum peaked at ~98% and delta function like of carrier light yield and intracavity power, and high finesse.

Towards 3D Digital Printing of Micro-electromechanical Systems

Ofer Fogel^{1,2}, Zeev Zalevsky¹ and Zvi Kotler²

1. Faculty of Engineering and the Nanotechnology center, Bar-Ilan University, Israel

2. Additive Manufacturing Lab, Orbotech Ltd., Israel

Additive manufacturing offers several advantages over conventional methods of production, such as flexibility in design and reduction of required steps during fabrication, leading to faster production times. One promising method for manufacturing complicated 3D devices is based on laser induced forward transfer (LIFT) method.

LIFT is a printing method which allows solid bulk materials to be printed directly. The backside of the supplier material, which is a transparent substrate coated with a thin layer of material, is heated with a pulsed laser and jets a micro-droplet (having diameter of about 6-8 um) of the coated material.

The ability to print almost any material and the high accuracy and resolution of the droplet deposition makes LIFT to become a promising concept usable in printed functional devices.

Moreover, in the field of 3D structures this method can contribute to designing novel structures such as multilateral structures and complicated geometries (e.g. hollow cubes). Such structures, that can be used for various implementations such as MEMS and micro-batteries, are very hard to create using conventional methods.

In this work we present a first step towards additive manufacturing of 3D functional devices by showing 3D metallic micro-structures printed using the LIFT method. In order to print complex 3D structures (e.g. bridges), a sacrificial layers technique was used. Sacrificial layers were printed for the purpose of providing mechanical support to the desired design and they are later removed using a selective etching process while leaving only the required 3D structure. We also present a study of the morphology and the electrical properties of copper structures which are printed by LIFT from a bulk copper.

A Simple and Robust Phase-locking of Optical Cavities with > 200 KHz Servobandwidth using a Piezo-actuated Mirror mounted in soft materials

David Goldovsky

Bar-Ilan University, Israel

The ability to lock an optical cavity to a specific length is essential to x a laser to a preselected frequency and phase. It has great importance in many applications, such as stabilization of frequency combs, atomic clocks and ultrafast optics. The simplest way to lock a cavity is by mounting one of its end mirrors on a piezo electric transducer (PZT). PZT locks are highly desirable, mainly because they are completely non intrusive, as opposed to other methods. However, low frequency resonances that emerge from the complicated acoustics of the PZT mount and surroundings prevent traditional PZT locks from achieving fast response and high bandwidth locks. Therefore, PZT locks are usually used only for low bandwidth operation (few KHz), leaving the critical fast response lock to the much more complicated techniques, such as electro-optic modulation. We present an approach to locking of optical cavities with PZT mirrors based on a simple and effective mechanical decoupling of the mirror and actuator from the surrounding mount. Using simple elastic materials, such as rubber, as mechanical dampers between the piezo-mirror compound and its surrounding, a firm and stable mounting of a relatively large mirror (8mm diameter) can be maintained that is completely isolated from external mechanical resonances, and is limited only by the internal piezo-mirror resonance of > 330 KHz. The soft material blocks the high frequency sound-waves from reaching the mount, and the PZT - mirror compound effectively oats in mechanical vacuum. This reduces tremendously the acoustic complication, allowing to reach record-high servo bandwidth with relatively large mirrors and PZTs. Our piezo lock showed positive servo gain up to within 208 KHz, and a temporal response to a step interference < 3 μ s . In all, we demonstrated that mechanical isolation by soft materials enables a record high bandwidth of optical servo-locking. Even though mechanical damping with soft materials is widely used in many engineering applications, the adoption of these principles to optics was generally avoided so far. Our experiments show that significant advantages of soft materials can be exploited, with no evident compromise of optical stability, enjoying the best of both worlds.

Carrier Dynamics in the SOA based on QDs Ensemble

I. Khanonkin, A. K. Mishra, O. Karni and G. Eisenstein

Electrical Engineering Dep. and Russel Berrie Nanotechnology Institute, Technion, Israel

Introduction: Recent multi-wavelength ultrafast pump-probe measurements of InAs/InP quantum dot semiconductor optical amplifiers (QD SOAs) have shed new light on the charge carrier dynamic in these optical gain materials. It was shown that during the first 2 ps following the pump perturbation, the gain relaxation mechanisms are determined by processes such as intra-dot relaxations and carrier capture and escape from and to high energy carrier reservoirs. At later time, the effect of two photon absorption (TPA) dominates the recovery. These experiments are confirmed by a numerical model, which was previously developed for modeling coherent light-matter interactions during propagation of an ultra-short pulse along SOA. The inhomogeneous broadened (40 nm) SOA is modeled as an ensemble of effective two-level systems with different transition energies, corresponding to the ground state transitions of the various QDs.

Methods: Comprehensive FDTD model solves the Maxwell and Schrödinger equations in the density matrix formalism without invoking the rotating wave or slowly evolving wave approximations. The advantage of the model is in consideration of the non-resonant interactions such as TPA and its accompanied Kerr like effect as well as the group velocity dispersion.

Results: The spatial and spectral distribution of the difference in carrier occupation probabilities of the effective two-level systems and the group index are recorded along the amplifier for each bias and excitation pulse energy when the pulse is close to the output facet. These data are translated to a time evolution using the calculated group index profiles.

Conclusions: The numerical analyses of time evolution of the charge carriers in the ensemble of QDs levels behind the pump pulse are in agreement with the experimental results. The most complicated trace are for the first 2–3 ps. At longer times, TPA dominates and the population inversion value rises to level higher than that prior to the pump pulse arrival.

Keywords: quantum dots, semiconductor optical amplifier, ultrafast phenomena

Vials Laser Sealing

Uri Maurice

QCC Hazorea Calibration Technologies, Israel

Introduction: Pharmaceutical packaging process in glass or plastic vials must ensure high standard of sterilization, impenetrability, sealing and other parameters in order to achieve desired drug quality and stability throughout the medicine shelf life.

Background: Traditional sealing processes are expansive and time consuming, most often include many stages to preserve sterile conditions, and in extreme cases are subject to detriment of the product or packaging materials. In 2011, 2% of all injections in the U.S were recalled due to drug contamination, and many cases of infections due to contaminated injections occurred in recent years around the world.

A new method that use a laser pulse to reseal the vial after the filling process has been developed, and is already implemented in the pharmaceutical industry. The use of a vial laser sealer can be automated, and guarantee fast sterile sealing. To validate the process, a comprehensive calibration of the laser is necessary.

Objective: This work compares the quality control and calibration procedures of the manufacturer, to those developed by QCC's radiometric department for in-house calibration.

Methods: The laser machine includes a built-in power meter to answer calibration needs. However, to instigate an extensive quality control procedure, the wide variety of laser properties must be considered. QCC calibrated and adjusted at costumer's site the beam profile and diameter, pulse length and energy, and laser power to ensure the vial is properly re-sealed while the drug in the vial is not affected.

Results: The vials are resealed using a laser pulse to weld the top layer of the sealer, which prevent drug contamination and extend shelf life.

Conclusions: The non-contact resealing procedure obviates other methods, which are expansive, time consuming and may be harmful to the product. The comprehensive calibration procedure is essential to ensure process validity.

Keywords: vial laser sealing, drug packaging, laser pulse, laser properties, calibration, quality control.

Single Crystal Fiber versus Yb:YAG Rod for Chirped Pulse Amplifier

Aleksej M. Rodin and Eimantas Zopelis

Solid State Laser Laboratory, Department of Laser Technologies, Centre for Physical Sciences and Technology, Lithuania

Introduction: We compare performance of double-pass chirped pulse amplifiers (CPA) based on single crystal fiber (SCF) Yb:YAG with larger aperture rods. High brightness laser diodes with total power of up to 140 W were used as a pump source. Emitted by fiber laser seed pulses were amplified up to ~ 30 W in SCF and up to ~ 50 W in the larger rods both featuring a beam quality of $M^2 \sim 1.1$. Amplified pulses were compressed to ~ 600 fs with 80 % efficiency.

Background: Passively mode-locked fiber lasers are unsurpassed in terms of the beam quality, operation stability and compactness. Further power and energy scaling in the SCF CPA benefit from the pump guiding and improved heat removal. We investigated also larger aperture Yb:YAG rods with unguided pump propagation.

Objectives: The main goal was to identify the best end-pumped configuration of a high average and peak power Yb:YAG CPA for the pumping of 1 TW class optical parametric chirped pulse amplifier.

Methods: We studied Yb:YAG amplifiers based either on SCF ($\varnothing 1 \times 40$ mm, 1 % at.) or rods ($5 \times 5 \times 5$ mm³ 5 % at., $5 \times 5 \times 20$ mm³ and $2 \times 2 \times 20$ mm³ 2 % at.) in a single and dual-end-pumped configurations seeded by chirped pulses of > 350 mW average power at a repetition rates of 10 – 500 kHz with a pulselength of ~ 210 ps and ~ 3.8 nm bandwidth. High brightness fiber coupled 70 W laser diodes at 940 nm were used as a pump source.

Results: Yb:YAG CPA based on $2 \times 2 \times 20$ mm³ rod doped 2 % at. considerably surpass the SCF in terms of gain while ensures nearly the same output beam quality with small spherical aberration. The output pulses of ~ 3.5 mJ energy were attained at 10 kHz. Despite the gain narrowing down to ~ 1.8 nm, we obtained ~ 600 fs pulses with power conversion efficiency of 80 % using 1700 grooves/mm diffraction grating compressor.

Conclusions: The unsurpassed gain exceeding 42 dB, amplified beam quality $M^2 \sim 1.1$, low cost and alignment simplicity makes the $2 \times 2 \times 20$ mm³ 2% at. Yb:YAG rod the best choice in high average output power and energy CPA under pump levels below 140 W.

Keywords: single crystal fiber, Yb:YAG, thermal distortions, pulse compression. Topic: lasers and applications

NIR-VIS-UV Multiple Wavelength Picosecond Laser for Industrial Applications

Aleksej M. Rodin and Nortautas Ulevicius

Solid State Laser Laboratory, Department of Laser Technologies, Centre for Physical Sciences and Technology, Lithuania

Topic: lasers and applications

Introduction: Fundamental radiation of ultrafast Nd:YVO₄ laser at 1342 nm wavelength was converted to the 2nd, 3rd and 6th harmonics at 671, 447 and 224 nm with the average power of 6 W, 4 W and 0.7 W respectively.

Background: Laser emission near 1342 nm has applications in micromachining, deep-UV laser source development for lithography at 224 nm and 192 nm and surgical treatment. Efficient wavelength conversion into the red 671 nm by second harmonic generation (SHG) or into the blue 447 nm by the sum frequency mixing (THG) is attractive for laser TV, laser printing, medical diagnostics and treatment, underwater communication. We describe the development of multiply wavelength mode-locked laser covering a wide range of applications.

Objectives: The main goal was to design high repetition rate multiply wavelength: NIR-Visible-UV ultrafast laser.

Methods: Picked from the oscillator train, seed pulses were injected into the cavity of the regenerative amplifier based on pumped at 880 nm composite Nd:YVO₄ crystal with diffusion-bonded segments of multiple Nd doping concentration. We used $4 \times 4 \times 15$ mm³ type-I CPM LBO ($\theta = 85.2^\circ$, $\phi = 0^\circ$) for SHG, $4 \times 4 \times 10$ mm³ type-I CPM LBO ($\theta = 90^\circ$, $\phi = 19.6^\circ$) for THG and $6 \times 5 \times 3$ mm³ type-I BBO ($\theta = 64^\circ$, $\phi = 90^\circ$) for 6th harmonic generation.

Results: Laser emits 13 ps output pulses of 10 W average power at 1342 nm and 300 kHz repetition rate with StDev ± 1 % energy stability and $M^2 < 1.1$ beam quality. Conversion to 671, 447 and 224 nm with efficiency of up to 80 %, 50 % and ~ 8 % was achieved. The average power reaches 6 W in red (StDev ± 1.5 %, $M^2 \sim 1.09$), 4 W in blue (StDev ± 1.5 %, $M^2 \sim 1.12$, 0.85 ellipticity) and 0.7 W ($M^2 \sim 1.43$, 0.9 ellipticity) in UV. The conversion to the 6th harmonics at repetition rates exceeding 100 kHz is limited by linear absorption at 224 nm, without any impact of two-photon absorption. Oven with temperature gradient is designed to improve UV output.

Conclusions and recommendations: The ultrafast Nd:YVO₄ laser designed demonstrates the highest average output power at 1342 nm wavelength. We expect improvement in conversion efficiency to 224 nm at high repetition rates with gradient temperature oven.

Keywords: NIR lasers; mode-locked lasers; thermal effects; harmonic generation and mixing; RGB lasers; UV and EUV lasers.

Dense Optical Packaging of High Power Laser Diodes

Ran Vered, Avram Boubli, Yefim Yashuvaev and Eyal Shekel

Civan Advanced Technologies, Israel

We report the technology, engineering methods and lab test results of a high brightness, high power, direct diode, fiber delivered laser module. This is achieved through dense optical packaging of eighteen BAL (Broad Area Laser)-type semiconductor laser diodes, together launching a total of ~150W of CW optical power into a delivery fiber of diameter 105/125 μ m and NA of 0.22. Such direct diode modules are advantageous in various application segments including fiber laser pumping, materials processing, medical and defense. This is due largely to the relatively low cost, high efficiency, wavelength flexibility, high robustness, light weight and small form factor. The design presented incorporates a modular configuration wherein each diode chip on submount is itself mounted on separate steps. Every 3 steps are part of a replaceable diode module. The 3 step diode modules are separately connected to the module baseplate with optimized thermal contact. Each diode channel incorporates two microlenses for collimation in both the fast and slow axes of the light diverging from the BAL's 90 μ m facet. We perform active alignment with multiple manipulators, each with 6 degrees of freedom, around a pivot point, and with

Topic: Medicine and Biology - Dr. Natan T. Shaked

Gold Nanoparticles based Imaging Technique and Drug Delivery for the Detection and Treatment of Atherosclerotic Vascular Disease

Rinat Ankri¹, Dorit Leshem-Lev², Eli I. Lev², Menachem Motiei¹, Edith Hochhauser² and Dror Fixler¹

¹. Faculty of Engineering and Institute of Nanotechnology and Advanced Materials, Bar-Ilan University, Israel

². Cardiac research labs at the Felsenstein Medical Research Center and the Cardiology Department Rabin Medical Center, Israel

Objective: Identification and treatment of inflamed, unstable atherosclerotic lesions is challenging. Recent studies have shown that high density lipoprotein (HDL) attenuates atherosclerotic vascular disease by exerting anti-inflammatory effects including inhibition of lipoprotein-associated phospholipase A2 (Lp-PLA2). We aimed to use gold nanoparticles (GNPs) as carriers of HDL to enable detection and target treatment directly to macrophage-rich plaques.

Methods: In vitro, human macrophage cell culture was incubated with GNPs that were coated with HDL. GNPs-HDL uptake and Lp-PLA2 levels were measured. In vivo study, performed on rat carotid artery balloon injury model. Two weeks after rats were exposed to carotid injury, GNPs or GNPs-HDL were injected. Diffusion-reflection (DR) measurement was taken 24 hours later, and injured arteries were pathologically tested after two weeks.

Results: In vitro experiments showed that macrophages uptake the GNPs-HDL particles, and that GNPs-HDL were associated with lower Lp-PLA2 levels in culture media. In the in vivo rat carotid injury model, the DR method clearly detected accumulation of both, GNPs and GNPs-HDL nanoparticles in the injured arteries after 24 hours. Two weeks following the GNPs-HDL injection the amount of inflammatory cells in the neointima was significantly lower compared to GNPs without HDL. Furthermore, HDL treatment caused a reduction in macrophage accumulation in the injured artery, as demonstrated by both high resolution CT images and by immunostaining with macrophages cell marker CD68.

Conclusions: Application of this unique method based on GNPs-HDL presents a potential tool for the simultaneous detection and treatment of atherosclerotic macrophage-rich unstable plaques.

Evaluation of DNA Fragmentation in Human Sperm by Interferometric Phase Microscopy

Itay Barnea, Lidor Karako, Natan T. Shaked

Tel Aviv University, Israel

DNA fragmentation in sperm is considered to be one of the main reasons of the low success rate of intracytoplasmic sperm injection (ICSI) in couples with fertility problems. Acridine orange is a dye that emits green fluorescence when binding to double-strand DNA, and red fluorescence when binding to single-strand nucleic acid. Interferometric phase microscopy (IPM) is a microscopy method that evaluates the optical phase delay (OPD) of different compartments within a cell.

In this work, we have fixed human sperm cells from two donors onto a gridded microscope slide and captured the cells using IPM. The IPM images were analyzed via computer for the estimation of different cellular parameters, such as acrosome weight and size. An expert embryologist also evaluated the IPM images. The sperm cells were then stained using acridine orange and captured by fluorescent confocal microscopy. Each of the sperm cell images was estimated by his color (red, orange, yellow and green). Both acridine-based and IPM-embryologist results were summarized, and statistical differences in morphological parameters between the different DNA fragmentation levels were evaluated using ANOVA.

Our results indicate that the size of an acrosome is a good predictor for the presence of intact DNA ($p<0.0001$). We have also observed that the larger cells, in terms of cell projection and dry mass, are more likely to have intact DNA. Interestingly, sperm cells with green emittance tend to have very large nucleus, so they are suspected to have abnormal amount of DNA, making them unsuitable for ICSI.

After the validation done by acridine orange, we conclude that label-free IPM images for sperm selection prior to ICSI, analyzed automatically or by embryologist, can help fertility technicians in selecting sperm cells with intact DNA, which can potentially increase the percentage of successful pregnancies in couples undergoing this procedure.

Closure of Incisions in Tissues using a Temperature Controlled System based on a Semiconductor Laser and on AgClBr Mid-IR Fibers

Svetlana Basov¹, Ilan Gabay², David Varssano³, Irina Barequet⁴, Mordechai Rosner⁴, Joachim Wagner⁵, Marcel Rattunde⁵, Max Platkov², Mickey Harley⁶, Ofer Doron⁷ and Abraham Katzir²

1. Dept. of Biomedical Engineering, Tel Aviv University, Israel

2. School of Physics and Astronomy, Tel Aviv University, Israel

3. Dept. of Ophthalmology, Sourasky Medical Center, Tel Aviv, Israel

4. Goldschlager Eye Institute, Sheba Medical Center, Ramat Gan, Israel

5. Fraunhofer Institut für Angewandte Festkörperphysik, Freiburg, Germany

6. Veterinary Service Center, Sackler Medical School, Tel Aviv University, Israel

7. Lahav Research Institute, Kibbutz Lahav, Israel

We developed a fiber-optic laser system for soldering of incisions in tissues. The system consisted of a $1.9\mu\text{m}$ semiconductor laser and a bundle of fibers consisting of a silica fiber, surrounded by six mid-IR transmitting silver halide (AgBrCl) fibers, each of diameter 0.7mm. The approximated edges of an incision were covered with a biological solder (e.g. albumin). The laser radiation was transmitted through the central fiber and heated a spot on the solder. The "black body" radiation from the heated spot was transmitted through the AgClBr mid-IR fibers onto an IR detector. The signal from the detector, which was proportional to the temperature T of the spot, was read by electronic circuitry which controlled the laser power so that T was constant for time t . Bonding was obtained at this spot, and best results were obtained for $T=60-65\text{C}$ and $t=6-8\text{sec}$. The distal tip of the fiber bundle was then moved to a neighboring spot and the process was repeated, spot by spot, along the incision. The system was successfully tested in vivo in incisions of lengths 1-2 cm in 20 porcine corneas. The radiation of this laser penetrates $\approx 0.2\text{mm}$ into the cornea and it provides strong bonding, yet it cannot reach the inner parts of the eye. Histopathologic examination showed little thermal damage and good wound apposition. Optical Coherent Tomography (OCT) measurements also gave good results. The average burst pressure was $1000\pm30\text{mmHg}$, which is higher than the normal pressure in the eye. Laser soldering provides water tight closure, it does not require great skills to apply and it provides faster healing. Therefore, in the future, it may replace suturing of various corneal incisions and wounds, including in traumatic corneal laceration, closure of incisions in cataract surgery and corneal transplantation. The method will also be useful for bonding of incisions in the skin, dura, cartilage and endoscopic surgery.

Versatile Adaptive Optics Device for Super Resolution

Grégory Clouvel, Julia Cantarini, Audrius Jasaitis, Xavier Levecq

Imagine Optic, France

Nowadays fluorescence microscopy is a breeding ground where different technologies are competing to offer the best imaging performance for biological sciences. Adaptive optics is one of such techniques, which by correcting aberrations of the optical setup and aberrations induced by the biological sample increases the number of detected photons, improves the contrast and resolution of acquired images, especially deeper inside biological sample. To meet the current need to image larger field of view (FOV) in fluorescence microscopy, Imagine Optic developed an all new adaptive optics module MicAO, which can be integrated on any standard invertedframe microscope equipped with sCMOS camera. The 52-actuator continuous-membrane deformable mirror, used for the correction of aberrations inside MicAO, features very high reflectivity, phase modulation accuracy and high dynamic range, which guarantees the best quality of corrected point spread function (PSF). Thanks to the unique design, MicAO can be used to correct aberrations in the whole FOV of sCMOS camera (2056x2056), using both large and small numerical aperture objective lenses (oil and water immersion) and at the same time remains very compact in size. MicAO can be implemented for a number of different microscopy techniques, such as single molecule localization microscopy (PALM/STORM), spinning disk and scanning confocal, multiphoton, structured illumination (SIM), stimulated emission depletion (STED) and phase contrast microscopy. Moreover, the device is controlled by the software, which contains versatile aberration detection techniques based on the latest wavefront sensing and image-based iterative algorithms. Details of the optical design and applications of the device in various types of microscopy will be discussed.

