Laser Sources and Applications

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Double clad Yb-doped fiber laser of up to 10 W output power is used in the experiment. Scanning Fabry-Perot interferometer with resolution down to 1.2 pm is applied for accurate spectral measurements. At power level less then 1 W a self-sustained pulsation regime accompanied by a narrow-line self-sweeping is observed. At higher power a quasi-CW generation regime with multiple longitudinal modes is established. Investigation of the regime shows linear increase of the generation width with generation power growth. Slope of the dependence has excellent agreement with the theory, but an additive quantity should be added to describe an absolute value that makes significant contribution at low powers. It has been shown that at low powers a spatial hole burning has to be considered. Theoretical model describing the hole burning effect for multimode cw generation is also developed. After inclusion of the hole burning effect the model starts to agree quantitatively with the linewidth measurements both at low and high powers.

Dual-wavelength operation of continuous-wave and mode-locked erbium-doped fiber lasers
Author(s): O. Pottiez; A. Martinez-Rios; D. Monzon-Hernandez; B. Ibarra-Escamilla; E. A. Kuzin; J. C. Hernandez-Garcia
We study numerically and experimentally multiple-wavelength operation of an erbium-doped figure-eight fiber laser including a multiple-bandpass optical filter formed by two concatenated fiber tapers. Both continuous-wave and pulsed operations are considered. In the continuous-wave regime, stable long-term operation at multiple closely spaced wavelengths is only obtained if fine adjustments of the cavity losses are performed. Under these conditions, simultaneous lasing at up to four wavelengths separated by 1.5 nm was observed experimentally. Tunable single-wavelength operation over more than 20 nm is also observed in the continuous-wave regime. In the passive mode locking regime, numerical simulations indicate that mechanisms involving the filter losses and the nonlinear transmission characteristic of the NOLM contribute in principle to stabilize dual-wavelength operation, allowing less demanding cavity loss adjustments. In this regime, the problem of synchronization between the pulse trains generated at each wavelength adds an additional dimension to the problem. In presence of cavity dispersion, the pulses at each wavelength tend to be asynchronous if the wavelength separation is large, however they can be synchronous in the case of closely spaced wavelengths, if cross-phase modulation is able to compensate for the dispersion-induced walkoff. Experimentally, fundamental and 2nd-order harmonic mode locking was observed, characterized by the generation of noise-like pulses. Finally, a regime of multi-wavelength passive Q-switching was also observed. We believe that this work will be helpful to guide the design of multiple-wavelength fiber laser sources, which are attractive for a wide range of applications including Wavelength Division Multiplexing transmissions, signal processing and sensing.

High-performance wavelength tuning of a mid-infrared solid-state laser using a resonant diffraction grating
Author(s): N. Vermeulen; P. Wasylczyk; S. Tonchev; P. Muys; H. Ottevaere; O. Parriaux; H. Thienpont
We report the first demonstration of laser wavelength tuning with a resonant grating in the mid-infrared spectral domain and with Littrow mounting of the grating. We show for a mid-infrared Cr:ZnSe solid-state laser that this tuning technique is much more wavelength selective than prism-based tuning, while inducing significantly lower cavity losses than in the case of a standard metal-coated grating. Furthermore, the resonant grating allows tuning the Cr:ZnSe laser over as much as 400 nm around a center wavelength of 2.38 μm. This shows the potential of employing Littrow-mounted resonant diffraction gratings for controlling and tuning the emission wavelength of lasers emitting in the mid-infrared spectral domain and other wavelength regions.

Compact and efficient Cr:LiSAF laser pumped by one low-cost single-spatial-mode diode
Author(s): Umit Demirbas; Stefan Eggert; Alfred Leitenstorfer
We present a minimal-cost Cr:LiSAF laser that is pumped by one single-spatial-mode diode. The pumping system (diode, diode driver, and the diode holder) has a total cost of about $500 and provided 130 mW of diffraction-limited pump power around 660 nm. The entire Cr:LiSAF laser system has an estimated total material cost below $5k, a footprint of about 20 cm × 35 cm, does not require cooling and can be driven by batteries, making the system ideal for applications that require portability. In continuous wave (cw) laser experiments, we have demonstrated lasing thresholds as low as 2 mW, slope efficiencies as high as 52%, output powers up to 58 mW, and a record tuning range extending from 780 nm to 1110 nm. In cw mode-

locked operation, using a 0.5% output coupler, 100-fs pulses with an average power of 38 mW, and with an optical spectrum centered around 865 nm have been obtained at a repetition rate of 235 MHz. With a more compact cavity and using a 0.1% output coupler, 70-fs