Keywords: adaptive optics, aberrations, super resolution, spinning disk microscopy

Phase Unwrapping of Optically Thick Biological Samples using Angular Information

Gili Dardikman

Tel Aviv University, Israel

We present a new phase unwrapping approach for quantitative phase contrast microscopy, which allows reconstruction of optically thick objects, by considering the additional information stored in interferograms captured from consecutive angles in small angular increments. Our algorithm combines 1-D phase unwrapping in the angular dimension with conventional 2-D phase unwrapping in each of the phase maps, resulting in phase imaging of thick objects that were previously impossible to image with quantitative phase contrast microscopy. This is particularly useful for tomographic phase microscopy, where interferograms are captured from multiple viewing angles as an integral part of the procedure. Results are presented, demonstrating the advantages of the method relative to the existing, 2-D approach.

In Vivo Imaging of Deformed Red Blood Cells in Capillary Flow

Inna Kviatkovsky, Matan Winer, Adel Zeidan and Dvir Yelin

Faculty of Biomedical Engineering, Technion - IIT, Israel

Blood cells in small capillaries undergo severe deformations due to the strong shear forces induced by the rapid flow and the dense cell population. Understanding these deformations is of great value for many scientific and clinical diagnostics applications. Unfortunately, most experimental and theoretical studies conducted on this topic are guided mainly by in vitro observations of blood flowing within flow chambers, tissue models and microfluidic channels. Here we present a new in vivo approach for observing these deformations and resolving the three dimensional structures of the cells while flowing in small blood vessels within the human lower lip. A technique termed spectrally encoded flow cytometry was used in our study for label-free confocal microscopy of the flowing cells. A three dimensional reconstruction of the cell membrane was accomplished using a custom built optical simulation model for analyzing the fringes patterns formed by the interference between the vessel wall and the membrane surface of a flowing red blood cell. Typical deformation patterns were observed in different capillary sizes, in agreement with theoretical and experimental predictions. Imaging blood cells in their natural environment provides a highly accurate and physiological evidence for the deformation of red blood cells, and presents a new tool for studying their unique dynamical properties.

A Self-interference Fluorescence Microscope for Single Particle Tracking

L. Maurice and A. Bilenca

Biomedical Engineering Department Ben-Gurion University of the Negev, Israel

Single particle tracking (SPT) is an important task in biophysics. In particular, SPT is used to map the trajectories of single fluorescent emitters in various systems, such as cells and biomaterials, from which the dynamical and mechanical properties of the medium microenvironment can be extracted. While particle tracking with <10-nm localization precision in two dimensions is a mature field of research, 3D fluorescent particle tracking has long been a challenge in optical microscopy. In general, current methods for 3D particle tracking are based on point-focus imaging (including, for example, focus-locking and circularly scanning laser techniques) and widefield imaging (e.g., localization microscopy with defocused or axially asymmetric point-spread function imaging).

Here, we will demonstrate a different approach, based on fluorescence self-interference, for tracking single fluorescent probes with high localization precision in 3D. In fluorescence self-interference, the emission from a point fluorescent source is divided into two beams that are recombined prior to detection, producing self-interference patterns that convey information on the axial displacement of the fluorescent source. By recording multiple (at least three) fluorescence self-interference phase-shift patterns, this axial displacement information can be retrieved. While self-interference fluorescence microscopes have been originally developed for nano-imaging of biological structures using multiple cameras or relatively complex interferometric schemes, we propose and experimentally show a relatively simple realization of a self-interference fluorescence microscope based on temporal phase-shifting interferometry. Furthermore, using the microscope, we demonstrate the ability to characterize material microenvironments using 3D-SPT with high localization accuracy.

Keywords: single particle tracking; fluorescence microscopy; fluorescence self-interference.

Automated Analysis of Sperm for In Vitro fertilization through use of Interferometric Phase Microscopy and Machine Learning

Simcha Mirsky

OMNI Group, Tel Aviv University, Israel

Introduction: At this time, sperm for in vitro fertilization (IVF) is analyzed and selected manually by a clinician, based purely on his/her subjective visual examination and prior experience. Through use of interferometric phase microscopy (IPM) and machine learning this process can be made objective and quantitative, and new metrics can be provided for sperm analysis as well.

Background: IPM is a process whereby an interferogram image is acquired by interfering light that passes through the sample with a reference beam that does not. This interferogram is then translated into a phase map representing the optical thickness of the sample at each point in the image.

Objectives: To achieve automated classification of sperm cell morphology at high specificity using IPM-based phase maps of sperm.

Methods: More than 300 sperm cells were immobilized and imaged using IPM and then examined by an experienced IVF clinician to determine whether they had proper morphology. Specially designed features concerning the structure of each sperm's head were extracted from phase maps. These features were then normalized and subsequently assessed using principle component analysis. The most relevant principle components produced were then used to train a classification SVM for the automatic selection of good sperm.

Results: Using leave-one-out cross-validation, the SVM was able to classify the morphology of the good sperm cells at a high specificity of 0.996 with a sensitivity of 0.177.

Conclusions: By implementing the method stated above, it is possible to classify sperm cell morphology from phase maps at a high specificity. The relatively low sensitivity achieved is of little significance, as there are millions of sperm in a single ejaculation. This is especially true for intracytoplasmic sperm injection, in which only one good sperm needs to be found and injected into the egg.

Keywords: in vitro fertilization, IVF, interferometry, IPM, holographic microscopy, machine learning.

Relevance: The above abstract details a novel method for applying IPM to classify sperm for IVF. We believe that this approach will be relevant to the OASIS conference as we propose to fulfill a biomedical clinical need through the use of quantitative optical imaging.

Extracting Integrated Refractive Index of Cells Grown in Three-Dimensions

Amit Nativ, Yoav Nygate, Natan T. Shaked

Department of Biomedical Engineering, Tel Aviv University, Israel

Background: Interferometric phase microscopy (IPM) measures the optical path delay (OPD) between a reference and a sample beam. The OPD does not represent the true thickness of the sample, but rather the product of the geometrical length and the difference between the optical refractive index of the sample and the optical refractive index surrounding the sample. Due to this ambiguity, it is impossible to conclude the true thickness or the refractive index of the sample without any prior information using a single exposure IPM.

Objectives: Recover the refractive index of cells grown in fibrin gel. The gel allows the cells to grow in 3D, in a manner which resembles cells growth in-vivo.

Methods: We used NIH-3T3 cells, with actin labeled by green fluorescence protein. Each cell was scanned with confocal fluorescent microscope to measure its height, and then imaged with IPM to measure the cell OPD. Since the fibrin gel is highly scattering, we used a broadband light source in the IPM setup.

Results: The integrated refractive index of NIH-3T3 cells was extracted by dividing the OPD measured with IPM with the geometrical path measured with the confocal fluorescent microscope.

Conclusions: We successfully measured the refractive index of cells grown in fibrin gel by comparing the OPD and the geometrical length, and comparing measurements from confocal fluorescent microscope and interferometric phase microscopy. The fibrin gel offers a unique environment for cells growth, since it allows cells to keep their 3D shape, which is more similar to what happens in vivo.

Keywords: phase measurement; digital holography; interferometric imaging

Realistic Modeling of Individual Eyes by Pre-distorting a Generic Model

Shani Rosen

Technion, Israel

Introduction: Numerous models were developed over the years to capture various aspects of the eye's optical properties. One example, the Liou-Brennan (LB) model is based on the average properties of the human eye's optical surfaces obtained from a large set of anatomical studies. Although it is widely used in vision research, this model, just as any other standard eye model, overlooks an important phenomenon: while most aberration modes tend to statistically average to zero, they exhibit a large variance, and in individual eyes they have highly significant, nonzero values.

Objective: To better account for varying aberrations in a state-of-the-art, yet highly accessible model of the eye's optics, we modified the LB model to allow for the integration of experimental aberration data measured for individual eyes.

Methods: The public-domain Indiana Aberration Study serves as an aberration database of 200 well-corrected eyes. The model is realized in the optical design platform Zemax, based on their implementation of the LB model. In the modified LB model, an individual eye is selected from the database, and Zernike coefficients up to the 4th order are added to the pupil plane. To compensate for the misrepresentation caused by originally present aberrations in the LB model, we pre-distort the Zernike coefficients in the pupil plane to yield the correct overall system aberrations.

Results: The modified LB model accurately reconstructs the measured aberrations of individual eyes for different pupil sizes. The model was successfully validated with respect to the point-spread-functions obtained from simplified forms of eye modeling.

Conclusions: We have successfully integrated individual variation in aberrations with the LB model, creating a realistic modeling platform based on widely available software and data with various potential applications in vision research. These include fundamental questions in eye research, as well as the design and engineering of optical systems that interface with the human eye.

Keywords: eye modeling, aberrations, Zemax

Tomographic Imaging of Forward-scattering Objects

Gregory Samelsohn

Center for Advanced Imaging Systems, Department of Electrical and Electronics Engineering,
Shamoon College of Engineering, Israel

In conventional X-ray tomography it is assumed that the radiation propagates along straight lines. The log-intensity measured in the observation plane is then a Radon transform of the attenuation coefficient a . Since the Radon transform is invertible, it is possible to reconstruct uniquely the distribution of a , providing the measurements are performed for all possible projection angles.

In optical tomography the propagation is no longer along straight lines, because the refraction and diffraction effects can play an essential role. In this situation the use of the same Radon-based algorithms leads to low resolution and strong artifacts in the image, or even makes the reconstruction impossible. In this paper we analyze a new reconstruction algorithm based on approximate propagators describing the high-frequency radiation scattered by (lossy) dielectric objects.

We assume that the wave propagation is governed by a standard parabolic wave equation. Since the parabolic equation coincides with the Schrödinger equation of quantum mechanics, we apply the path integral formalism to obtain a required solution. The main motivation of using the path integral technique here is to reduce the (infinite-dimensional) path integral to an approximate finite-dimensional quadrature provided the solution is able to reproduce the relevant diffraction effects. An approximate solution can be expressed in terms of a propagation operator that transforms (the complex exponential of) a linogram of the illuminated object into a set of its diffraction patterns [G. Samelsohn, IEEE Trans. Antennas Propagat. 61, 5637, 2013].

Since the propagation operator is easily invertible, a computational multiple-shot scatter correction may be successfully performed, in order to realize a projective/tomographic imaging of forward-scattering structures. The results of simulations show a rather good resolution of reconstructed images well beyond the weak scattering regime [G. Samelsohn, J. Opt. Soc. Am. A 33, 1181, 2016]. In contrast to many known lensless imaging techniques suitable for reconstructing only thin samples, our method allows for imaging extended objects.

Comparison of Systolic Blood Pressure Value Obtained by Photoplethysmography and by Oscillometry in Neonates

Eran Shalom¹, Shlomo Engelberg², Zivanit Ergaz-Shaltiel³, Sinan Abu-leil³, Yitzhak Yitzhaky⁴, Meir Nitzan¹

1. Department of Physics/Electro-Optics Engineering, Jerusalem College of Technology, Israel

2. Department of Electrical and Electronics Engineering, Jerusalem College of Technology, Israel

3. Department of Neonatology, Hadassah Medical Center, Israel

4. Department of Electro-Optics Engineering, Ben-Gurion University of the Negev, Israel

Introduction: Oscillometry is the principal technique used to perform automatic noninvasive blood pressure measurements. The oscillometric measurement is based on inflating a pressure cuff above the systolic blood pressure (SBP) and then deflating it. The SBP is calculated by analyzing the oscillations in the cuff air-pressure. The SBP can also be measured using a pressure cuff and a photoplethysmographic (PPG) probe on the finger distal to the cuff. The PPG probe includes a light source and a detector which measures the light transmitted through the finger. The PPG signal contains pulses at the heart rate that disappear when the cuff air-pressure increases above the SBP value. During deflation, the PPG pulses reappear when the cuff pressure decreases to below SBP value, enabling the measurement of SBP. In examinations on adults, the PPG-based technique was found to be significantly more accurate than the oscillometry-based technique. In our study, we examined the accuracy of the PPG technique in newborns.

Methods: The non-invasive techniques for the measurement of SBP were tested by examining newborns with an arterial line. The oscillometry-based measurement was performed using standard hospital equipment. The invasive blood pressure measurement – the gold standard – was performed using an arterial line, inserted for medical purposes. The PPG measurements were performed using a device designed at the Jerusalem College of Technology (JCT).

Preliminary results: Fifteen examinations were performed on three preterm newborns. The average difference in SBP between the oscillometry-based and the invasive technique was 13.6 mmHg. The average difference in SBP between the PPG-based technique and the invasive technique was 6.5 mmHg. A reduction of the error in SBP measurement by more than 5 mmHg is significant.

Conclusion: Based on our preliminary measurements, we found that the PPG-based technique is significantly more accurate than the oscillometry-based SBP measurement.

In Vivo Microscopy of Leucocytes in the Lip

Matan Winer

Technion, Israel

Analysis of white blood cells in patients is an important part of the complete blood count, providing good indication of the patient's immune system status. The most common types of leucocytes are the Neutrophils and Lymphocytes that comprised approximately 60% and 30% of these cells in humans, respectively. Differentiating between these cells at the point of care would assist in accurate diagnosis of the possible source of infection and in effective prescription of antibiotics. In this work, we utilize a label-free imaging technique termed spectrally encoded flow cytometry for identifying and studying the image characteristics of leucocytes flowing in capillaries within the human lower lip.. We find that the appearance of leucocytes changes with vessel size and with the depth of imaging within the vessel, and determine optimal imaging conditions (vessel orientation, spectrometer speed and imaging depth) for counting the leucocytes and differentiating between their main types. The presented technology could serve for monitoring the immune system status at the point of care, and for studying the morphological and dynamical characteristics of blood cells at their natural environment.

Keywords: In vivo, Flow cytometry, Confocal microscopy, Spectral encoding, Diffraction grating

Cancer Cell Grading using Texture Signatures Obtained by Interferometric Phase Microscopy (IPM)

Darina Roitshtain¹, Lauren Wolbromsky¹, Evgeny Bal¹, Hayit Greenspan¹, Lisa L. Satterwhite², Natan T. Shaked¹

1. Department of Biomedical Engineering, Faculty of Engineering, Tel Aviv University, Israel

2. Department of Biomedical Engineering, Duke University, USA

Introduction: During the progression from a healthy cell to a cancerous cell and later to a metastatic cell, its biophysical, morphological and optical properties change. By detecting these changes at the individual cell level, we will be able to identify the grade of the cancer, potentially allowing for early treatment. We compared optical path delay (OPD) maps, obtained by interferometric phase microscopy (IPM), of healthy and cancerous cells, and primary cancer and metastatic cancer cells, whereby each pair of cell lines originated from the same individual.

Objectives: Our goal is to characterise and distinguish between different cell populations of isogenic cell lines based on OPD parameters using semi-automatic, real-time, non-invasive and label-free imaging.

Methods: The cells were imaged, unattached to the substrate, using cytometry in a low-coherence off-axis IPM setup, which allows for single-exposure acquisition mode. We extracted the OPD maps of the cells, and then calculated fifteen parameters that indicate the cell's 3D morphology and texture.

Results: We found statistical difference between different cell populations of isogenic cell lines, as well as the same trends of progression for all statistically significant parameters. Furthermore, by using a machine learning algorithm implemented on phase map extracted features, we demonstrated success rates of 79% – 99% to correctly diagnose the cell (healthy / cancerous / metastatic).

Conclusions: The quantitative phase imaging approach presented in this paper could be the basis for advanced label-free techniques for grading cancer cells in a flow cytometer for samples collected from body fluids.

Tissues Sensing by a New Nanophotonic Iterative Technique

Inbar Yariv¹, Menashe Haddad^{2,3}, Hamootal Duadi¹, Menachem Motiei¹, and Dror Fixler¹

1. Faculty of Engineering and the Institute of Nanotechnology and Advanced Materials, Bar Ilan University, Israel

2. Sackler School of Medicine, Tel-Aviv University, Israel; 3Mayanei Hayeshua Medical Center, Israel

Extracting optical parameters of turbid medium (e.g. tissue) by light reflectance signals is of great interest and has many applications in the medical world, life science, material analysis and biomedical optics. The reemitted light from an irradiated tissue is affected by the light's interaction with the tissue components and contains the information about the tissue structure and physiological state. In this talk we present a novel noninvasive nanophotonics technique, i.e., iterative multi-plane optical property extraction (IMOPE) based on reflectance measurements. The reflectance based IMOPE was applied for tissue viability examination, detection of gold nanorods (GNRs) within the blood circulation as well as blood flow detection using the GNRs presence within the blood vessels. The basics of the IMOPE combine a simple experimental setup for recording light intensity images with an iterative Gerchberg-Saxton (G-S) algorithm for reconstructing the reflected light phase and computing its standard deviation (STD). Changes in tissue composition affect its optical properties which results in changes in the light phase that can be measured by its STD. In our talk we will present, for the first time, reflectance based IMOPE tissue viability examination, producing a decrease in the computed STD for older tissues, as well as investigating their organic material absorption capability. Finally, differentiation of the femoral vein from adjacent tissues using GNRs and the detection of their presence within blood circulation and tissues are also presented with high sensitivity (better than computed tomography) to low quantities of GNRs (<3 mg).

Implantable Optical Interface for Holographic Large-area Deep Cortical Stimulation in Behaving Animals

Guy Yona¹, Ronnie Boutte², Steve Blair², Itamar Kahn¹, Shy Shoham^{1*}

1. Technion - Israel Institute of Technology, Israel

2. University of Utah, USA

A remaining challenge in developing optical control tools is the ability to produce defined light patterns such that power-efficient, precise control of large-scale neuronal populations is obtained. Here, we describe a system for patterned stimulation that transmits optical patterns from computergenerated holograms through an optical fiber bundle onto a device chronically implanted in a mouse cortex.

We have previously described the use of computer generated holography for fiber bundle coupling and in-vitro precise control of single-cell activity in ChR2-expressing cortical cell cultures as measured by extracellular electrophysiological recordings [1]. The design of an in vivo system require taking into account the strong scattering of visible light in brain tissue, which severely limits the activation depth and spatial resolution [2]. To overcome this, we use the Utah glass array, with optical needle-shaped wave-guides that protrude into the cortex [3]. In addition, experiments consisting of multiple repetitions per subject require a chronically implanted, detachable connector. Such a design pose further issues, including precise optical coupling, small size and manufacturability. To handle these concerns we use miniature 3D printed parts in combination with micro-manufactured glass components, whose design we present in this work. The implant, designed for MRI-compatibility, will allow for functional imaging experiments of awake, head-fixed behaving animal and enable the investigation of local lateral inhibition in the cortex, as well as co-activated distal targets and their relation to network activity.

[1] Farah et al., Holographic fiber bundle system for patterned optogenetic activation of large-scale neuronal networks. *Neurophotonics*, 2015. [2] Yona et al., Realistic numerical and analytical modeling of optogenetic light scattering in brain tissue for optogenetic applications, *eNeuro*, 2016. [3] Abaya et al. A 3D glass optrode array for optical neural stimulation. *Biomedical Optics Express*, 2012.

Acousto-optical Interferometry using Ultrasound Pulses for Transparent Sample imaging

Shira Zapesotsky and Natan T. Shaked

Tel Aviv University, Israel

We present a new contrast mechanism to improve imaging of transparent biological samples. Imaging of transparent biological samples is important for biological research. We propose a way to image transparent sample without the need for staining. We propose to image both the phase of the object and its acoustic properties, both of which are internal contrast mechanisms. To do this, we use an interferometric system in combination with ultrasound modulation pulses to perform speckle decorrelation.

Topic: Optical Engineering - Dr. Ariela Donval

Fundamental Limits of Photonic RF Phase-shift Amplification by RF Interferometry

Moshe Ben Ayun, Daniel Gotliv and Shmuel Sternklar

Department of Electrical and Electronic Engineering, Ariel University, Israel

Introduction: Traditional techniques for measuring displacement with sub-micron resolution are based on optical interferometry. The reason is clear: monitoring sub-micron displacements requires a stable, coherent light source having a wavelength of the same order of magnitude. Therefore, one would not consider an RF source, with a wavelength on the order of 10 cm, to be appropriate for these applications. The accrued round-trip phase shift of sinusoidal radiation at modulation frequency over an incremental distance is . In order to accrue 1 deg of phase for a displacement of 10 nm, the modulation frequency must be approx. 4000 GHz. This is obviously not attainable with state of the art RF electronics. However, many applications in RF radar and sensing, including RF photonic applications, require the sensitive detection of the RF phase shift. The phase-shift sensitivity of these applications are limited by the capabilities of standard state-of-the-art RF phase detectors to a minimum value of approx. 1 degree, due to nonlinear effects as well as noise.

Objective and Method: We have reported on a new method, Phase Amplification by RF Interferometry (PARFI), for amplifying small RF phase-shifts [1]. This method is based on destructive interference between two sinusoidal RF signals. A dominant and novel feature of PARFI is the fact that it does not amplify the input phase noise, which is usually the main noise source in these systems. Therefore, as opposed to other amplifiers, the phase-shift sensitivity improves with the phase-shift gain of the amplifier. Another attractive feature of this amplifier is the fact that it does not amplify amplitude noise as well if this noise fulfills a simple correlation condition. In this work we present an extended theory of PARFI which includes additive noise, such as thermal and shot noise. We also present experimental results of an improved two-stage PARFI system. The objective is to determine the ultimate sensitivity of the PARFI amplifier.

Results: We have developed the full theory of PARFI, which incorporates all of the noise sources which can pose a fundamental limit on the phase-shift sensitivity. We demonstrated a hybrid implementation consisting of a photonic PARFI stage followed by an electronic PARFI stage. A unique feature of this phase amplifier which sets it apart from other phase amplifiers is that the source phase noise is not amplified together with the phase signal. Therefore, the phase-shift sensitivity is enhanced with increasing phase amplification. For these reasons, destructive interference is useful for phase-shift amplification, despite the fact that it is accompanied by amplitude reduction. However, for high phase-shift gain, we predict that the phase-shift sensitivity is limited by the detector's thermal and shot noise. Applying this technique to displacement measurement, we demonstrate resolution at a phase-shift amplification of 3000.

Conclusion: Our work describes the ability to significantly boost the ultra-small phase-shifts before the phase detection process takes place, without amplifying the phase noise or amplitude noise as well. Therefore, for any given RF operating frequency, it is apparent that our technique can reach higher sensitivity than other types of phase amplifiers. Assuming an increase of the RF source frequency by factor of 10, leads to a minimum length resolution of 30 , which represents a significant improvement. Increasing the dynamic range of the detector, e.g. use of a high-compression current detector, and increasing the value of G by another factor of 10 will bring the resolution to the single-nanometer regime. Therefore, PARFI can be an attractive competitor to optical interferometry for high resolution metrology applications.

Keywords: Phase detection, RF photonics

References

- [1] Moshe Ben Ayun, Arye Schwarbaum, Seva Rosenberg, Monika Pinchas and Shmuel Sternklar, "Photonic radio frequency phase-shift amplification by radio frequency interferometry", Opt. Lett. 40, 4863 (2015)

Automated Diagnostic System for Clustering Individual Cell based on Frequency Domain FLIM Apparatus

Elnatan Davidovitch, Oran Herman

Bar-Ilan University & Intel, Israel

Under supervision: Dr. Dror Fixler, Mr. Gilad Yahav

Fluorescence lifetime imaging microscopy (FLIM) is an imaging microscopy technique to measure the fluorescence lifetime (FLT) of a specimen ([chapter 1](#)). Measurements using this technique can be analyzed in two methods: Time domain (TD) and Frequency Domain (FD). Our work based on the FD technique ([chapter 2](#)). The main advantage of using FD method is the fast FLT acquisition for the entire image in comparison to TD confocal method that derives the measurement pixel by pixel.

In FD method, a high frequency sinus wave excites the specimen and thus, the emission is in the same frequency but with a diversion in phase and decrease in modulation depth. The variations in the phase and modulation depth of fluorescence material are measured in comparison to a reference sample of known FLT. We used 4 ns fluorophore as reference.

Our main goal was to create an automation system for analyzing FLT of the cancer samples ([chapter 5](#)). Using FD-FLIM Imaging system of Lambert Instruments we have developed an algorithm costumed for cell detection in Matlab, created helpful graphical user interface (GUI) for this matter and obtained statistics for cluster of cells resides in a single image taken from FLIM system.

Moreover, to identify cells, we used Circular Hough Transform (CHT) upon the fluorescence intensity, phase or modulation images of cells ([chapter 5.4](#)). With our algorithm, we believe that soon it can help minimizing the work time, use less human resources and help us in getting results that are more accurate.

Using FD-FLIM system, we can discover different physiological states. In our work, we can differentiate between normal cells, inflamed cells and cancer cells. Prior to our automation system, there was no, as we know, an automatic program suitable for analyzing FLT data from clusters of cells.

Experimental System of the Full Scattering Profile of Cylindrical Phantoms

Idit Feder, Hamootal Duadi and Dror Fixler

*Faculty of Engineering and the Institute of Nanotechnology and Advanced Materials, Bar-Ilan University,
Israel*

Human tissue is one of the most complex optical media since it is turbid and nonhomogeneous. We suggest a new optical method for sensing physiological tissue state, based on the collection of the ejected light at all exit angles, to receive the full scattering profile. We simulate the light propagation in homogenous and heterogeneous cylindrical tissues and obtain the full scattering profile. In addition we built a unique set-up for noninvasive encircled measurement. We use a laser, a photodetector and tissues-like phantoms presenting different diameters and different reduced scattering coefficients. Our method reveals an isobaric point, which is independent of the optical properties and linearly depends on the exact tissue geometry. Furthermore, while adding nanoparticles to the tissue our new method can detect it due to the change they cause in the reduced scattering coefficient. In addition, the blood vessels in human tissues are the main cause of light absorbing and also scattering. Therefore, the effect of blood vessels on light-tissue interactions is essential for biomedical applications based on optically sensing, such as oxygen saturation, blood perfusion and blood pressure. We show the vessel diameter influence on the full scattering profile, and found higher reflection intensity for larger vessel diameters accordance to the shielding effect, while the isobaric point overcomes the shielding effect. The importance of the immunity to the shielding effect is that it allows self-calibration in clinical measurements and decreases the calibration error. These findings can be useful for biomedical applications such as non-invasive and simple diagnostic of the fingertip joint, lips, ear lobe and pinched tissues.

Time Lens Array

Moti Fridman, Avi Klein, Tomer Yaron and Shir Shahal

*Faculty of Engineering and the Institute of Nanotechnology and advanced materials, Bar Ilan University,
Israel*

There exists a duality between the equations describing the paraxial diffraction of light in space and the narrow-band dispersion of pulses in time. This duality, allows transforming optical phenomena, from the space-domain into the time-domain [1]. Specifically, the concept of a lens in space is adapted to the time-domain for obtaining the time-lens, which enables to extend and compress optical signals in time, and to perform Fourier transform.

The principle of a time lens is based on the temporal equivalent of spatial imaging. In spatial imaging the lens imposes a quadratic phase shift in space which compensate for the free space propagation. Therefore, the temporal equivalent is imposing a quadratic phase shift in time which compensate for dispersion [1]. We focus on time-lenses which are based on four-wave mixing process, since they are highly robust and can impose large phase shifts on ultra-fast signals [2, 3].

We developed time-lens array composed from a series of time-lenses each with its own pump wave. We utilized our time-lens array to obtain 3d imaging in the time-domain of optical signals with different dispersion as a function of time. Our measured and calculated results will be presented.

References

- B. H. Kolner, "Space-time duality and the theory of temporal imaging," *IEEE Journal of Quantum Electronics* 30, 1951–1963 (1994).
- M. A. Foster, R. Salem, D. F. Geraghty, A. C. Turner-Foster, M. Lipson, and A. L. Gaeta, "Silicon-chip-based ultrafast optical oscilloscope," *Nature* 456, 81–84 (2008).
- R. Salem, M. A. Foster, A. C. Turner, D. F. Geraghty, M. Lipson, and A. L. Gaeta, "Optical time lens based on four-wave mixing on a silicon chip," *Optics letters* 33, 1047–1049 (2008).

Asymmetric Meta-Materials

Vitali Kozlov¹, Dmitry Filonov^{1,2}, Alexander S. Shalin², Ben Z. Steinberg¹, Pavel Ginzburg^{1,2}

1. Tel-Aviv University, Israel

2. ITMO University, Russia

Introduction: Natural materials reflect incident illumination similarly regardless of the direction of light propagation, owing in part to the small magnetic polarizability found in nature. Asymmetric reflection with respect to the incident field direction of propagation could nonetheless be achieved with metamaterials by carefully engineering the constitutive meta-atoms that comprise them. This asymmetric behavior to the direction of illumination joins other novel capabilities of metamaterials, enabling the construction of new devices such as sensors, filters, optical resonators and more.

Objectives: The Hybrid Magneto Electric Particle (HMEP), comprised from coupled magnetic and electric elements, is presented theoretically and experimentally and is shown to possess asymmetric scattering properties that depend on the direction of the incident plane wave. The design parameters enable suppression of backscattering for one direction of propagation while for the opposite direction backscattering remains substantial.

Methods and Results: The asymmetric backscattering of the HMEP is shown to be rooted in the coupling between perpendicular magnetic and electric dipole-like structures. The effect is studied analytically, numerically (CST Studio) and experimentally (GHz range) in an anechoic chamber.

Conclusions: The HMEP joins other meta-atoms possessing unusual properties, enabling the construction of metamaterials with asymmetric reflection with respect to incident field direction of propagation. Such metamaterials could find use in sensing applications and be the building blocks of optical devices such as filters, resonators, optical diodes and more.

Keywords: metamaterials, asymmetric backscattering, asymmetric reflection, electromagnetic devices, meta atoms, coupled dipoles

Fault Localization and Estimation Method using Sub-Carrier Multiplexed Low Frequency Tone Sweep

Renata G. Leibel, Patryk J. Urban and Jean Pierre von der Weid

PUC-Rio, Brazil

With soaring demand for high capacity, a solution has been proposed for Radio over Fiber combining several data channels over the optical carrier using Sub-Carrier Multiplexing (SCM). Monitoring fiber links is thus increasingly important. Current OTDR technology operates at a separate optical wavelength and wide bandwidth detection. The pursuit of a low cost, high precision monitoring alternative is of paramount importance for cost effective QoS improvement. In this work employment of SCM for data multiplexing is exploited embedding a low frequency tone sweep monitoring technique into data transmission. A mathematical model for the frequency response of the link has been derived and the fault location and intensity is estimated through comparison with acquired amplitude and phase of the backscattered light for the varying frequency by applying a simple least mean squared (LMS) algorithm. The monitoring signal is modeled as $s(t) = P_i A_{RI} e^{j(2Kdri - \omega t)} + R L_0 A_{0E} e^{j(2Kz - \omega t)} dz$. Integration reveals the form of a phasor with time-invariant complex factor $S(f) = S_r(f) + S_b(f)$ which is used by the LMS. Reflections are derived from $S_r(f)$ while lossy events can be inferred from $S_b(f)$. For a single lossy event the phasor becomes $S_b(f) = \delta 2A_0 d \sin(Kd) K_d e^{jKd} + (1 - \delta^2) A_0 d \sin(KL) K_L e^{jKL}$. Multiple faults are modeled in a similar way. This result was expanded to accommodate branched networks by considering the overlap of single link responses: $SP_{ON}(f) = \sum_{n=1}^N S_n(f)$. The extended model indicates the algorithm is able to estimate fault position, intensity and the corresponding branch. Simulation results demonstrate the method's efficiency and preliminary experimental results match OTDR measurements.

Detuned Brillouin Amplification of OTDR Signals with Enhanced Signal-to-noise Ratio and nanostrain sensitive

Egor Liokumovitch, Eliashiv Shacham, Daniel Gotliv and Shmuel Sternklar

Department of Electrical and Electronic Engineering, Ariel University, Israel

Introduction: Since its first introduction several decades ago, optical-time-division reflectometry (OTDR) has become an indispensable tool to characterize fiber defects in fiber optic communication links. In addition, various types of fiber sensors for strain and vibration sensing have developed in this period. Among the different underlying mechanisms, advanced coherent OTDR-based systems show excellent strain sensitivity, and are widely used in fiber sensors systems for intrusion sensing as well as for monitoring strain in structures such as bridges and buildings. Despite these technological advances, the main issue still remains - high-sensitivity sensors based on coherent OTDR are expensive.

Objective and Method: In the past we reported on a new mechanism for OTDR-based sensing: Brillouin amplification of Rayleigh scattering (BARS) [1]. We have shown that BARS is uniquely suitable for processing the information in the Rayleigh-scattered signal. In this work we focus on the use of external BARS (eBARS) to amplify and process the OTDR signal that is due to vibration-induced strain on the fiber. In eBARS, the OTDR signal serves as the Stokes light to the input of a Brillouin amplifier, after exiting the sensing fiber. We show that with optimum detuning between the pump and Stokes light of the Brillouin amplifier, significantly enhanced SNR of the OTDR signal is achieved.

Results: We develop the theory and validate experimentally that the SNR of the Brillouin amplified OTDR signal is optimized for a certain value of frequency detuning of the Brillouin amplifier from the resonant condition. For a given pump power, this value depends upon the Stokes signal power, and is due to the dependence of the Brillouin amplifier linewidth on the power ratio of the inputs to the amplifier. This leads to up to an order of magnitude improvement in the SNR.

Conclusion: We describe a new and relatively inexpensive solution for fiber-optic vibration monitoring and strain sensing, with applications in intrusion sensing and structural monitoring. The eBARS system replaces the expensive components of Coherent OTDR with a relatively inexpensive system, and shows very high strain sensitivity (in the nanostrain region) with proper detuning of the Brillouin amplifier.

Keywords: Optical-time-division reflectometry, RF photonics, Brillouin amplification, fiber sensors

References

[1] David Mermelstein, Eliashiv Shacham, Moran Biton and Shmuel Sternklar, Opt. Lett. 40, 3340 (2015)

Usage of Time Multiplexing for Geometrical Aberration Corrections in Imaging Systems

Gilad Rand, Shilo Levavi, Asaf Illovitsh and Zeev Zalevsky

Faculty of Engineering and the Nanotechnology Center, Bar-Ilan University, Israel

In this research we present a novel concept for correction of geometrical aberrations of an imaging lens by applying time multiplexing super resolution (TMSR). We demonstrate the capability of correcting chromatic aberration, spherical aberration and astigmatism.

In general TMSR scheme two moving gratings are introduced into the optical setup. The first grating is placed near the object, and is used for encoding the spatial information. The encoding grating may also be projected on top of the object. The second grating is placed near the detector and is used for decoding the spatial information. The decoding grating can also be added digitally. The highest spatial frequency of the grating needs to be chosen according to the purpose and the specifications of the optical system and it will set the maximal super resolving factor. The two gratings are shifted between image capturing frames during the imaging sequence, and a temporal summation is performed at the detector. The moving gratings generate duplication of the optical transfer function (OTF). When summing the duplications of the OTF and normalizing the outcome, a new OTF of the system is obtained.

During the experiments, we chose a setup that isolates each relevant aberration that was tested. The experimentally obtained results validate the capability of the imaging setup to cope with the above mentioned aberrations and show significant enhancement of the quality and the contrast of the final reconstructed image.

Banded Spectra Resulting from Diffraction by Two Gratings: The Talbot-Lau Effect in the First Order

Jonathan Amasay and Stephen G. Lipson

Physics Dept, Technion, Israel

When a beam of white light is transmitted by two identical and parallel diffraction gratings, in planes separated by a small distance, a banded spectrum can be observed in some orders of diffraction. This arrangement is known as the Talbot-Lau effect, but appears to have been investigated previously only in the zero order, although it was first observed in a higher order by Barus in 1916. The origin of the banding is discussed using three approaches: 1- as an interference between the orders diffracted by the two gratings individually, 2- as resulting from registration or misregistration of the Talbot duplicate image of the first grating on the second one (the Talbot-Lau effect) and 3- as an example of diffraction by a three dimensional object, using the Ewald sphere construction. The results are compared to experimental data in the first order using a pair of blazed gratings. They can be related to some aspects of interference colors of birds and beetles. An application to multi-dimensional metrology is also suggested.

Topic: Non-linear Optics - Prof. Meir Orenstein

Nonlinear Polymeric Waveguide with Nanocomposite Core of Dispersed CdSe Nanoparticles in PFCB

Moran Bin Nun, Yedidya Lior and Dan M. Marom

The Hebrew University of Jerusalem, Israel

One of the components in all-optical signal processing is nonlinear (NL) optical waveguides (WGs) that exploits the instantaneous Kerr type nonlinearity, which can be used in an ultrafast device that will enable handling extremely high speed data rates. Various optical applications, such as optical switching, phase modulation and wave mixing were demonstrated by Kerr type NL-WGs. The requirements from a NL-WG can be roughly divided into two domains: nonlinearity characteristics (e.g. the nonlinearity types and dynamics) and guiding characteristics (e.g. confinement, dispersion, scattering losses).

Here we present an elegant way to produce NL-WG using nanocomposite core of CdSe nonlinear nanoparticles (NPs) in PFCB polymer. CdSe has been chosen due to its high Kerr coefficient of $n_2=1.9\times10^{-16} \text{ m}^2/\text{W}$ and its appropriate band gap of $\sim 2\text{eV}$ to avoid two photon absorption (TPA) in telecom wavelength. PFCB has been proven a good host for NPs and also is transparent at telecom wavelength. Cytop, the WG cladding, was chosen due to its low refractive index of 1.34 allowing for high index contrast of 10% leading to tight confinement of the optical mode. We succeeded in achieving a homogeneous dispersion of 1.3% volume fraction of CdSe in PFCB and made a full integration of this layer within the WG.

Initial characterization of the NL-WG was demonstrated. We coupled light to the NL-WG and measured its propagation loss using both Fabry-Perot fringes and time domain insertion loss analysis. Several WGs with different widths were tested. 6.15 dB/cm propagation loss were measured for $2\times5.3\mu\text{m}^2$ rib NL-WG at the length of 1.1cm. This was 3 times larger than an identical WG only without CdSe NL NPs. To determine the reason for this great increase we took a STEM image of the WG cross-section. Pillars of aggregates were witnessed at the bottom core/clad surface. We are now aimed at improving the fabrication process to decrease the propagation loss. Further characterization of nonlinear performance is needed.

Emulation of Nonlinear Dynamics with RF Devices

Dmitry Filonov^{1,2}, Pavel Ginzburg^{1,2}

1. School of Electrical Engineering, Tel-Aviv University, Israel

2. ITMO University, Russia

Introduction: Nonlinear systems feature a variety of phenomena of great significance for both fundamental studies and applications. Being often challenging for detailed mathematical analysis, they may be studied by applying experimental tools and cross-disciplinary concepts. Scalability of Maxwell's equations in respect to the operation frequency enables mapping of complex optical phenomena to centimeter waves regime, where both fabrication and characterization tools provide capabilities of addressing quite complex dynamical processes. This analog type of simulation, to some extent, could outperform existent numerical tools.

Objectives: The main objective of this contribution is to review recent activities in the field of emulation experiments and focus on newly developed metamaterial toolbox for addressing complex nonlinear dynamics. In particular, doubly resonant three-dimensional geometries are developed for achieving tunability and enhancement of nonlinear responses. Those structures serve as building blocks for creating nonlinear meta-atoms with nonlinearity on demand.

Methods and Results: Meta-atoms contain designed as coupled split ring resonators with the first (larger) ring acting as a receiver with the resonance tuned to the incident-wave carrier frequency (2ω). The second ring is a transceiver, and its resonance is adjusted to fit a higher harmonic, i.e., 2ω , 3ω , or any other. The source of the nonlinearity is a varactor diode, which is placed at a joint gap, shared by both rings. A voltage drop on the diode produces a current which contains multiple harmonics, due to its nearly exponential I-V response. Spatial orientation of the rings enables controlling individual components of nonlinear tensor and building it term-by-term almost on demand. All the proposals were verified experimentally by implementing printed circuits geometries and testing them with GHz at an anechoic chamber.

Conclusions: Constructing nonlinear responses on demand with atom-by-atom assembly was proposed and demonstrated at GHz range by adopting the concept of metamaterials. The developed toolbox enables addressing complex nonlinear processes, challenging for observation in optical domain and complex for numerical analysis. Powerful concepts of emulation and analog simulations will be highlighted during the presentation.

Keywords: electromagnetic interactions, nonlinear optics, coupled resonators, second harmonic generation, nonlinear dynamics

Boundary Conditions for Surface Second Harmonic Generation at a Metal-dielectric Interface Revisited

K. Nireekshan Reddy¹, Parry Y. Chen¹, Antonio I. Fernández-Domínguez² and Yonatan Sivan¹

¹Unit of Electro-Optic Engineering, Ben-Gurion University, Israel

²Departamento de Física, Teórica de la Materia Condensada, Universidad Autónoma de Madrid, Spain

Second harmonic generation (SHG) from metal-dielectric is being studies extensively as one can enhance the electric fields at the interface utilizing surface plasmonics. SHG from metal surface arises due to broken symmetry and it is customary to describe this nonlinearity with a vectorial surface nonlinear polarization $P_{NL\ S}(2\omega)$ [1]. $P_{NL\ S}(2\omega)$ enters the Maxwell's equations at 2ω as external sources placed at the interface. While the treatment for tangential component of $P_{NL\ S}(2\omega)$ is straight forward, since the normal component represents a dipole layer at the interface, special attention is needed in implementing the boundary conditions [1].

A special boundary condition (BC) for E_k was derived which generalizes the standard textbook boundary conditions to account for this dipole layer [1]. As a consequence, the tangential component of electric field E_k across the interface is discontinuous. Based on rather lengthy arguments, it was also shown that this dipole layer radiates as if placed outside the metal [2]. Although several studies implemented the BC correctly, there exists no study on spectral dependence of this discontinuity.

We provide an alternative approach to calculate SHG from the surface nonlinearity based on the spectral decomposition method (SDM) [3]. Remarkably, the SDM does not require the special BC, yet, it reproduces previous results based on the well known free space Green's function. SDM elegantly shows that the dipole layer radiates as if placed outside the metal without any special effort, thus, confirming the lengthy derivation of Ref. [2]. Furthermore, we study the spectral dependence of E_k discontinuity and provide a simple physical insight based on analytical structure of SDM. Specifically, we show that the errors in E_k due to incorrect application of BC can amount to the order of ten percent near the SH resonance (of the structure) and upto hundred percent away from it. Finally, we show that the popular numerical packages, e.g. COMSOL Multiphysics, implement the special BC incorrectly, rendering the far field maps of many recent studies quantitatively incorrect. We outline a possible implementation that can lead to correct results.

References

- [1]. T. F. Heinz, "Second-order nonlinear optical effects at surfaces and interfaces." *Nonlinear surface electromagnetic phenomena* 29 (1991), Pg. 360-364; and references therein. [2]. J. E. Sipe et al., *Phys. Rev. B* 21, 10 4389 (1980). [3]. D. J. Bergman and D. Stroud, *Phys. Rev. B* 22, 8 3527 (1980).

Broadband Pairwise Mode-locked Oscillation in a Coupled Parametric Oscillator

Yaakov Shaked, Leon Bello and Avi Pe'er

Department of Physics and BINA Center of Nano-Technology, Bar-Ilan University, Israel

Parametric oscillators differ from regular lasers in the behavior of their oscillation phase. While regular lasers are free to "choose" any oscillation phase, parametric oscillators are coherently linked to the oscillation phase of their pump. This difference is emphasized when the oscillation is generated in a coupled resonator. Coupled laser oscillations were widely studied and demonstrate a wide variety of phenomena, such as synchronization and chaotic dynamics on one hand, and stabilization of the oscillation mode on the other. However the dynamics of coupled parametric oscillation is inherently different, since the entire oscillation is locked to the external pump at the optical cycle level. We analyze the effects of coupling between two parametric oscillators in several operation regimes, starting with CW oscillation, through tunable two-mode full beating behavior, and finally, ultra-broadband pairwise mode-locked oscillation. Pulsed operation in parametric oscillators is extremely inefficient, since the parametric gain medium cannot store the pump energy (as opposed to a regular laser amplifier). Thus, pump energy that is delivered to the parametric amplifier when the pulse is not present in the amplifier, is wasted. Here we offer a new type of pairwise mode-locking of the parametric oscillator that induces a broadband white-like oscillation locking the relative phase of frequency-pairs instead of individual frequency modes. As a preliminary demonstration of these ideas we present an experiment with two radio-frequency parametric oscillators with a pump frequency of 800MHz. We achieve pairwise mode-locking over ~800MHz of bandwidth filling the entire bandwidth between DC and the pump frequency.

Topic: Photonics in Defense - Dr. Joelle Schlesinger

Modeling and Simulation of Wet Painted Surfaces

D. Steiner¹, A. B. Lessin¹, R. Ben-Dov², B. Milgrom², Y. Bar-Ilan¹, D. Sheffer¹

1. IARD Sensing Solutions Ltd., Israel

2. DDR&D IMOD, Israel

Maritime objects simulation is usually based on consideration of two classes of elements: dry and elements covered by a considerable water layer. Optical properties of dry elements are obtained from laboratory measurements. Optical properties of seawater are known and may be treated as characteristic of "soaked" elements. Real maritime objects contain also a third type: "wet" elements. They are covered by a thin water-layer. These elements may cover large areas and have optical properties between those of water and dry paint.

The objective of the present investigation is to partially bridge the knowledge gap concerning modeling and simulation of the optical properties of wet surfaces. The work started from measurement of optical properties (spectral DHR, BRDF) of dry samples with different paints. Later, these samples were wetted and their optical properties were measured again. Optical instrument for the BRDF measurements was the newly developed SOC-210. The parameters of BRDF models were then fitted to the measured optical properties.

A simple object containing painted plates was chosen for investigation in maritime conditions. The plates were thermally isolated at the internal surface and their painted external sides were subjected to all environmental effects. Variations in the plate orientation permitted us to simulate various parts/elements of a generic platform and their interference with the sea and other sources of light. Measurements of these plates in the MWIR and LWIR bands were made by radiometric cameras whose orientation could be varied, giving a capability to investigate cases with dominant specular reflection and with mainly diffuse behavior of dry and wet surfaces.

Modeling and simulation of the expected radiance over the plates were performed by use of TAITHermIR and Oktal-SE tools. Comparison of the results offered valuable insights concerning the SW tools, the preferred methods of selecting optical parameters and of implementing the simulations.

Keywords: Wet surface, Optical properties, Radiometry, Thermal modeling, EO Simulation

Sequence-Coded Laser Range-Finder Based on Semiconductor Technology

Gil Bashan¹, Omer Shachor², Yosef London¹, Nadav Arbel¹, Ran Vered², Eyal Shekel², Nadav Levanon³, and Avi Zadok¹

1. Faculty of Engineering, Bar-Ilan University, Israel

2. Civan Technologies Ltd., Israel

3. Faculty of Engineering, Tel-Aviv University, Israel

The most common paradigm for laser range-finder instruments relies on the transmission of intense, short and isolated pulses, and measurement of the two-way time of flight of reflected echoes. The peak power level of optical pulses in km-range measurements reaches kW levels. Such pulses require mode-locked or Q-switched solid-state laser sources, and cannot be generated using semiconductor laser diodes and optical amplifiers. Hence the scaling of laser range-finder technologies towards mass production is restricted.

In this work, we report the field trials of a laser range-finder prototype that is based on semiconductor laser diode and tapered power amplifier (TPA) at 1550 nm wavelength, integrated within the transmitter channel. Instead of single intense pulses, measurement is based on the continuous transmission of periodic, extended, binary sequences. Reflected echoes are collected and compressed by a post-processing algorithm [1]. The sequence-compression protocol supports ranging measurements with peak transmission power that is only 0.5 W. The binary sequences are unipolar, hence their transmission involves direct amplitude modulation only, and they are incoherently detected. Unlike most sequence compression protocols, the transmission or detection of phase information is not necessary, and the system is therefore considerably simplified. The sequences used are derived from bipolar Legendre codes, and their compression results in zero ranging sidelobes [1]. Limitations imposed by additive detector noise are addressed in both analysis and experiments [1].

Ranging measurements were successfully performed over 1,100 m distance with 15 cm resolution. Transmission was eye-safe. The transmission and detection apertures diameters were 3 cm, and the acquisition duration was 0.65 seconds. The tested module represents an important step towards laser range-finders and laser radars that are based exclusively on semiconductor technology.

Reference

N. Arbel, L. Hirschbrand, S. Weiss, N. Levanon and A. Zadok, "Continuously Operating Laser Range Finder Based on Incoherent Pulse Compression: Noise Analysis and Experiment," IEEE Photonics Journal 8, 6801211 (2016).

Topics: Remote Sensing - Dr. Eyal Agassi

GENESIS - Generation of Space Image Simulation

Yael Efraim

Israel Aerospace Industries, Israel

Genesis is an end-to-end simulation of hyper-spectral (HS) imaging by a space-craft payload. The main purposes of GENESIS are to analyze payload performance at various geometric and atmospheric conditions, to test sensor design influence on performance, and to verify the HS data-analysis algorithms on a mass of images. We shall present GENESIS main modules and show few examples of its applications.

Remote Glucose Sensing using Time varied Speckle Patterns

Nisan Ozana¹, Ariel Schwarz¹, Ran Califa², Amir Shemer¹, Sagi Polani², Javier Garcia³ and Zeev Zalevsky¹

1. Faculty of Engineering and the Institute of Nanotechnology and Advanced Materials, Bar Ilan University, Israel

2. ContinUse Biometrics Ltd, Israel

3. Departamento de Óptica, Universitat de València, Spain

The ability to perform a remote sensing of glucose in blood stream can be very applicable. The novel method presented in this paper is based on two optical approaches both based on the extraction and analysis of the changes in the collected speckle field. The first physical effect used for the detection is the temporal changes of the back scattered secondary speckles produced in the skin due to the changes of the blood stream parameters as a function of the glucose concentration in the blood. These cardio related changes can be analyzed with different machine learning algorithms in order to enhance the sensitivity of the measurements. The second physical effect assisting in performing the remote glucose sensing is the Faraday rotation effect in which the polarization of linearly polarized light is rotated by materials exhibiting this effect while being exposed to a magnetic field. When a glucose substance is injected into a solenoid generating an alternating (AC) magnetic field, Faraday rotation effect is exhibited. The Faraday rotation affects the temporal changes of the secondary speckle pattern distributions. The relatively small magneto-optic effect is enhanced by performing the data analysis at the temporal frequency resulting from the AC magnetic field while the noise does not have a specific characterizing frequency. Thus the magnetic excitation frequency was found to have a lock-in amplification role. A single wristwatch-style device containing a laser and a camera is the design for the proposed prototype. The device also contains an AC electro-magnet generated by a solenoid. Experimental tests which are the first steps towards an in vivo noncontact device for detection of glucose concentration in blood stream are presented.

Topic: Solar Energy - Dr. Yaakov Tischler

Solar Conversion by Thermally Enhanced Photo-Luminescence Device - Practical Design

Nimrod Kruger, Matej Kurtulik, Assaf Manor, Tamilarasan Sabapathy and Carmel Rotschild

Technion, Israel

While single-junction photovoltaics (PV's) are limited in conversion efficiency, concepts such as solar thermo-photovoltaics aim to harness lost heat and overcome the Shockley-Queisser limit, but as yet fail to do so. We claim the novel concept of Thermally Enhanced Photoluminescence (TEPL) as a practical route to achieve this goal. Here we present a practical TEPL device where a thermally insulated photo-luminescent (PL) absorber, acts as a mediator between a photovoltaic cell and the sun. This high temperature absorber emits blue-shifted PL at constant flux, then coupled to a high band gap PV cell. This scheme promotes PV conversion efficiencies, under ideal conditions, higher than 62% at temperatures lower than 1300K. Moreover, for a PV and absorber band-gaps of 1.45eV (GaAs PV's) and 1.1eV respectively, practical conditions allow conversion efficiencies to potentially exceed 46%. Some of these practical conditions belong to the realm of optical design; including high photon recycling (PR) and absorber external quantum efficiency (EQE). High EQE values, a product of the internal QE of the active PL materials and the extraction efficiency of each photon, have successfully been reached by experts in laser cooling technology. PR is the part of emitted low energy photons (in relation to the PV band-gap) that are reabsorbed and consequently reemitted with above band-gap energies. This parameter is dependent both on the absorber properties and the PV back-reflector. Today excellent PV back-reflection is already successfully achieved by cutting edge high efficiency PV cells. We examine emission and absorption of rare-earth doped transparent matrixes and present their PR and EQE performance in regard to TEPL efficiency. This work paves the way to the design a working prototype of an efficient TEPL converter.

Keywords: Photovoltaics, Thermal-emission, Photoluminescence, Optical-Engineering, Rare-earth doped ceramics, Thermal-management.

Poster Presentations

Tuesday, 28 February, 2017



Conference and Exhibition
on Optics and Electro-Optics

Topic: Quantum Optics - Dr. Barak Dayan

Photon Echo in InAs/InP QD SOA

Akhilesh Kumar Mishra, Igor Khanonkin, Ouri Karni, Gadi Eisenstein

1. Technion - Israel Institute of Technology, Electrical Engineering Department, Israel
2. Technion - Israel Institute of Technology, Russell Berrie Nanotechnology Institute, Israel

Keywords: Coherent optical effects, photon echo, two-level system, QD SOA.

Introduction: Photon echo accounts for the restoration of the dephasing in an ensemble of two-level systems and holds tremendous implications in quantum memory applications.

To meet the goal of realizing practical communication devices capable of performing quantum information processing, a couple of important strides have been made with the demonstration of triggering, and controlling, the coherence in electrically fed InAs/InP quantum dot semiconductor optical amplifier (QD SOA) , operating at room temperature.

Objective: We analyze numerically the control over the temporal and the intensity profiles of the echo signal by shaping the excitation pulse in an inhomogeneously broadened room temperature InAs/InP QD SOA.

Model: Our FDTD model simultaneously solves the Schrodinger and Maxwell's equations in the density matrix formalism and follows the co-evolution of the electromagnetic field and the electronic states of the ensemble of the two-level systems of the QDs which are distributed along the length of the amplifier.

The pulse shaping is performed for the first pulse only while the second pulse is transform limited. Quadratic spectral phase (i.e. linear chirp) of different magnitudes and signs is utilized to materialize the shaping.

Results and conclusions: For an excitation pulse centered symmetrically on the spectral gain profile i.e. at the gain peak of the QD-SOA, the shaping only changes the amplitude of the echo signal and the gain medium does not differentiate the interaction sequence introduced by the chirp. In contrast, when the excitation pulse is centered on the short or long wavelength side of the SOA gain peak, it interacts with the gain medium asymmetrically and any shaping changes both the appearance time and the amplitude of the echo signal.

Hence the appearance time and the intensity of the echo signal can be controlled by shaping the excitation of the first pulse.



High-Tc Superconductor-Semiconductor Photon-Assisted Tunneling

Dmitry Panna, Shlomi Bouscher, Vicky Perepelook, Leonid Rybak and Alex Hayat

Department of Electrical Engineering, Technion, Israel

Introduction: We demonstrate photon-assisted tunneling in Bi-2212/Si junctions. The significant shift in conductance spectra observed with increasing light intensity, provides new approaches to deep High-Tc band structure investigation with applications in light detection.

Background: Extensive research is focused on understanding the properties and characteristics of the hightemperature superconductors (HTS). Various techniques have been used to this purpose, but the short coherence lengths and surface sensitivity of the HTS have made it difficult to achieve consistent results. Photon-assisted tunneling was previously studied only in conventional low-Tc superconductors and metals. Our approach can provide information about the deep band structure of the HTS, and give new insights into the physics of HTS. Moreover, the light intensity dependent conductance can be exploited for photon detection.

Methods: We fabricated a HTS-semiconductor tunnel junction, based on Bi-2212 and highly doped n-type bulk Si – using our newly-developed mechanical-bonding technique. Our experimental setup included a 800 nm laser with pulse width of less than 100fs – to avoid heating the sample.

Results: Here we demonstrate for the first time, the effect of photon-assisted tunneling in a hybrid HTSsemiconductor device. We show a clear shift in tunneling spectra to higher energies under pulsed laser excitation due to the effect of photon-induced carrier transient population change of superconductor quasiparticles. Differential conductance without optical excitation at different temperatures exhibits typical change in the depth of the V-shaped d-wave tunneling spectra. Whereas under pulsed laser excitation at a fixed temperature of 10K, the spectra shift to higher energies with a clear correlation to the increase in laser intensity.

Conclusions: We observed photon-assisted tunneling in a mechanically bonded Bi-2212/Si device exhibiting a differential conductance spectrum shift under pulsed laser excitation. Our results open a new direction in the investigation of high-temperature superconductivity, as well as demonstrate a new approach to photon detectors.

Keywords: Nonconventional superconductivity, Hybrid devices, Photon-matter interaction

Semiconductor-Superconductor Optoelectronic Devices

Dmitry Panna, Shlomi Bouscher, Leonid Rybak and Alex Hayat

Department of Electrical Engineering, Technion, Israel

Introduction: We demonstrated superconducting proximity in semiconductor light-emitting structures proposed for enhanced two-photon gain, electrically-driven entangled-photon generation and Bell state analyzers. We produced high-temperature superconductivity in topological insulators Bi₂Se₃ and Bi₂Te₃ and high-temperature superconductor-semiconductor tunnel diodes.

Background: Hybrid structures were proposed by us as an efficient approach for generation of entangled photons, based on Cooper-pair luminescence in semiconductors, which does not require isolated emitters. Semiconductor quantum wells, remove the light-heavy-hole degeneracy, allowing efficient photon entanglement generation in simple electrically-driven structures, taking advantage of the superconducting macroscopic coherence. We analyzed a new effect of enhanced light amplification in electrically-driven semiconductorsuperconductor structures, including Cooper-pair based two-photon gain. We also proposed a compact and highly-efficient scheme for a complete Bell-state analysis using two-photon absorption in a superconducting proximity region of a semiconductor avalanche photodiode. This Cooper-pair based two-photon absorption results in a strong detection preference of a specified entangled state.

Methods: We demonstrated experimentally hybrid high-Tc-superconductor-semiconductor tunnel junctions. These devices were fabricated by the newly-developed mechanical bonding technique, resulting in high-Tcsemiconductor planar junctions acting as superconducting tunnel diodes.

Results: Tunneling-spectra characterization of the hybrid junctions of BSCCO combined with bulk GaAs, or a GaAs/AlGaAs quantum well, exhibits excess voltage and nonlinearity. We produced high-temperature superconductivity in topological insulators Bi₂Se₃ and Bi₂Te₃ via proximity to BSCCO, persisting up to at least 80K – a temperature an order of magnitude higher than any previous observations. Moreover, the induced superconducting gap in these devices reaches values of 10mV, significantly enhancing the relevant energy scales. Andreev reflection is observed as an excess current and an increase in differential conductance.

Conclusions: These results open new directions for fundamental studies in condensed matter physics and lightmatter interaction and enable a wide range of applications in optoelectronics and quantum information processing.

Topic: Ultrafast Phenomena - Prof. Oren Cohen

Octave Spanning Coherent Hyperspectral Near-field imaging of Plasmonic Nanostructures

Uri Arieli, Michael Mrejen, Assaf Levanon, Achiya Nagler, Haim Suchowski

Raymond and Beverly Sackler School of Physics and Astronomy, Tel Aviv University, Israel

Ultrafast photo-induced plasmonic phenomena, which occur both at a very small spatial length scale and in ultra-short time scales (span time scales from femtoseconds to picoseconds), find increasing importance in ultrafast sensing, nonlinear spectroscopy, and high speed nanophotonic devices [1,2]. Although most of the plasmonic phenomena can be considered as effective medium effects [3,4], those nonetheless draw on the light interaction at the nanoscale with the constituent nanostructures, which is commonly spectrally characterized with an incoherent source and integrated over tens of micrometers squared due to the diffraction limit.

Here we experimentally measure a spatially resolved ultra broadband optical response of a single gold nanoantenna with a deep subwavelength resolution using a sub 8 femtosecond few cycle pulse, spanning near octave at visible-near infrared optical range. Our approach is based on a nano-FTIR (Fourier Transform InfraRed) [5,6] spectrometer combined with a scattering-type scanning near-field microscope (s-SNOM) [NeaSpec], excited by a few-cycle femtosecond Ti:Sapphire laser (Venteon dual, 8 fs). We measured the hyperspectral response, spanning 650–1020nm bandwidth, of a single gold nanostructure (length 155nm, width 50nm and thickness 40nm) with a 25 nm spatial resolution. The measured spectral phase and intensity of the gold nanostructure showed a harmonic oscillator-like behaviour.

Our proposed VIS-NIR nano-FTIR allows us to unveil a much richer and complex picture of the optical behavior of the nanostructure at the single element level as well as to acquire hyperspectral data that resolves spectrally and spatially resonances of individual nanoantennas.

References

- [1] M. Aeschlimann, Science 333, 1723 (2011).
- [2] M. I. Stockman, New J. Phys. 10, 025031 (2008).
- [3] W. Cai and V. Shalaev, "Optical Metamaterials Fundamentals and Applications", Springer (2010).
- [4] N. Engheta, "Metamaterials: Physics and Engineering Explorations", Wiley (2006).
- [5] F. Huth, et al., Nano Letters, 12, 3973, (2012).
- [6] J.W. Gadzuk, Chemical Physics 251, 87 (2000).

Ultrafast Spin Dynamics in Monolayer MoS₂ under Two-photon Excitations

Jayakrishna Khatei¹, Dmitry Panna¹, Amit Bendel¹, Barak Lavy¹, Leonid Rybak¹, Hadar Steinberg² and Alex Hayat¹

1. Faculty of Electrical Engineering, Technion-Israel Institute of Technology, Israel.
2. Racah Institute of Physics, The Hebrew University of Jerusalem, Israel

Background: Monolayers of transition-metal dichalcogenides (TMDCs) such as MoS₂ have drawn great interest because of its direct band gap nature in monolayers to explore 2D valley excitons. So far there have been various spectroscopic efforts to study exciton dynamics in MoS₂ such as reflectance, photoluminescence excitation spectroscopy and pump-probe spectroscopy. However, little is known related to exciton relaxation dynamics under two-photon excitation, where a thorough knowledge of the valley selective selection rules for optically inactive dark excitons in monolayer MoS₂ is needed.

Experimental method: In this work, we have studied two-photon excited ultrafast spin dynamics in monolayer MoS₂, by performing two-photon excited pump-probe differential reflection and photoluminescence (PL) studies near 1200 nm excitation wavelength.

Results and conclusions: By exploiting the interplay between same and opposite pump-probe circular polarizations the differential reflection signal associated with the exciton dynamics of optically inactive dark excitons created under circularly polarized two photon pump excitation are probed using broadband white light via optically active bright excitons (~625 nm and ~695 nm). The pump-probe signal is attributed to transformation of dark exciton to bright exciton via phonon assisted inter-valley scattering. In our two-photon excited PL studies, a two-photon absorption (TPA) saturation effect (with high unsaturated TPA co-efficient two orders magnitude larger than those of conventional semiconductors) is observed at higher excitation intensity (>0.05 GW/cm²). Due to strong increase in density of states of carriers near the band edges of monolayer MoS₂ between 2 eV and 2.5 eV, we observed four orders of magnitude increase in TPA coefficients between 1200 nm and 1100 nm excitation. Moreover, the enhanced PL intensity for linearly polarized emission as compared to circularly polarized emission at different polarization angle suggests that the linearly polarized excitation at 1250 nm creates exciton valley coherence where phonon assisted intervalley scattering is prevented due to insufficient excitation energy. Our results provide important experimental information for exciton-valley coupling in monolayer MoS₂ which can be useful for future valleytronics and photonic devices applications.

Keywords: Two-photon processes, Photoluminescence, Nonlinear optics, Ultrafast processes

Topic: Micro and Nano Optics - Prof. Jacob Scheuer

Temperature Sensing with Plasmonic Fluorescence-based Probes

Tmiron Alon, Ivan Shishkin, Ronen Dagan, Gary Rosenman and Pavel Ginzburg

Tel-Aviv University, Israel

Introduction: The ability to control and monitor the temperature at real time and with high precision is required in vast number of applications. Inapplicability of conventional methods, such as thermocouple measurements or infrared thermography for temperature studies on micro- and nano- scales, has led to search for alternative probes. Several techniques of micro- and nano-thermometry have been developed in order to monitor properties of very small objects, in particular, methods basing on the change of fluorescent properties of the quantum emitters have been implemented.

Objectives: Life-time and spectral measurements of fluorescence dyes, enhanced by plasmonic structures are proposed and demonstrated for temperature sensing with high accuracy and high spatial resolution. The interplay between fluorescent tags interactions with solvents and plasmonic structures enable outperforming existent proposals.

Methods and Results: Fluorescent dyes are known to be sensitive to surrounding environment that influence different quenching processes. While quenching mechanisms directly reflect properties of an embedding media, such as its local temperature, auxiliary plasmonic nanostructures enable improvement in spatial resolution and readout of signals, to be detected. In order to demonstrate this concept a series of experiments on lifetime decay dynamics and emission intensities were performed.

Polymer films with embedded dyes and dye solutions were studied. A strong linear connection between the emission properties (lifetime and intensity) and the temperature was found in the range of 77 to 300K. A high sensitivity to phase transition in case of aqueous solutions (both in lifetimes and intensities) of the dye was demonstrated. Several plasmonic auxiliary structures were suggested for further substantial improvement in sensitivity.

Conclusions: Fluorescence thermometry is a promising technique, providing enormous advantages on the up-to-date thermometry at the micro and nano scale. Incorporation of plasmonic nanostructures into designs enables creation of accurate and stable temperature sensors, valuable for a large span of applications.

Keywords: Temperature sensing, photon counting, plasmonics, metamaterials, Purcell Effect, phase transitions

Enhanced Phase Contrast Microscopy by Shaping Gold Nanocrystals

Lina Atamny¹, Yael Roichman¹ and Natan Shaked²

¹. School of Chemistry, Tel-Aviv University, Israel

². The Department of Biomedical Engineering, Tel-Aviv University, Israel

Keywords: Interferometric imaging; digital holographic microscopy; phase measurement; nanoparticles; plasmonics; nanoparticles synthesis.

Introduction and Objectives: Gold nanoparticles can be used for label-free biomedical imaging based of quantitative phase microscopy. The heat emitted from the nanoparticles upon illumination affects the local refractive index and thickness of cells and tissues, resulting in enhanced phase contrast. Our aim is to optimize the shape of such nanoparticles to maximize their phase fingerprints. To this end, we analyzed theoretically gold nanoparticles with various shapes and their expected phase fingerprint, experimentally synthesized the chosen nanoparticles, and compared the simulation results with measurements. Here, we present preliminary results for gold nanoparticles in the shape of spheres, rods, and new bipyramids.

Methods: We synthesized different sizes of both gold nanorods and gold bipyramids, then predicted by simulation both the photothermal phase fingerprint and the heat distribution of each nanoparticle type. In order to verify our results, we used a custom-built wide-field interferometric phase microscopy system to measure the photothermal phase signatures of the stimulated nanoparticle solutions. In each measurement, a NIR laser light is used to excite the plasmon oscillations in the gold nanocrystals, heat emitted from the nanoparticle affects the measured phase signal via both the nanoparticle surrounding refractive index and thickness changes resulting in a high phase contrast.

Results: We were able to predict by new numerical simulation both the thermal distribution map and the photothermal phase profile for gold nanoparticles with three different shapes. The results show that gold bipyramidal particles give the highest and narrowest phase profile peak due to the sharp tips of this structure. In the future, we plan to measure the photothermal phase signals of nanoparticles solutions with different morphologies and compare them to the numerical calculations.

3D Sol-gel Optical Devices by Soft Nano Imprint Lithography

Ofer Bar On

Tel Aviv University, Israel

The field of integrated photonics is growing fast and the demand for new and versatile fabrication tools is continuously expanding. In this work we demonstrate the combination between two emerging technologies, fast Sol-gel technology and Soft Nano Imprint Lithography (Soft NIL) for achieving high quality passive and active optical devices.

Sol-gel technology offers a large range of tunable optical materials. These materials are robust, transparent and their refractive index can be tuned along with other important parameters. Soft NIL is an unconventional micro and nano fabrication technique enabling simultaneous 3-D structuring on a large scale using a huge variety of materials. The freedom in the choice of materials and geometries along with a fast and inexpensive process render this combination a good basis for complex integrated photonics.

In this work we demonstrate high quality optical devices such as 3D whispering gallery mode resonators with high quality factors up to 10^5 . We also show active resonators that function as lasers with thresholds of 15 kW/cm^2 . In addition, we demonstrate a 'two layer scheme' which is composed of optical devices in two different layers. These devices can be made of different materials and interact with each other enabling a large variety of possibilities.

In conclusion, we believe that the technology presented in this work can serve as a versatile, simple and inexpensive platform for integrated photonics in different fields including sensing, communication, computing and more.

Biological Computing using Fluorescence Lifetime Imaging Measurements

Eran Barnoy, Dror Fixler, Rachela Popovtzer

Faculty of Engineering & The Institute of Nanotechnology and Advanced Materials, Bar-Ilan University, Israel

Introduction and Background: Gold nanoparticles (GNPs) are well known for their biocompatibility, easy surface modification, and ability to strongly interact with fluorescent molecules in their vicinity. Using responsive conjugation and activatable probes, it is possible to make a system that reacts fluorescently in a manner corresponding to specific triggers or environments. A combination of a number of biological triggers can be viewed as a form of biological computing. Although activated fluorescence is highly explored in the literature, combinations of triggering inputs viewed through the lens of fluorescence lifetime (FLT) rather than fluorescence intensity (FI) raises issues still at the forefront of research.

Objectives: The purpose of this study was to effectively display the effects of a combination of biologically meaningful inputs on a fluorescent nano-system. These effects would then be imaged using fluorescence lifetime imaging microscopy (FLIM) to demonstrate different logic operations.

Methods: GNPs were functionalized using a caspase-cleavable peptide consisting of the elements Asp-Glu-Val-Asp (DEVD). The particles were then conjugated to fluorescein or fluorescein diacetate (FDA). Connection to the GNPs was severed by adding caspase-3, and FDA was activated by increasing solution pH. Fluorescent characterizations were determined using time-domain FLIM.

Results: FLIM results revealed a decreased FLT for fluorescein prepared with GNPs from 4ns to 3ns, indicating successful conjugation. In fluorescein samples, incubation with caspase-3 restored the unbound FLT and raised the FI from under 2000 to over 14000 AU. In FDA samples, particles with FDA exhibited an FLT of 1ns and intensity of 100 AU. Incubation with caspase-3 raised the FLT to 3ns and FI to 2000 AU. Raising surrounding pH increased the FLT to 3.7ns and FI to 8000 AU. Meanwhile, a combination of caspase-3 and raised pH recovered a FLT of nearly 4ns and FI of 10000 AU.

Conclusions: By using controlled chemical reactions and the sensitive FLIM modality, we have successfully shown logic operations in simple probes appropriate for biological application. Specifically, we have demonstrated initial, intermediary, and final steps in a system consisting of combined enzyme activation and change in pH. Using both FI and FLT perspectives, we are able to differentiate between situations of YES, NOT, AND, and OR gates from this simple to manufacture and biologically relevant probing system.

Keywords: fluorescence lifetime; gold nanoparticles; biological computing; logic gates.

Instantaneous Spatial Variation of Purcell Enhancement in Complex Nanostructures via Robust Eigenmode Expansion

Parry Y. Chen^{1,2}, David J. Bergman¹ and Yonatan Sivan²

*School of Physics and Astronomy, Raymond and Beverly Sackler Faculty of Exact Sciences, Tel Aviv University, Israel
Unit of Electro-optic Engineering, Ben-Gurion University, Israel*

Introduction: Radiation of optical sources is strongly influenced by plasmonic nanostructures, enabling applications such as single photon sources for quantum computing, and single molecule sensing and spectroscopy. However, this Purcell factor depends heavily on the molecule's location and orientation, which requires repeated simulation using finite-difference time-domain or finite-element methods. Thus, the spatial variation of Purcell factor is time consuming to simulate.

Objectives: We consider a rapid simulation method, requiring only a single numerical simulation of a complex nanostructure. Then, the electric fields generated by any arbitrary spatial distribution of sources are obtained near-instantaneously. This provides the spontaneous emission enhancement, and the Green's tensor for the structure, useful for many further calculations such as radiative heat transfer, van der Waals forces, and quantum friction. Analytic insight is obtained because spatial variation over both source and detector positions are obtained simultaneously.

Methods: Our general method solves Maxwell's equations with arbitrary sources, $\nabla \times (\nabla \times E) + k^2 \epsilon(r) E = i\omega \mu_0 J(r)$, expanding the nanostructure's influence in terms of its eigenmodes [1]. The total interaction between source and structure is captured analytically by an overlap integral, and for point sources by simply evaluating the eigenmode at the source location. Very few eigenmodes are required for nanostructures, with over 95% of radiated energy captured by a single mode. Finally, we resolve all interpretation and implementation issues of previous methods based on quasi-normal-modes [2], by employing eigenmodes with permittivity as the eigenvalue.

Results: Implementation is simple, which we demonstrate using the widely used COMSOL. We obtained fields generated by both point and extended near-field sources, and far-field sources. This versatility allowed surface second harmonic generation simulations in the undepleted pump approximation, for example. Our eigenmodes were checked against analytic cylinder modes, and fields confirmed against Mie theory.

Conclusion: Variation of plasmonic enhancement over source position is obtained from one simulation, via an eigenmode method easily implemented on commercially available software.

Keywords: (Micro and Nano Optics) - rapid simulation, spontaneous emission, Purcell enhancement, Green's tensor, eigenmode expansion

References

- [1] D. J. Bergman and D. Stroud, "Theory of resonances in the electromagnetic scattering by macroscopic bodies," *Phys. Rev. B*, 22 3527-3539, (1980). A. Farhi and D. J. Bergman, "Electromagnetic eigenstates and the field of an oscillating point electric dipole in a flat-slab composite structure," *Phys. Rev. A*, 93 063844, (2016).
- [2] C. Sauvan, J. P. Hugonin, I. S. Maksymov, and P. Lalanne, "Theory of the spontaneous optical emission of nanosize photonic and plasmon resonators," *Phys. Rev. Lett.*, 110 237401, (2013). P. T. Kristensen and S. Hughes, "Modes and mode volumes of leaky optical cavities and plasmonic nanoresonators," *ACS Photon.*, 1 2-10, (2014).

Double Fano Resonance in a Plasmonic Double Grating Structure

Brenda Dana

Tel Aviv University, Israel

Asymmetric resonances are the subject of considerable research efforts in photonic and plasmonic nano structures. Historically, asymmetric pro-files were found in rare gas spectra and were explained by Fano by taking into account the electron energy dependence on the interaction between a discrete autoionized state and the continuum. A similar resonance was discovered by Feshbach when studying nuclear reactions. The unique line shape is the result of interference between two pathways – one involving direct scattering to a continuum and the other a transition to the continuum through a meta-stable discrete bound state. A generalization of the formalism to include several discrete states or several continua is relevant to different multi-resonance systems. In particular two bound states that are coupled to the same continuum can result in a very narrow line-shape. We present a simple gratings-based plasmonic structure that supports a nearly-degenerate double Fano resonance. The double-resonance spectral location and line-shape are controllable by either adjusting the periodicity of two different unit-cells of the grating or by adjusting the angle of incidence of the incoming radiation. The ability to achieve such narrow line shapes with controllable parameters can be important for purposes such as sensing and slow light applications.

Tuning and Decoupling the Light Scattering and Absorption Resonances in Nanostructures

Yossef Danan^{1,2}, Yehonatan Ramon^{1,2}, Jonathan Azougi^{1,2}, Alexandre Douplik^{3,4,5} and Zeev Zalevsky^{1,2}

- 1. Faculty of Engineering, Bar-Ilan University, Israel
- 2. The Bar-Ilan Institute of Nanotechnology & Advanced Materials, Bar Ilan University, Israel
- 3. Department of Physics, Ryerson University, Canada
- 4. Keenan Research Centre of the LKS Knowledge Institute, St. Michael Hospital, Canada
- 5. Clinical Photonics Lab (CPL) of School of Advanced Optical Technologies (SAOT) at Friedrich-Alexander University of Erlangen-Nuremberg (FAU), Germany

The localized surface plasmon resonance (LSPR) effect enables the use of metallic nanoparticles as contrast agents in a variety of applications for diagnostic and treatment. These applications can use both the enhanced scattering and absorption properties of metallic nanoparticles. There are certain applications where domination of the absorption over scattering or vice versa would be an advantage. However, the scattering and absorption LSPR peaks are practically at the same spectral location at a certain domination of one over the other. We present a nanostructure combined of gold nanoparticle coated with silicon that switches the order between the absorption and the scattering magnitude at the LSPR peak and tune the LSPR over the spectrum. This is obtained by changing the refractive index of the silicon coating of the nanostructure due to the plasma dispersion effect in silicon by illuminating it with a pumping light.

Water Fiber

Mark L. Douvidzon¹, Shai Maayani², Leopoldo L. Martin² and Tal Carmon²

Technion, 1 Department of Nanoscience and Nanotechnology RBNI and 2 Department of Mechanical Engineering, Israel

Fibers constitute the backbone of modern communication and are used in laser surgeries; fibers also generate coherent X-ray, guided-sound and supercontinuum. In contrast, fibers for capillary oscillations, which are unique to liquids, were rarely considered in optofluidics. Here we fabricate fibers by water bridging an optical tapered-coupler to a plensed coupler. Our water fibers are held in air and their length can be longer than a millimeter. These hybrid fibers co-confine two important oscillations in nature: capillary- and electromagnetic-. We optically record vibrations in the water fiber, including an audio-rate fundamental and its 3 overtones in a harmonic series. Transforming Micro-Electro-Mechanical-Systems [MEMS] to Micro-Electro-Capillary-Systems [MECS], boosts the device softness by a million to accordingly improve its response to minute forces. Furthermore, MECS are compatible with water, which is a most important liquid in our world.

References

- [1] C. Kao, W. S. Boyle, and G. E. Smith, *Nobel Prize Phys.* (2009).
- [2] B. Temelkuran, S. D. Hart, G. Benoit, J. D. Joannopoulos, and Y. Fink, *Nature* 420, 650 (2002).
- [3] A. Rundquist, *Science* (80-), 280, 1412 (1998).
- [4] C. G. Durfee, A. R. Rundquist, S. Backus, C. Herne, M. M. Murnane, and H. C. Kapteyn, *Phys. Rev. Lett.* 83, 2187 (1999).
- [5] P. Dainese, P. S. J. Russell, N. Joly, J. C. Knight, G. S. Wiederhecker, H. L. Fragnito, V. Laude, and A. Khelif, *Nat. Phys.* 2, 388 (2006).
- [6] J. M. J. Dudley, G. Genty, and S. Coen, *Rev. Mod. Phys.* 78, 1135 (2006).
- [7] F. Vollmer and S. Arnold, *Nat. Methods* 5, 591 (2008).
- [8] Y. Fainman, L. Lee, D. Psaltis, and C. Yang, *Optofluidics: Fundamentals, Devices, and Applications* (McGraw-Hill, Inc., 2009).
- [9] L. He, S. K. Ozdemir, J. Zhu, W. Kim, and L. Yang, *Nat. Nanotechnol.* 6, 428 (2011).
- [10] Armstrong, *Electr. Eng.* 154 (1893).
- [11] R. Garcia, M. Calleja, and H. Rohrer, *J. Appl. Phys.* 86, 1898 (1999).
- [12] L. Sirghi, R. Szoszkiewicz, and E. Riedo, *Langmuir* 22, 1093 (2006).
- [13] E. E. C. Fuchs, J. Woisetschläger, K. Gatterer, E. Maier, R. Pecnik, G. Holler, and H. Eisenkölbl, *J. Phys. D: Appl. Phys.* 40, 6112 (2007).
- [14] J. Woisetschläger, K. Gatterer, and E. C. Fuchs, *Exp. Fluids* 48, 121 (2009).
- [15] A. Widom, J. Swain, J. Silverberg, S. Sivasubramanian, and Y. N. Srivastava, *Phys. Rev. E: Stat. Nonlin. Soft Matter Phys.* 80, 016301 (2009).
- [16] A. A. Aerov, *Phys. Rev. E* 84, 036314 (2011).
- [17] R. Namin and S. Lindi, *Phys. Rev. E* (2012).
- [18] J. C. Knight, G. Cheung, F. Jacques, and T. A. Birks, *Opt. Lett.* 22, 1129 (1997).
- [19] L. G. Cohen and M. V. Schneider, *Appl. Opt.* 13, 89 (1974).

Genetically Optimized Dielectric Metasurface for Flat Optics

Victor Egorov, Michal Eitan, Jacob Scheuer

Department of Physical Electronics, School of Electrical Engineering, Tel Aviv University, Israel

Flat metasurfaces facilitating subwavelength light control are among the most promising approaches for the realization of flat optical components such as lenses, holograms and more. During the last few years, much research efforts have been focused on designing a metallic single-layer metasurfaces based on plasmonic effects. Such metasurfaces, however, suffer from the intrinsic high losses of metals and very low transmission efficiency at optical frequencies. All-dielectric metamaterials, on other hand, exhibit low absorption losses in the infrared (IR) and visible spectral ranges. Generally speaking, such dielectric metasurfaces implement the Huygens surface principle, by utilizing an overlap of electric and magnetic Mie-type resonances of the constituent high refractive index elements to reduce significantly backscattering of the impinging light. The conventional approach to obtain high transmission properties (amplitude, phase, etc.) based on simulating infinite periodic arrays of single antennas with varying dimensions. However, mutual coupling between adjacent elements with different radii is not considered, thus limiting the optimization capability and the device performance.

Here we demonstrate a new design for obtaining wide angle, highly efficient, all-dielectric metasurface beam deflector. Our approach is based on a genetic optimization algorithm for determine the scatterers dimensions (lateral and vertical) within a unit-cell of the metasurface. Compared to previously employed design approaches we demonstrate an improvement in transmitted diffraction efficiencies power of 82% for high deflection angles such as 30.5° without sacrificing rectangular grid arrangement.

The proposed device, consisting Si disks was fabricated with varying radii, arranged in a square lattice. The Si disks were positioned on 500 nm thick SiO_2 pedestals, and covered with the SU-8 resist and carefully chosen anti-reflective layer on top. Good agreement was found between the theoretical work to the transmitted efficiency and the deflected angel of the 1st order diffraction.

Eigenfunction based Calculation of the Electric Field Generated by Oscillating Currents in a Two General Constituents Composite Medium

Asaf Farhi

Tel Aviv University, Israel

A negative refractive index lens can amplify the evanescent waves which encode the high spatial frequencies, theoretically leading to unlimited resolution. Motivated by this, we developed a formalism to calculate the electric field of oscillating currents in a two general constituents composite medium. We performed an exact calculation of the local electric field of an oscillating dipole in a setup of an ϵ_1, μ_1 slab in an ϵ_2, μ_2 host medium. We calculated the general electromagnetic eigenstates of a flat-slab structure and used them to expand the electric field. To facilitate the calculation we developed a procedure to treat current sources analytically, enabling to readily explore the effect of varying the dipole location and orientation and analyze volume currents.

The calculations of the lowest order eigenvalues showed that the high k components are enhanced for the TM field when $\epsilon_1 = -\epsilon_2$ and for the TE field when $\mu_1 = -\mu_2$, where the enhancement of the evanescent waves starts from lower k values as we approach a setup with both $\epsilon_1 = -\epsilon_2$ and $\mu_1 = -\mu_2$. The formalism can be applied to analyze phenomena such as nonlinear response and Purcell effect.

Study of Evanescent Fields Distortion Perturbed by Nanoparticle with Metasurfaces on Ridge Waveguides

Yakov Galutin¹ and **Alina Karabchevsky¹**

¹ Electrooptical Engineering Unit and Ilse Katz Institute for Nanoscale Science and Technology, Ben-Gurion University of the Negev, Israel

Introduction: Metamaterials play substantial role in various branches of optical science and engineering by providing schemes to tailor electromagnetic fields into desired spatial patterns. Specifically, metamaterials can be designed in such a way to allow the control of evanescent field for hiding an object. Here, we report on the modeling of clock on a chip.

Background: During the last decades, there has been a considerable interest in studying the electromagnetic properties of artificial media inducing properties otherwise impossible with natural materials. One of the most appealing applications of these metamaterials is achieving "invisibility". Integrated optics, or the transmission and processing of signals carried by optical beams using waveguides rather than by electrical current requires different ways of light manipulation. One of the requirements is reducing the scattering of objects in the light path, effectively making the object invisible. Evanescent wave coupling is commonly used in photonic and nanophotonic devices as waveguide sensors or couplers. Controlling these surface waves can be achieved by manipulating the properties and geometry of the metal layer at the metal-dielectric interface.

Objectives: The main goal of this project is to control evanescent fields with designed metasurface on a waveguide.

Methods: We developed the numerical simulator based on (FTDT) of Lumerical and fine element method (FEM) solver of COMSOL Multiphysics to study the propagation of coherent light in the composite plasmonic waveguide covered by a metasurface overlayer.

Results: Our results show that by designing and manipulating a thin overlayer of a plasmonic metasurface on a ridge waveguide, one can distort the fields and further hide an object just by tailoring the evanescent fields.

Conclusions: Varying the metasurface pattern yields a way to control the evanescent fields on optical waveguides in the visible spectrum. Numerous photonic functions and metamaterial concepts can be expected to follow from such a platform. The experimental realization of this research is expected to successfully create a "black hole" on a chip. Thus, camouflaging an object.

References

- [1] Karabchevsky, A., Zervas, M. N. and Wilkinson, J. S. 2015. Transmittance and surface intensity in 3D composite plasmonic waveguides. *Opt. Express*, 23:14407-4423.

Multifrequency Near Field Scanning Optical Microscope

H. Greener, M. Mrejen, H. Suchowski

Tel Aviv University, Israel

Significant advances in understanding the basic properties of light-matter interactions have been made these past few decades, due to improved spatial and temporal resolution in experimental measurements. In this context, we have achieved higher spatial resolution, by extending the newly developed multifrequency atomic force microscopy (AFM) [1] technique to the optical domain, on near field scanning optical microscopy (NSOM).

The main challenge faced in NSOM is to achieve high optical contrast, usually solved by detecting optical signals at higher harmonics [2], while eliminating optical background [3], in order to obtain a clear, artifact-free signal. Our theoretical and preliminary experimental results of optical contrast measurements, which are pending publication, have indeed shown an increased resolution with an improved signal to noise ratio by a factor of >40. This is due to a unique lock-in detection scheme, that can only be realized by implementing this multifrequency method. This will not only allow us to measure dynamical responses of nanostructures in very accurate spatial resolution, but will also be the best optical near field microscope, allowing further state of the art capabilities to emerge in other fields, such as imaging and sensing of ultrafast chemical reactions, bio-sensing and metallurgy.

References

- [1] Garcia, R. & Herruzo, E.T. "The emergence of multifrequency force microscopy," *Nat. Nanotechnol.* 7, 217-226 (2012)
- [2] B. Knoll and F. Keilmann, "Enhanced dielectric contrast in scattering-type scanning near-field optical microscopy," *Opt. Commun.* 182, 321-328 (2000)
- [3] M. Labardi, S. Patane, and M. Allegrini, "Artifact-free near-field optical imaging by apertureless microscopy," *Appl. Phys. Lett.* 77, 621 (2000)

The usage in E-K diagram for Bulk PbS to Customize its Lorentz Oscillator Model to Quantum Dots

Elad Hechster¹, and Gabby Sarusi¹

1. *Electro-Optics Engineering Unit and Ilse Katz Institute for Nanoscale Science and Technology,
Ben-Gurion University of the Negev, Israel*

Accurate knowledge of the Complex dielectric function of semiconductors is a key parameter as it determines their optical and electrical properties. PbS has large mobility and small electron and hole effective masses. Its large exciton Bohr radius enables to study its strong confinement in relatively large structures. These superior properties have been motivating the research of PbS nanostructures, and more specifically Quantum Dots (QDs), for few decades. The dielectric function of PbS QDs has, unexpectedly, never received adequate attention. In this work we address this issue. We adapt the approach that the quantum confinement in the nano regime affects all electronic transitions throughout the entire Brillouin zone. With this in mind, we have simulated the Complex dielectric function as a function of the particles' size. This has been done by attributing equal contribution of energy, caused by quantum confinement, for each critical point in the E-K diagram, equivalent to the bandgap extension. We added this contribution to the central energies parameters of the Lorentz oscillator model (LOM) for bulk PbS. Doing so, we have got a good agreement with previous works, for both, the dielectric function and the refractive index and extinction coefficient of PbS QDs. To the best of our knowledge, this is the first attempt to adjust the LOM's bulk parameters to nanostructures ones. We conclude that the approach mentioned above is justified. In addition, our way to solve this problem opens a new attitude to simulate the dielectric function of PbS QDs and other indispensable parameters that can be calculated from it, as a function of the particles' size.

Sperm Selection under Phase Imaging using a Disposable Microfluidic Tool

P. J. Eravuchira¹, I. Barnea, S. Mirsky and N. T. Shaked

Department of Biomedical Engineering, Tel Aviv University, Israel

Introduction: According to world health organization, approximately 50-60 million couples are affected by infertility, in which about one half is attributed to male factors. Low sperm count and reduced sperm motility impairs the ability of sperms to fertilize the female egg. Intracytoplasmic sperm injection (ICSI) is one of the widely used assisted reproductive techniques that scale down the male infertility related issues. In ICSI, a sperm with high motility and good morphological characteristics is selected and injected directly into a female egg. The selection of sperm is crucial as it affects the health of the offspring and success rate of the treatment. However, the selection of sperm for ICSI solely depends on the technicians experience and eyes. Recently, microfluidic devices are gaining interest as a tool for the sperm selection based on their motility.

Objective: We develop a new method which integrates interferometric phase microscopy with microfluidics for selecting sperms with good morphological characteristics and motility. The selection of sperms is based on evaluating the quantitative phase images of sperms flowing through the microchannel.

Methods: PDMS microchannel with a width and height of 12 μm and 7 μm were fabricated using soft lithography. The device has one inlet through which the sperm cells are injected into the channel and two outlets to select good and abnormal sperms. Syringe pumps are connected to the outlets to control the flow of sperm cells and to select them based on quantitative phase imaging. The selection pump is activated upon the detection of a good sperm.

Results and conclusion: Selection of sperm cells based on the dry mass, size, and shape of head and acosome, position of nucleus and motility of sperm was achieved with the setup. The selected sperms can be used for ICSI.

Keywords: Microfluidics, phase imaging, Sperm selection, ICSI

Silicone Waveguides for Broadband Overtone Spectroscopy of N-Methylamine and Aniline in Near-infrared

Aviad Katiyi^{1,2}, Benyamin Hadad¹ and Alina Karabchevsky^{1,2}

1. *Electrooptical Engineering Unit and Ilse Katz Institute*

2. *Nanoscale Science and Technology, Ben-Gurion University of the Negev, Israel*

Introduction: It has been shown experimentally¹, and validated theoretically², that a waveguide scheme can be efficiently utilized for detection of molecular overtones. Therefore, despite the fact that the cross section of vibrational transitions overtones are few orders of magnitude smaller than that of the fundamental transitions that correspond to the same degree of freedom, overtones and combination modes can be studied on waveguides in near-infrared.

Background: Silicon photonic devices are made using existing semiconductor fabrication techniques. Since silicon is already used as the substrate for most integrated circuits, it is beneficial to study the guided light and matter interaction with silicone on insulator waveguides which are operating in near-infrared.

Objectives: We are aiming to identify amine bond based molecules such as N-Methylaniline (NMA) and Aniline from their overtone absorption spectra on engineered silicone waveguides platform.

Methods: We performed the systematic experimental study where, we utilize the enhanced interaction of multimode SOI (Silicon-On-Insulator) rib waveguides with molecular media. We illuminate the waveguides with broadband source butt-coupled to the end facets. 2.5 mL of pure probe molecules and 2.5–3.5 mL of their dilutions in hexane are dripped onto the waveguide surface. Differential transmittance is evaluated from collected signals, analyzed and compared to the literature.

Results: The molecular fingerprints of probe molecules from their overtone absorption spectra were successfully demonstrated with silicone waveguides in near-infrared however. This is surprising, since at normal incidence, considering the same interaction length and longer the molecule and their mixtures were not detected.

Conclusions: We are the first to demonstrate the feasibility of detection molecular fingerprints on silicone waveguides platform in near-infrared.

References

- [1] Karabchevsky, A. and Kavokin, A. V. 2016. Giant absorption of light by molecular vibrations on a chip. *Nat. Sci. Rep.*, 6:1–7.
- [2] Katiyi, A., Karabchevsky, A., ‘Nano-tapers: squeezing light in a dielectric nano-guide for overtone spectroscopy’, MetaNano, Anapa, Russia 5 – 9 Sep 2016. Invited Talk.

Scanning High Spatial Resolution Spectroscopic Micro-ellipsometer for Arbitrary Landscape Measurements

Ralfy Kenaz¹, Moshe G. Harats², and Ronen Rapaport^{1,2}

1. *The Department of Applied Physics, Rachel and Selim School of Engineering, The Hebrew University of Jerusalem, Israel*

2. *The Racah Institute of Physics, The Hebrew University of Jerusalem, Israel*

Ellipsometry is a widely used tool both in industry and research for determining optical constants and thickness of various optical materials and thin films. Generally, standard spot sizes of current commercial ellipsometers are very large (mostly in millimeter-scale) which strongly inhibits their ability to measure local properties. Furthermore, these ellipsometers require a pre-determined fixed alignment of the sample angle. These two limitations do not allow ellipsometers to measure non-flat, micron-scale surfaces and samples, which are nowadays very common in modern industry and research. Recently we have developed in our lab a new type of a scanning high spatial resolution micro-ellipsometer (HSRME), which allows us to accurately and quickly obtain complex refractive indices and thickness values of flat and non-flat surfaces with a sub 10-micron spatial resolution and over a broadband optical spectrum. Our system opens up opportunities to characterize local optical properties of micron-scale optical devices, and small area surfaces such as optical meta-surfaces, and new electro-optical devices based on two-dimensional materials such as graphene or transition-metal dichalcogenides.

3D-Laser Printing of Miniature Mode-Sorter for Vortex Beams

Shlomi Lightman^{1,2}, Raz Gvishi¹ and Ady Arie²

1. *Electro-optics Division, Soreq NRC, Israel*

2. *Department of Physical Electronics, School of Electrical Engineering, Tel Aviv University, Israel*

The need to manipulate light beams has become a key factor in many areas of science, as it is possible to generate beams of complex structures. Hence, an astonishingly wide range of prospective applications have emerged because of this capability: Noncontact optical manipulation of matter (optical tweezers), subwavelength resolution microscopy, nanofabrication, laser cooling (atom trapping) and so on. Many of these methods exploit the distinctive properties arise of each generated beam, e.g.: phase properties, spatial intensity distributions and (orbital\spin) angular momentum. These new light beams can be generated in several ways, as the key element is the change of phase or amplitude of the original beam. In principle, phase modulation is a better approach than amplitude one, mainly since the latter is lossy and splits the incoming beam into multiple diffraction orders. Conventional ways of generating phase modulation have several drawbacks, as custom-made optical devices are usually manufactured by long, multiple-steps, fabrication process; and electrically driven liquid-crystal mediums, i.e. spatial light modulators, are expensive, planar and cannot be integrated. Here we show a new approach for manipulation of light beams by phase only features which are fabricated using unique lithography process, 3D-Direct laser writing. By this fabrication capability, arbitrary micron-scale structures can be written directly on optical elements (e.g. nonlinear crystal, lenses and so on), as they modify the phase of the incoming light, by corresponding to a desired phase modulation. Hence, structuring complicated beams, acquire mode sorting capability of orbital angular momentum beams, reduce lens aberrations, are all in the scope of this research. This innovative method may advance new prospects in optical technology, as the integrated phase masks proposed here can produce complex structured light along with a compact, stable and cost effective routine.

Cavity Optocapillaries

Shai Maayani¹, Leopoldo I. Martin¹, Samuel Kaminski¹ and Tal Carmon¹

1. Mechanical Eng. Department, Technion - Israel Institute of Technology, Israel

Droplets, particularly water droplets, are abundant in both natural and artificial systems. Their capillary oscillations are governed by surface tension and therefore distinguished from acoustic oscillations. These capillary oscillations play a major role in droplet coalescence for example, and are also an important phenomenon in interface theories. Here, we experimentally and theoretically analyze the capillary oscillation within an optical cavity with walls of water. Our droplet benefits from an optical finesse of 520 that, accordingly, boosts its sensitivity in recording Brownian capillaries with an amplitude of $1\pm0.025\text{Å}$ and kilohertz rates in agreement with natural-frequency calculations. Our hybrid device allows resonantly-enhanced interactions between electromagnetic and capillary waves that could potentially lead to optical excitation or cooling of droplet capillary oscillations.

Silicon-on-insulator 1x4 Power Splitter Based on Multi slot Silicon-Aluminum Nitride Waveguide Structures

Dror Malka

Faculty of Engineering, Holon Institute of Technology (HIT), Israel

Introduction: Slot waveguide structures are based on a combination of low-index material and high-index material. The low-index layer is surrounded by two high-index layers that enable the total internal reflection effect in order to guide the light into the slot waveguide structure. There are no confinement losses in slot waveguide structures due the strong high power confinement inside the slot area (low-index). Therefore, there is a significant interest in designing a photonic device based on a slot waveguide structure that integrates semiconductor materials.

Objective: In this work, we present a compact silicon on insulator 1x4 optical power splitter using a multi slot-waveguide structures. Aluminum nitride surrounded by silicon was used to confine the optical field in the slot region. Numerical optimizations were carried out on the sizes of coupling lengths between slot-waveguide structures in order to obtain an efficient splitting of the quasi transverse magnetic mode. Therefore, this work shows the study of using coupling light between slot-waveguide structures to realizing a 1x4 power splitter.

Results: Simulation results show that using a multi slot-waveguide structures can lead to better performances. The proposed device can split the power of an input light beam into four equal powers and it can be as short as $14.5\mu\text{m}$ with excess loss of 0.159 dB at 1550nm and better than 0.23dB across the whole C-band (1530–1565nm).

Conclusions: To conclude, in this work, we have shown that a 1x4 silicon-aluminum Nitride power splitter can be implemented using seven horizontally slotted waveguide structures, where the slot is made from aluminum Nitride.

Optical Manipulation with Long Working Distance Objectives

Hen Markovich¹, Ivan Shishkin¹, Paulina Segovia¹, Pavel Ginzburg^{1,2}

1. Tel-Aviv University, Israel

2. ITMO University, Russia

Introduction: Optical manipulation with focused laser beams is a widely used tool in many multidisciplinary applications. Recent research activities in the field are concentrated on reduction of optical powers, required for trapping, increase of stability and localization of trapped objects, and achieving flexibility in manipulation by configuring near-field interaction. However, many practical applications require tools for non-invasive optical manipulation deep inside a sample (e.g. biological tissue) or require trapping at long distances (for example in a vacuum chamber). Our report will address this important problem by means of developing new optical schemes.

Background: In general, optical trapping is employed with high numerical aperture (NA) objectives, that enable achieving laser beams focused to a diffraction-limited spot. The main drawback of those techniques is very short focal distances and usually immersion objectives are needed to achieve high NA values. Low NA objectives have many advantages compared to immersion ones. In terms of performances they have a wider field of view, longer focal length and a broader depth of focus – all on expense of optical trap stiffness.

Objectives: The main goal here is to study optical trapping characteristics, delivered by different low-NA objectives and vortex beams. The tradeoff between NA and optical trapping efficiency, improved by shaping a vorticity of optical beams will be demonstrated underlining the benefits of the first approach for the certain range of applications.

Methods and Results: Trapping characteristics for a set of objectives with increasing NA in the optical tweezers, applied a set of various microparticles of different sizes and materials were studied. A comprehensive comparison on the trapping effectiveness dependency on NA and different beams (Gaussian, azimuthally and radially polarized Laguerre-Gaussian beams) was made.

Keywords: optical trapping, opto-mechanics

Nonlinear Rayleigh Anomaly and Surface Lattice Resonance in Split Ring Resonator Arrays

Lior Michaeli^{1,2}, Shay Keren-Zur¹, Ori Avayu¹, Haim Suchowski², Tal Ellenbogen¹

*1. Department of Physical Electronics, Faculty of Engineering, Tel-Aviv University, Israel
2. Raymond and Beverly Sackler School of Physics & Astronomy, Tel-Aviv University, Israel*

Artificial structural nonlinearity of metallic nanoparticles has been shown recently to enable nonlinear optical conversion, e.g. second harmonic generation (SHG), with large effective nonlinear coefficients and in a variety of light manipulation schemes [1]. The ability to obtain controlled nonlinearity by modifying the geometry of nanostructured materials opens the door to new fundamental studies in the realm of nonlinear optics. Several studies have been performed in recent years on trying to unveil the fundamental mechanisms for the measured artificial nonlinearity, mainly focusing on the single plasmonic nanoparticle [2], or extended nearfield influence [3], where the influence of nonlinear coherent coupling of the plasmonic nanoparticles has remained unexplored.

In the linear regime it is well known that fulfilling the Rayleigh-anomaly (RA) condition in arrays of metallic nanoparticles at their localized surface plasmon resonance leads to excitation of so-called surface lattice resonances (SLRs), which substantially change the collective optical response of the plasmonic arrays [4]. Very recently, the Kauranen group has shown that excitation of SLR at frequency can lead to 10-fold enhancement of the SHG process at .

In this study we experimentally observe, for the first time to our knowledge, nonlinear SLR (NL-SLR) as a result of nonlinear RA (NL-RA) at coupled to a dark localized mode. The NL-SLR is manifested by sharp features of the SHG emission and attains more than 30-fold enhancement of the SHG with respect to normal incidence. By varying both the angle of incidence and the fundamental frequency, the correspondence between the NL-RA location and the sharp feature of the resonant response of the second harmonic were examined, and show very good agreement.

References

- [1] N. Segal, S. Keren-Zur, N. Helder, and T. Ellenbogen, "Controlling light with metamaterial-based nonlinear photonic crystals," *Nat. Photonics*, vol. 9, no. 3, pp. 180–184, Feb. 2015.
- [2] K. O'Brien, H. Suchowski, J. Rho, A. Salandrino, B. Kante, X. Yin, X. Zhang, K. O'Brien, H. Suchowski, J. Rho, A. Salandrino, B. Kante, X. Yin, and X. Zhang, "Predicting nonlinear properties of metamaterials from the linear response," *Nat. Mater.*, vol. 14, no. 4, pp. 379–383, Feb. 2015.
- [3] S. Linden, F. B. P. Niesler, J. Förstner, Y. Gryko, T. Meier, and M. Wegener, "Collective Effects in Second-Harmonic Generation from Split-Ring-Resonator Arrays," *Phys. Rev. Lett.*, vol. 109, no. 1, p. 015502, Jul. 2012.
- [4] B. Auguié and W. L. Barnes, "Collective resonances in gold nanoparticle arrays," *Phys. Rev. Lett.*, vol. 101, no. 14, 2008.

External Compact Holographic Module for Optical Micro and Nano Metrology under Low-spatial Coherence Illumination

Amit Nativ, Natan T. Shaked

Department of Biomedical Engineering, Tel Aviv University, Israel

Background: Digital holographic microscopy (DHM) uses interference to record the complex wave front of light interacting with matter. By digital post processing, it is possible to quantitatively reconstruct both the amplitude and phase of the specimen. The sensitivity of DHM in the vertical direction is in the order of nanometers. Therefore, DHM offers the opportunity to accurately measure profiles of nanomaterials. However, certain nanomaterial patterns are characterized by sharp edges. Illuminating the interferometric system by high spatially coherent light creates strong ringing artifacts around edges of the sample. To solve this problem, it is required to achieve interference under low-spatial-coherence illumination. However, there is a tradeoff between improving image quality obtained by decreasing the spatial coherence of the source, and the accuracy of the phase measurements.

Objectives: Our goal was to find the optimal spatial-coherence working point in phase imaging and demonstrating using it in a compact and easy-to-align interferometer that can connect externally to any existing microscope illuminated by low spatially coherent source. **Methods:** We have experimentally implemented the reflection-mode optical imaging system and the compact module. In addition to the experimental results, we performed computer simulations to find the correct amount of spatial coherence required for accurate phase measurement.

Results: The experiments were performed on silicon wafers, containing objects of few microns in the lateral direction, and a few hundred nanometers in height. Results were compared to atomic force microscopy (AFM) measurements. In spite of using low spatial coherence source, strong interference was achieved. Different amounts of spatial coherence were measured, and compared with computer simulations. Finally, the optimal amount of spatial coherence was found.

Conclusions: Our compact and simple interferometer performs accurate digital holographic microscopy under low-spatial-coherence illumination and is suitable for imaging micro and nano structures with sharp edges.

Keywords: Phase measurement; Digital holography; Interferometric imaging; metrology.

Organic Lasers with Extremely Small amount of Gain Material

Alexander Palatnik¹, Hagit Aviv¹, Ora Bitton² and Yaakov R. Tsichler¹

1. Department of Chemistry and BINA Center of Nano-Technology, Bar-Ilan University, Israel

2. Chemical Research Support department, Weizmann Institute of Science, Israel

We demonstrate lasing from low amount of gain material for two different configurations of micro-lasers: distributed feedback (DFB) laser and vertical cavity surface emitting laser (VCSEL). For the DFB laser the concentration of the gain material in the waveguide core is varied across two orders of magnitude, from 5% down to 0.025% and the laser dye DCJTB (4-(Dicyanomethylene)-2-tert-butyl-6-(1,1,7,7-tetramethyljulolidin-9-enyl-vinyl)-4H-pyran) incorporated into a PVK (poly(9-vinylcarbazole)) host matrix provides the gain. The threshold pulse energy for achieving lasing increased as the concentration of DCJTB was reduced, however the threshold excitation density quantified in terms of number of excited molecules per unit area remained nearly constant at 1.3×10^{13} molecules/cm². We show that this effect can not be explained by a standard 4-level lasing model, but rather that it is due to optically induced charge separation for the DCJTB molecules situated in the PVK host matrix. In the VCSEL configuration we demonstrate lasing when all the gain media is confined into a single molecule thick film of fluorescent dye. This is the first demonstration of lasing using organic monolayer and the first demonstration of lasing using any monolayer in planar microcavity configuration. The monolayer was assembled via Langmuir-Blodgett deposition and situated between two highly reflective dielectric mirrors. Lasing was observed upon excitation by nanosecond pulses at 4.4 $\mu\text{J}/\text{cm}^2$ when 5% of the fluorescent molecules were excited. Lasing was accompanied by a change in slope of the output intensity curve, the appearance of polarized emission, and a narrow spectral line above the threshold. We observed that the lasing threshold depends sensitively on normalized differential gain and less on the emission lifetime as result of Purcell effect.

Keywords: (140.3945) Microcavities, (140.3948) Microcavity devices, (240.0310) Thin films, (160.4890) Organic materials.

Sub-wavelength Grating Structured Optical Elements for Spectral Windows and Variable Filter

Michael Rosenblit

Ilse Katz Institute for Nanoscale Science and Technology, Ben Gurion University of the Negev, Israel

Different technologies exist to create optical elements, namely, multilayers technology and grating structure technology, and some combinations. In case of color filters, manufacturing using multilayers coating technology operates on the principle of wave interference between closely spaced reflecting surfaces for certain number of pairs of thin layers (up to 50 and more). In case of sub-wavelength surface grating structure technology an optical filter operates on the different physical principles, using different structures and materials, and consists from sub-wavelength grating surface structures and low number of layers (2-4) with constant thickness.

We develop, design and simulate structures for optical colour filters in RGB and IR spectral ranges, based on sub-wavelength grating technology and using materials coincident for different ranges and suitable for space application. Optimization and structure evaluation for ranges VNIR, SWIR and MWIR were completed for polarization dependent and independent filters and include, also, additional materials check for covered and uncovered structure versions. First structure is based on 1D metal-dielectric resonant waveguide grating structure. The transmission bandwidth can be controlled by tuning the "buffer" layer thickness. Second structure is based on 2D symmetric metal-dielectric resonant waveguide grating structure. In accordance with the guided mode resonance (GMR) effect a strong transmission can be introduced at certain wavelengths. Incident light is orthogonally diffracted by the symmetric grating towards two directions of the grating groove. Polarization independent band-pass filtering was thus achieved around specific wavelengths.

Optimization and structure evaluation for filters in different spectral ranges (RGB and IR) gives results for pass band filters: pass band transmission $\sim 85\%$, stop band transmission $\sim 7\%$). Initial tolerance analysis showed working window in order of 5% variation in relevant parameters. Further development was structure evaluation for filters integration. Detail simulation and design that satisfied space application requirements for spectral window combined the spectral ranges was done.

Direct Laser Writing for Photonic Applications

Ivan Shishkin¹, Hen Markovich¹, Anton Samusev², Kirill Samusev², Yael Roichman¹, Pavel Ginzburg¹

1. Tel-Aviv University, Israel
2. ITMO University, Russia

Introduction: Volumetric opto-electronic device fabrication opens venue for many practical applications. While conventional cleanroom fabrication methods are mostly limited to two dimensions and require complex multi-step fabrication process, direct laser writing (DLW) offers the capability of creating complex three-dimensional structures with sub-micron resolution in a single run.

Objectives: Two multidisciplinary applications in the field of photonics enabled by DLW capabilities will be presented focusing on our recent achievements: optical microcavities and tools for optical manipulation of large spherical objects.

Methods: The DLW method is based on highly nonlinear two-photon absorption of light in a photopolymer which results in local polymerization of material. After development the excess polymer is dissolved resulting in three-dimensional structures. The two-photon absorption gives rise to very high accuracy in this truly three-dimensional microfabrication.

Results: Optical microcavities with high Q-factors are used in broad range of applications. We demonstrate, using DLW, the fabrication of three-dimensional microcavities made of free-standing microdiscs and auxiliary structures. Such structures allow efficient coupling between microcavities and light in three dimensions. A non-invasive observation of whispering gallery modes in microdisk cavity fabricated by DLW was demonstrated. Dark-field imaging and spectroscopy were implemented for measurement of mode spatial distribution, spectrum of eigenmodes, mode indices and density of optical states.

One constraint of optical trapping is the inability to rotate biological spherical objects around their axis. This is desired, for example, for tomographic imaging of spherical cancer HeLa cells. To overcome this challenge an auxiliary structure was designed and used to rotate such objects in the whole range of 360 degrees, with high angular precision and control.

Conclusions: DLW is very powerful technique, providing enormous advantages for certain applications over other lithographic methods, especially in fabrication of volumetric structures, such as 3D photonic chips and microfluidic robots, which are in the focus of this presentation.

Keywords: direct laser writing, optical trapping, microcavity, photonic devices, opto-mechanics, micro-fluidic motors

STED Nanoscopy assisted by Small Metal Nanoparticles - New Advances

Yonatan Sivan¹, Matthew R. Foreman², Nicolai T. Urban³, Stefan W. Hell³

1. Unit of Electro-Optics engineering, Ben-Gurion University, Israel
2. Max Planck Institute for Science of Light, Germany
3. Max Planck Institute for Biophysical Chemistry, Germany

The diffraction limit was broken in the early 2000's in the context of fluorescence microscopy, eventually resulting in the awarding of the Nobel Prize of 2014. The most prominent super-resolution technique is probably stimulated-emission-depletion (STED) nanoscopy [1], which offers superb resolution and fast acquisition times. However, STED nanoscopes use high laser powers, requiring expensive laser sources and causing strong photobleaching. Recently [2], we showed that metal nanoparticles can be used to improve the performance of STED nanoscopes with a potential resolution improvement by more than an order of magnitude, or equivalently, depletion intensity reductions by more than 2 orders of magnitude; these come along with a reduction of photobleaching due to the shortened fluorophore lifetime. The first proof-of-concept of this approach [3], referred to as nanoparticle assisted STED (NP-STED) nanoscopy, was performed with 150nm gold shells in oil, and demonstrated only moderate super-resolution levels.

Here, we report deep super-resolution, down to ~100nm with 20nm gold spheres coated with fluorescent silica in aqueous environment, (as appropriate for bio-imaging) and a shorter STED wavelength, of 595nm, achieved at up to 2 times lower intensities compared with a standard STED.

We also demonstrate up to a 3-fold reduction of the bleaching rate in both confocal and STED modes, thus, providing the first confirmation of the second part of the NP-STED theory.

Our approach is especially suitable for parallel STED systems where the lack of sufficient power limits the scan speed. It could also enable additional imaging capabilities, such as photothermal imaging, nonlinearity-based super-resolution imaging, and most importantly, correlated light-electron imaging. Our particles can also enable combination of STED with procedures that rely on insertion of plasmonic nanoparticles to cells, such as gene therapy treatments, stimulation, monitoring and signaling in neurons, drug delivery, and Biodiagnostics based on spherical nucleic acids [4].

References

- [1] T.A. Klar, S. Jakobs, M. Dyba, A. Egner and S.W. Hell. Proc. Nat. Acad. Sci. U.S.A 97, 8206-8210 (2001)
- [2] Y. Sivan et al., ACS Nano 6, 5291-5296 (2012); Y. Sivan, Appl. Phys. Lett. 101, 021111 (2012)
- [3] Y. Sonnenfraud, H.G. Sinclair, Y. Sivan, M.R. Foreman, C. Dunsby, M.A.A. Neil, P. French, S.A. Maier. Nano Lett. 14, 4449 (2014)
- [4] C. Mirkin, Nature 382, 607-609 (1996); N.L. Rosi and C. Mirkin, Chem. Rev. 105, 1547-1562 (2005).

Recent Advances in Modelling Pulse Propagation in Complex Nano-structures

Tal Weiss¹ and Yonatan Sivan²

1. Department of Physics, Ben-Gurion University, Israel

2. Unit of Electro-Optic Engineering, Ben-Gurion University, Israel

Pulse propagation in optical fibers or waveguides is based on a Taylor expansion of the wavevector, yielding a series of dispersion terms ... [1]. When two or more pulses, potentially at different modal order, are interacting in the structure, the standard coupled mode theory (CMT) [2] is employed.

Although these models are in extremely wide use, they have several well known limitations. First, for lossy media, the various dispersion coefficients become complex, making the interpretation of the dynamics non-trivial. Specifically, the group velocity, which is the leading order dispersion term, partially loses its physical meaning, and its imaginary part is related to the attenuation coefficient in a rather non-trivial way. Second, in the slow (or even stopped) light regime, the dispersion expansion diverges, making the approach not useful and requiring the use many dispersion orders to maintain accuracy. Third, standard CMT is applied only for stationary media, and for monochromatic waves. We describe novel derivations of the pulse propagation and CMT equations that resolve all these problems, by expanding the permittivity and field in a Taylor series, or expanding the diffraction instead of the dispersion. We apply our models to pulse propagation in plasmonic waveguides, and demonstrate simple grating coupling of incoming pulse to a zero group velocity point. We also study short pulse generation, time reversal and ultrafast switching in optically pumped dielectric (glass and semiconductor) waveguides [3, 4, 5]. All these cases otherwise require cumbersome and lengthy exact (FDTD) simulations, so that our approach offers a significant simplification of previous numerical studies.

References

- [1] G. P. Agrawal. Nonlinear Fiber Optics. Academic Press, 3rd edition, 2001.
- [2] A. Yariv and P. Yeh. Photonics. Oxford University Press, 6th edition, 2007.
- [3] Y. Sivan, S. Rozenberg, and A. Halstuch. Coupled-mode theory for electromagnetic pulse propagation in dispersive media undergoing a spatiotemporal perturbation: Exact derivation, numerical validation, and peculiar wave mixing. *Phys. Rev. B*, 93:144303, 2016.
- [4] Y. Sivan, G. Ctistis, E. Y'uce, and A.P. Mosk. Femtosecond-scale switching based on excited free-carriers. *Opt. Express*, 23:16416–16428, 2015.
- [5] Y. Sivan, S. Rozenberg, A. Halstuch, and A. Ishaaya. Nonlinear wave mixing of short pulses of different spatio-temporal extents. submitted, 2015.

Designing Metal Enhanced Fluorescent Nanostructures using Genetic Algorithms

Chen Tzur, Dror Fixler, Zeev Zalevsky (advisors)

Faculty of engineering, Bar Ilan University, Israel

Designing complex fluorophore conjugated gold nanostructure (FGNS) constructs is a new development in the world of bioimaging. These constructs allow us to use the plasmonic qualities of GNS along with qualities of fluorophores (such as radiative fluorescence lifetime (FLT) and fluorescence intensity) and perform multimode imaging: conducting a number of advanced measurements such as fluorescence lifetime imaging microscopy (FLIM), diffusion reflection (DR) and X-ray CT using the same contrast agent. The dominant effect in the interaction between the nanostructure and the fluorophores around it is the metal enhanced fluorescence effect (MEF). In this effect, the radiative FLT and quantum yield are affected by the distance and orientation with respect to the nanoparticle. Therefore, optimizing the geometry of the FGNS will improve the effectiveness of the MEF mechanism resulting in better components for the measurements mentioned above. A genetic algorithm (GA) is a method for optimization, based on a natural selection process that acts like biological evolution. The algorithm is iterative and modifies a population of individual solutions for the optimization problem, allowing the evaluation of a vast number of possibilities. We propose a method to design FGNS constructs using a GA. GA is being used in other fields of engineering such as RF, protein structure engineering, solar cells and more. Without a computed search tool such as GA it would be extremely hard to check the enhancement of most of the possibilities for orientation, distance and GNS shape. Our final result will provide a tool for evaluating the vast number of possibilities for the design for a multimode imaging contrast agent. We are positive it will bring novelty to the development of new multimode imaging procedures.

Single Molecule and Nanoparticle Absorption Spectroscopy

Eitam Vinegrad¹, Daniel Vestler², Gil Markovich² and Ori Cheshnovsky²

1. School of Physics, Tel-Aviv University, Israel

2. School of Chemistry, Tel-Aviv University, Israel

Single molecule spectroscopic detection in fluorescent microscopy is well established now. The technique highly relies on the fact that it is practically background free. Extensive research pertaining to the dynamics of single molecules is based on single-molecule spectroscopy. However, not all molecules of interest fluoresce. In many cases, the introduction of fluorescent marker molecule is required in order to investigate or monitor the required dynamics. In other cases, the spectroscopic properties of non-fluorescent molecules cannot be studied with this technique. In the last few years, few techniques capable of single molecule detection via optical absorption have emerged. Due to the fact that the area of diffraction limited laser spot is of the order of magnitude of $0.1 \mu\text{m}^2$ and the absorption cross section of molecules is of the order of $10^{-7} \mu\text{m}^2$, detection capability of extremely small optical densities is required in these methods. In this work, we present a new approach in measuring the absorption of single nano objects. We use a super-continuum laser (Fianium) and Acousto-optic tunable filters to choose the wavelength of operation. The absorption detection is then carried out by balanced photodiodes aimed to suppress the laser noise. Scientific goals: A. Spectroscopic characterization of specially designed Si/Ge core shell nanowires (fabricated by our collaborators in F. Patolsky's lab), which according to theoretical predictions by A. Zunger are characterized by a direct band gap. B. Chirality measurements of single nano objects both of artificially designed chiral nano objects and chiral nanoparticles (with our collaborators in G. Markovich's lab). We will present our experimental methodology as well as preliminary results on the absorption of several nanoparticle systems, as well as chirality measurements of single artificial nano objects.

Employment of Linear-optics Nanoscopy using Optical-tweezers on Biological Samples

Omer Wagner¹, Moty Schultz^{2,3}, Reut Nuri⁴, Eli Slutskin^{2,3} and Zeev Zalevsky¹

1. Faculty of Engineering and the Nanotechnology center, Bar-Ilan University, Israel

2. Physics Department, Bar-Ilan University, Israel

3. Institute of Nanotechnology and Advanced Materials, Bar-Ilan University, Israel

4. Department of Structural Biology, The Weizmann Institute of Science, Israel

Previous work that employed linear-optics nanoscopy using optical tweezers achieved sub-200 nm resolution with a visible light, imaging gold nanowires and e-beam lithography samples. Yet, the ability to reach adequate imaging results with biological samples remains a challenge.

This work set to prove the method's compatibility with biological samples, and achieve super-resolution imaging, beyond the diffractive limit of an applicative sample.

Particle trapping is employed to scan a Mimivirus with 80nm gold nanoparticles. The combination of the light scattered by the sample and by the trapped particles encodes super-resolution information, which we decode by post image processing, with the trapped particle locations predetermined.

As the first proof of concept, scanning images using the method are shown and compared to a confocal scan. Improved performance is achieved with the fluorescence of the trapped particles employed.

Improving Micro-endoscopy Imaging Resolution through Scattering Media

Omer Wagner¹, Aditya Pandya², Irina Schelkanova², Asaf Shahmoon¹, Alexandre Douplik², and Zeev Zalevsky¹

1. Faculty of Engineering and the Nanotechnology center, Bar-Ilan University, Israel

2. Physics Department, Ryerson University, Canada

Imaging through scattering media is a very applicative field, especially for minimal invasive imaging where it may supply vast diagnostics capabilities.

Common micro endoscope configurations use gradient refractive index (GRIN) microlenses, which allow wide imaging range. However, the GRIN lens is limited by the mechanical rigidity, length and endoscopes diameter, which may prevent it to reach deep internal organs without damaging their functionality. A different micro endoscope configuration is based on multi core fiber. In this case, the imaging device consists of a few thousand and up to a few tens of thousands of step-index single mode cores which are incorporate together to perform the required imaging operation. Imaging can be done at a certain working distance above the surface at fast overlapping scans enlarging the region of interest. Still, special system design and dedicated image processing are needed in order to gain reliable imaging with high resolution from this kind of configuration.

In this work we use a specially fabricated micro endoscope multi core fiber having cores of 0.5 micron in size with 2 micrometer pitch between cores, to image samples that are located inside an environmental scattering media. We also present the image processing tools that were needed to image 50 μm in tissue channels (e.g. blood vessels) through a scattering media of up to 360 μm thick with scattering coefficient of $\mu_s' = 0.993 \text{ mm}^{-1}$.

Color Control through FRET Efficiency Modulation Using CDI

Karni Wolowelsky, Eric Guyes, Shimon Rubin, Matthew Suss, Moran Bercovici, and Carmel Rotschild

Faculty of Mechanical Engineering, Technion - Israel Institute of Technology, Israel

Although much progress was made in light emitting devices, the ability to electrically control their spectral emission remains limited. We will present a novel approach and experimental results for dynamic color control, by electrically modulating the non-radiative Forster resonance energy transfer (FRET) efficiency between donor and acceptor dyes in a solution. FRET efficiency depends on the 6th power of the distance between donor and acceptor dye molecules, and thus, it is sensitive to variations in acceptor's concentration. Controlled acceptor concentrations could be achieved by attracting or repelling ionic dyes from the electrodes using a capacitive deionization (CDI) cell, with high surface area porous electrodes. This approach to dynamic color control may open new directions in 100% fill-factor displays, and can be expanded to energy saving applications such as controlling building's external wall emissivity.

We studied the modulation of a single dye emission using a CDI cell with negatively charged Fluorescein Sodium Salt in aquatic solution. Photoluminescence was measured along few charging-discharging CDI cycles and showed the ability to control extensive optical response through CDI.

We experimented with two types of FRET-pair dyes: a) anion-cation, where the acceptor and the donor ions are oppositely charged, and b) zwitterion and ion, where the donor is neutrally charged. We found that electrical control on FRET in aquatic solution is weak due to hydrophobic attractive interaction between the acceptor and the donor. In order to avoid this effect, we are experimenting FRET control in organic solvents. These results will be presented in the talk.

Keywords: Forster resonance energy transfer(FRET), Capacitive deionization (CDI), Color control.

Wet Etching of Chalcogenide Glass Waveguides

Moshe Katzman¹, Mirit Hen¹, Dvir Munk¹, Yuri Kaganovskii², Michael Rosenbluh²
and Avi Zadok¹

1. Faculty of Engineering, Bar-Ilan University, Israel

2. Department of Physics, Bar-Ilan University, Israel

In recent years, optical communication systems are being required over ranges that continuously grow shorter: within racks, servers, boards and even intra-chip. These requirements are driving research in photonic integrated circuit (PIC), in which multiple optical components are realized on single chip. Chalcogenide glasses draw increasing interest in PIC applications, due to their high refractive index, pronounced nonlinearities, and broad portfolio of photo-sensitivity effects [1]. Waveguides are usually fabricated in chalcogenide glass films using reactive-ion dry etching processes [2], nano-imprinting lithography [3], and direct laser writing [4]. In this work we present the fabrication of fewmicron-wide waveguides using a simple, wet-etching process.

A 1 μm -thick film of As₂S₃ chalcogenide glass is deposited on a substrate of silica-on-silicon by thermal evaporation. Waveguide patterns are first defined in the chalcogenide glass layer using photo-lithography. Two lithographic platforms are successfully employed: a) the point-by-point scanning of the sample through a focused beam from a femto-second Ti:Sapphire laser at 810 nm wavelength; and b) the exposure of the sample to UV light through a photomask. Both processes induce photo-chemical changes to molecular bonds within the exposed regions. The first protocol relies on two-photon absorption of sub-bandgap irradiation, whereas the second involves single-photon absorption. Subsequent development of the exposed glass film in dicyclohexylamine (DCA) solution leads to the removal of the unexposed regions, and the definition of waveguides [5]. Atomic force microscope images reveal that the surfaces of waveguides are very smooth. Transmission of light at 1550 nm through the wet-etched waveguides will be presented.

References

- [1] B. Eggleton, B. Luther-Davies and K. Richardson, "Chalcogenide Photonics," Nat. Phot., vol. 5, pp. 141-148, 2011.
- [2] S. J. Madden et al., "Long, low loss etched As₂S₃ chalcogenide waveguides for all-optical signal regeneration," Opt. Express, vol. 15, no. 22, pp. 14414-14421, 2007.
- [3] T. Han, S. Madden, D. Bulla, and B. Luther-Davies, "Low loss Chalcogenide glass waveguides by thermal nano-imprint lithography," Opt. Express, vol. 18, no. 18, pp. 19286-19291, 2010.
- [4] A. Zoubir et al., "Direct femtosecond laser writing of waveguides in As₂S₃ thin films," Opt. Lett., vol. 29, no. 7, pp. 748-750, 2004.
- [5] C. M. Schwarz et al., "Processing and properties of arsenic trisulfide chalcogenide glasses for direct laser writing of 3D micro-structures," Proc. SPIE vol. 8974, pp. 1-11.

Topic: Electro-Optic Devices - Prof. Dan Marom

Dynamic of Electron-Photon Exchanges into VCSEL, Stability Optimization under Delayed Carrier-Photon Interaction in Time

Ofer Aluf

Private Engineer, Israel

Introduction: In this article, we discuss the dynamics of electron-photon exchanges into VCSEL, stability optimization under delayed carrier-photon interaction in time. Vertical-cavity surface-emitting lasers (VCSELs) employ current-blocking layers to funnel the current to the active region located between the mirrors of the laser.

Objectives: We analyze the behavior of VCSEL by using nonlinear dynamics. There are two main VCSEL's variables, Carrier density in the active region $N(t)$ and Photon density in the active region $S(t)$. Due to VCSEL active region parasitic effects, there is a time delay (t) of the carrier-photon interaction time. The VCSEL rate equations with delay parameter (t) of the carrier-photon interaction time are analyzed for stability switching under variation of (t) parameter.

Methods: We review the VCSEL structure, characteristics and inspect deeply the main variables and parameters. First is to write the VCSEL rate equations with delay parameter (t) of the carrier-photon interaction time. We combine graphical information with analytical work to effectively study the local stability of the VCSEL model involving delay dependent parameters.

t_n - Carrier recombination lifetime.

t_p - Photon lifetime.

G - Gain coefficient.

N_{tr} - Carrier's transparency number.

β - Spontaneous emission coupling coefficient.

ϵ - Gain compression factor.

I - VCSEL's injection current.

I_{off} - VCSEL's offset current.

Conclusions: The VCSEL active region has many parasitic effects which can be presented as a time delay (t) of the carrier-photon interaction time. We draw the map of possible values of the (t) parameter vs the stability by using criteria for local stability of the model involving delay dependent parameters.

Index Terms: VCSEL, Carrier, Photon, Fixed point, Stability, Delay Differential Equation (DDE).

References

- [1] Kuang, Y., 1993. Delay Differential Equations with Applications in Population Dynamics. Academic Press, Boston.
- [2] Beretta E., Kuang, Y., 2002. Geometric stability switch criteria in delay differential systems with delay dependent parameters. SIAM J. Math. Anal. 33, 1144-1165.

Cooper Pair Based Waveguide Amplifier Design for Enhanced Two-Photon Gain

Amit Bendel, Itay Russo, Krishna Balasubramanian, Alex Hayat

Electrical Engineering, Technion Institute of Technology, Israel

Introduction: Optically coupled superconductor and semiconductors are currently among the hottest investigation avenues for implementation of the quantum computers. Starting from enhanced emission in the semiconductor to the entangled photon-pair emission was predicted and experimental evidences are already being published. While, entangled photon pair sources are already reported, amplification of such emission and its dynamics when being singly or fully simulated is a very interesting and an open area.

Objective: Here we report on the design of the amplifier for effective interaction of stimulation light mode with the injected cooper pairs. Based on the design considerations, we have identified the best material combination and thickness ratio that could provide the best cooper-pair – optical mode overlap for the most efficient light amplification.

Background: Heterojunction semiconductor rib waveguides have been traditionally used for light amplification due to the charge confinement obtained by the quantum well and high spatial optical confinement provided by the ribs. The quantum well structure could also be engineered to improve recombination rates and optical linewidth. In order to inject efficiently the cooper pairs into the quantum well, the traditional LED stack was modified.

Results: The proposed stack now would be a thin superconducting material followed by a heavily n doped ($5 \times 10^{18}/\text{cm}^2$) region for better cooper pair injection. This was followed by the intrinsic InGaAs region as the active layer. The P doped InP layer at the bottom serves both as the substrate and the cladding. We have chosen InGaAs as the active region to align with the optical wavelength standards. For typical low temperature superconductors, the penetration depth in semiconductors are in the order of few 100s of nanometers and for high-T_c superconductors, this values drops down to about ~ 40 nm. Using Eigen mode simulations, it was identified that an active layer thickness of 200 nm and cladding thickness of 100 nm gave the maximum optical power overlap of 3.76%.

Keywords: Light Emission, Superconductors, Entangled Photons, Two Photon, WaveGuides, Quantum Computers

Wavelength Demultiplexer Operating over Mode Division Multiplexed Signals on Rectangular Fiber

Miri Blau and Dan M. Marom

Applied Physics Department, The Hebrew University, Israel

We introduce a wavelength demultiplexer operating with multimode waveguides of rectangular geometry matching rectangular fibers. This eliminates the spatial-spectral mixing at output waveguide coupling. Performance is stretched between the need to separate wavelengths and modes. We propose a multimode waveguide grating router (WGR) design with rectangular waveguides constrained to be single mode in one direction (width, defined in lithography) and multi-moded in height. This waveguide configuration matches the mode structure of rectangular core fibers, and allows for direct interface to this SDM fiber variant and realization of an SDM demultiplexer. By dispersing the signals in the WGR plane, where the mode structure is single mode, the coupling to the demultiplexed output waveguides is devoid of spatial structure which can lead to ill-shaped passbands and modal crosstalk. However, due to different mode propagation constants within the WGR, modal dependency still arises. We analyze this form of WGR demultiplexer, establish its performance bounds, and suggest realizations to make it feasible as a wavelength demultiplexer. The existence of multiple modes (which should be routed together) leads to mode-dependent-spatialshifts and as an outcome, to a significant reduction in resolution in standard WGR devices. We propose adjusting the FSR to overlap diffraction orders and generate noncontinuous demultiplexing. For example, for a waveguide supporting 3 spatial modes, if we increase the FSR to obtain two overlapping diffraction orders on the output plane, we can couple the light of the spectral channels using both diffraction orders. This way we don't use neighboring spectral channels and eliminate spectral and mode mixing. Our solution, based on noncontinuous demultiplexing, can lead the way to SDM-WDM devices on chip.

Semiconductor-Superconductor Bell-state Analyzer

Evyatar Sabag, Shlomi Bouscher, Raja Marjeh and Alex Hayat

Department of Electrical Engineering, Technion, Israel

Introduction: We propose a new and efficient method for performing Bell-state analysis which can have many applications in the field of quantum information.

Background: Bell-state analysis requires the use of non-linear effects. In addition, Superconducting optoelectronics is a developing field which can yield structures which enhance effects such as entangled-photon-pair generation and two-photon gain. We propose a device based on photon-pair detection through hole pair formation in a reversed-bias Quantum-Well (QW) based Avalanche Photo-Diode (APD) whose N-type layer is coupled to a superconducting contact. The QW removes Heavy(Light) Hole (HH/LH) degeneracy, thus resulting in a preferential detection of a specified pure Bell state. The other three Bell states are transparent to the QW-APD but can be converted into detectable form through a special optical scheme.

Objectives: Our objectives are first to demonstrate the theoretically feasibility of such a device followed by actual fabrication of the device and lab measurements. We have used perturbation theory to describe hole generation through photon absorption while taking into account parasitic effects such as short and long range disorder which results in small rates of single photon absorption in order to theoretically prove that such a device could work.

Results: Theoretical results have shown that Bell-state detection is possible through two-photon absorption which is at least two orders of magnitude stronger than parasitic one-photon absorption.

Conclusions: We have shown that the proposed semiconductor-superconductor device has significant potential as a practical Bell-state analyzer. The device was shown to have high detection purity with very little false readings for a vast range of photon energies, providing a reliable entangled-photon detector for quantum information applications.

Keywords: Bell-state, Nonlinear Optics, Quantum Optics, Electro Optic Devices, Superconductivity, Entanglement

Boosting the Intra Data Transport in Data Centers by Dynamic Electroholographic Circuit Switching

Sagi Frishman, Neta Rozen Schiff, David Hay, and Aharon J. Agranat Rachel and Selim Benin

School of Engineering and Computer Science, The Hebrew University of Jerusalem, Israel

Data centers (DCs) are critical components of today's cyberspace. As such they have to handle humongous data flows that travel into, out of, and predominantly within the DCs. It is already evident that the current technologies and architectures cannot be scaled up to handle the expected requirement for bandwidth.

Dynamic Electroholographic Circuit Switching (DECS) is a generic switching paradigm that was conceived specifically to relieve the bandwidth bottlenecks in DCs by providing direct interconnections between the DC racks. The DECS layer resides conceptually between circuit switching and packet switching and is interlaced with the existing hardware.

Specifically, DECS is an auxiliary network that provides WDM channels in a fiber cable loop that connects a large number of Top-of-the-Rack (ToR) switches across the DC. As such, DECS provides direct ad-hoc circuits between any pair of ToR switches, enabling to shift flows from the oversubscribed core of the DC network to the auxiliary high-bandwidth DECS network. DECS is used only to transmit flows that require high bandwidth.

The DC performance under DECS was evaluated through simulations, showing a dramatic improvement in performance. Our results show that a network equipped with DECS can handle significantly larger amount of traffic. Specifically, for today's medium-scale DCs, with typical load level of 18 GB/s, 20 circuits suffice to increase the goodput to 100%. Moreover, adding DECS circuits to the network significantly decreases average end-to-end delay incurred by the DC's traffic.

DECS requires for its implementation optoelectronic functionalities such as wavelength fast wavelength selective switching and fast wavelength tunability that are realized at the device level. These are not provided by the state of the art. We argue that these devices can be realized by employing electroholography, and we shall describe the roadmap for their realization based on recent experimental results.

A Novel Dispersion Model for Organic Materials to Accurately Simulate Optical Interactions

Nathaniel Mirilashvili and Dr. Rafi Shikler

Ben-Gurion University, Israel

Introduction: Production of renewable energy from the conversion of solar energy into electricity and in particular the usage of solar cells is an ever increasing research field. One of the promising candidates is the organic solar cell (OSC) that has excellent mechanical properties. The most efficient device is the Bulk-Heterojunction (BHJ) OSC, in which the active layer is a blend of two organic compounds. The optical properties of this blend need to be accurately modeled for the simulation of new and improved cell's architectures.

Background: The commonly used models to describe the dispersion relation of organic material are inaccurate and do not capture the behavior over the entire absorption spectra. Moreover, in the case of a blend the deviations are larger.

Objectives: We aspire to describe adequately the dispersion relation of both single organic compound and blend. We also would like to find a model that will enable easy and fast implementation of optical phenomena simulation within the cell.

Methods: We used three oscillators based on the Critical Point (CP) dispersion model, to describe the experimental results for every individual compound followed by six oscillators for the blend.

Results: The three and six CP models give an extremely accurate description to both individual and blend films, respectively. They consistently outperform all other models. The blend's CP oscillators have similar resonant frequencies as the individuals, but their width and phase changed. This can be interpreted as the effect of interactions between the two blend constituents. Another advantage is that the CP approach can be directly implemented in FDTD simulation.

Conclusions: This work shows that the dispersion relation of organic materials and blends can be accurately described by the CP model. Moreover, additional information about the interaction between the materials can be extracted. The FDTD implementation of the model is straight forward.

Keywords: Renewable Energy, Organic Solar Cell, Organic Photovoltaic, FDTD, Dispersion Model, Critical Point Model. Relevant Conferences' Track: Electro Optic Devices/Solar Energy.

Towards Super-resolved Imaging in Silicon based on Plasma Dispersion Effect

Hadar Pinhas

Bar-Ilan University, Israel

We present a new method for laser beam shaping, in silicon, based on plasma dispersion effect (PDE). We demonstrate the shaping of 1440nm laser beam passed through a silicon slab resonator. The shaping is done by a second laser beam at 532nm illuminating the slab simultaneously. The 532nm laser beam is absorbed on the surface of the silicon slab while generating in it concentration of free carriers which block the 1440nm beam. We propose this method to overcome the diffraction resolution limit in silicon in approach similar to stimulated emission depletion (STED) scanning fluorescence microscopy.

Real-time Implementation of Video Restoration Modules in Case of Atmospheric Degradation

Nadav Raichman

IAI (Israel Aerospace Industries), Israel

Long range imaging is often degraded by several kinds of atmospheric effects. The main effects are turbulent motion, reduced contrast and increased image blur, and these effects become more pronounced as the imaging distance increases. Several algorithmic tools in the field of video processing are well known for handling each effect independently. However, for real-time implementation of these algorithms there are several limitations that must be considered, such as reliability, low-latency and computational capability.

In this work I will present a set of video processing modules which were designed to mitigate the atmospheric effects described above and optimized to work in real time as a set. The resulting software can run on a standard PC and the full set of modules can operate with a latency of less than one frame. The software allows the user to control the parameters of the modules in real time.

The implementation process involved developing general models in Matlab, which were then converted into exact reference Matlab models and transferred to a software engineer. The software was then optimized using several standard tools.

Keywords: Electro-optics devices, atmospheric degradation, turbulence, blur

Comparing Rectangular and Circular Fiber Core Geometries for Mode Division Multiplexing

Lior Rechtman and Dan M. Marom

Hebrew University of Jerusalem, Israel

Higher capacity optical transport networks based on space division multiplexing (SDM) using few-mode fiber (FMF) offers the highest, easily managed spatial information density. In such fibers, matched phase velocities of degenerate modes, hence belonging to the same mode group, tend to strongly intermix as distributed perturbations are phase matched, requiring the reception of all the mixed channels followed by signal processing to unravel the information. Attempts to break the modal degeneracy by unconventional core geometries such as elliptical or annular (modes are encoded azimuthally) have been demonstrated.

We investigate an alternative fiber form in support of SDM with a rectangular core fiber (RCF) geometry which supports a single mode along the rectangle's height, and multiple modes along the rectangle's width. RCF has mode groups of two polarizations, which are regularly placed, reducing mode mixing, and facilitating planar device integration.

We compared a circular core fiber (CCF) and RCF, by numerically simulating the two geometries using a mode solver based on Comsol Multiphysics for spatial and propagation profiles of the modes. We used same material properties for both fibers, in step and parabolic index profiles. The two fibers were dimensioned to support six modes, for equal capacity. With the step index profile we found that CCF effective modes indices spanned a wider range while in the case of parabolic profile the CCF's LP_{21} and LP_{02} modes converge, and RCF achieves extremely uniform spacing. Overall, parabolic profile group indices shows lower differential modal spread for transmitted signals. We further analyzed offset coupling, finding RCF offsets trigger crosstalk only along the long axis, whereas the IL is even and low along the short axis, and is tolerant to rotation errors. These features indicate RCF may be suitable for short range interconnectivity.

Design and Analysis of a Square Spiral Nano-Rectenna for Infrared Energy Harvest and Conversion

Kai Wang^{1,2}, Lingju Guo¹, Dror Fixler³, Adi Salomon³, and Tao He^{*1,2}

1. CAS Key Laboratory of Nanosystem and Hierarchical Fabrication, CAS Center for Excellence in Nanoscience, National Center for Nanoscience and Technology, China

2. University of Chinese Academy of Sciences, China

3. Bar-Ilan University, Israel

Nano-rectennas, as one of the new nano devices, have been used as infrared (IR) detectors, novel solar cells, optoelectronic devices, near-field imaging, and biochemical sensors. A nano-rectenna is comprised of an optical nanoantenna and a metal-insulator-metal (MIM) diode. Under illumination of visible and IR light, a tremendous electric field (hot spot) can be generated at the feed point of the metallic nanoantenna due to surface plasmon resonance, meanwhile alternating current (AC) will be induced on the antenna surface. Moreover, the MIM diode embedded in the nanoantenna is used to rectify the AC oscillations to DC power based on the asymmetric of the tunnel junction. In this work, we have designed a nano-rectenna composed of a square spiral nanoantenna and an Au-TiO_x-Ti diode rectifier for IR energy harvest and conversion. To analyze the optoelectronic properties of the target nano-rectenna, three-dimensional frequency-domain electromagnetic field calculation software based on the finite element method is used at IR frequencies (5~30 μm). The simulation results indicate that three types of resonance wavelengths and local field enhancement are significantly influenced by the geometric parameters of the square spiral nanoantenna, as well as the structure and composition of the dielectric layer. The output current of the designed nano-rectenna can reach approximately at tens of nA with an incident electric field intensity of 1 V/m. In addition, photoelectric conversion efficiency is calculated to be about several percentages. The related mechanism has been thoroughly discussed. All the simulation results can be confirmed in experiment through fabricating the optimized device. We envision that the proposed structure may lead to applications in the fields like IR detectors and integrated photonic circuits, especially our future research in plasmonics photocatalysis by the cooperation with the groups of Dror Fixler and Adi Salomon in Bar-Ilan University.

Topic: Electro Optics in Industry - Dr. Michael Berger

Challenges and Potential Solutions for Detecting Toxic Gases With Uv Based Open-Path System

Yossi Ben-Adert

Spectroinx (Emerson), Israel

Introduction: Release of toxic gas is a significant contributor to risk in the oil and gas industry and various types of detection methods for rapid detection of gas are therefore installed for elimination or reduction of the dangerous releases.

Background: Open Path Gas Detectors are commonly used today to identify combustible gas accumulations or monitor gas cloud migrations but the detection of toxic gas like Hydrogen Sulfide (H_2S) or Ammonia (NH_3) require higher sensitivity. And this is because exposure to very low concentrations of toxic gases are unsafe for humans to breathe, doses typically of part per million (ppm).

Objectives: In this article we will discuss the challenges and solution in developing Open Path gas technology that will detect toxic gases in concentration levels of down to 50ppm/M.

Methods: In this optical detect approach the signal is absorbed by the gas while it passes through the detector's optical path. Based on the UV observation spectrum band in UV band, the toxic gases have characteristically a strong absorption in the solar blind range of 189–230 nm. The open path gas detector includes two main units, a transmitter broadband flash light source and a receiver. The receiver includes two sensors; one is to acquire the reference signal and the other for the response signal which is absorbed by the gas.

Results: The Open Path Gas Detectors operating in the UV coverage of long range over paths of up to 50m and fence line monitoring of Toxic gases H_2S and Aromatic J, coverage of low concentration 0–500ppm m. the detectors are reliable and have fast response time <10sec.

Conclusions: Open path gas detection method that is based on the UV absorption spectrum is superior to traditional detection methods (for example, chemical reactions) in terms of accuracy, speed, and even security. They are especially suited for harsh and hazardous environments applications.

Keywords: Open Path Gas Detectors, Toxic gases, UV absorption, DOAS

Methods for Applying Anti-reflective Coatings on Sapphire for Ultra-high Temperatures

Evyatar Kassis, Gal Reich, Shay Joseph, Doron Yadlovker, Arit Shienmann

Rafael - Optical Components Center, Israel

Sapphire is the strongest optical material suitable for use at elevated temperatures, as high as 900°C. In most cases, optical coatings, based on transparent thin films which cause destructive interference of the reflected radiation, are applied in order to reduce the surface reflection of sapphire which is about 8%. At elevated temperatures, coatings are not expected to last, mainly due to thermal stress. Reducing surface reflectance can also be realized by sub wavelength structures (SWS) which create a zone near the surface with an effective index of refraction that is an average of the air gaps in between the structures and the structures themselves. The reflectance will be governed by the ratio between structures and gaps and their depth. Since the structures are an integral part of the surface, there exist no issues of thermal stress or any typical coating issues such as environmental durability.

Methods based on SWS were used in order to create anti-reflective properties. The periodicity of the structures was about 200nm. The SWS were created by Deep Reactive Ion Etching (DRIE). Due to the very small features required, photolithography or direct laser lithography were ruled out as an option and other techniques were examined: (i) Electron Beam (EB) Lithography. This method can be used to create well defined structures although the time required for writing an area of 1mm² is approx. 4 hours, making this method impractical for manufacturing. (ii) Nano Imprint Lithography (NILT). This method is based on producing a stamp with the reciprocal structure required on the part using conventional expensive lithography techniques. Once the stamp has been produced, it can be used repeatedly to stamp a resist film applied on the surface of the part and then cure it using either UV or heat thus allowing the formation of structures without the tedious steps of conventional lithography.

The different methods are discussed and the results presented. All samples were subjected to rigorous environmental testing and a temperature exposure for 10 minutes at 900°C. Following the tests, the optical transmission was measured and compared to that before the tests. It was found that there was hardly any transmission loss at 1064nm.

Keywords: Sapphire, anti-reflection coating, sub-wavelength structures, ultra-high temperatures

High Power LED illumination for Defect Detection on Advanced Packaging Modules

Ofer Zaharan

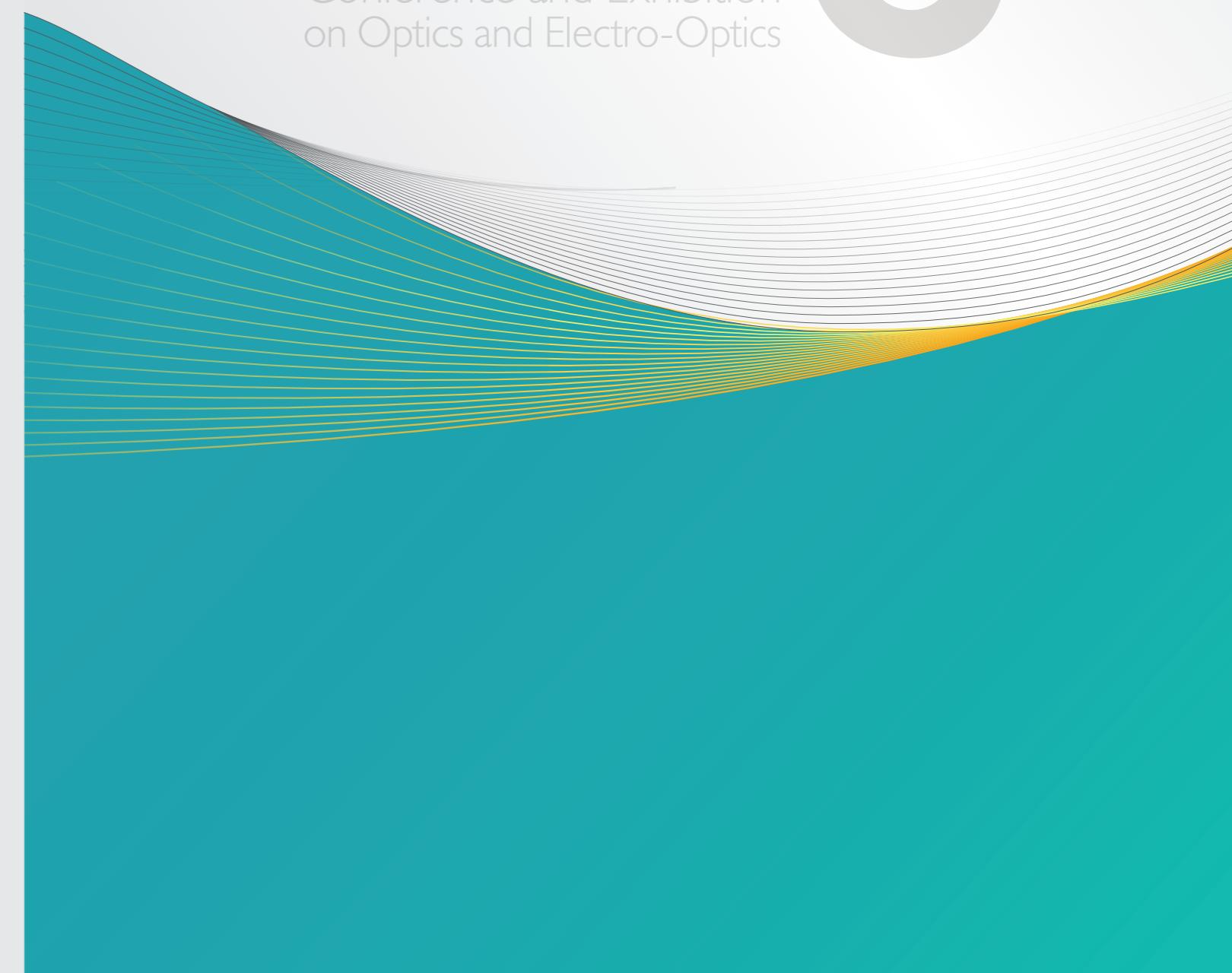
Camtek, Israel

Automated optical inspection requires high volume acquisition of images of a target substrate/ wafer which are then digitally processed and analyzed to pinpoint irregularities which constitute a defect in wafer manufacturing process. To achieve this inspection, one implements high frame rate cameras with a bright illumination short pulse duration source.

Typically these sources would be gas discharge lamps which produce short bright light pulses. However the pulse shape, duration and intensity are poorly controlled due to the underlying physics of the discharge process. In addition , the lamps intensity varies with time and its lifetimes are short.

We describe our use of LED devices as illumination sources for detection systems. The intensity, width and duration of the pulse which much better controlled than a discharge lamp. Consequently image sharpness, smearing, symmetry and brightness are superbly controlled and hence the defect detection algorithms produce higher reliable detection ratios.

Comparison of detection with various illumination methods is presented showing increased detection with LED illumination sources.



Organization and Production by:

KALEIDOSCOPE

Conferences | Events | Multimedia

96 Usishkin St., Tel-Aviv, 6203105

Tel. 972-3-5445015 | Fax. 972-3-6048473 | www.kld.ltd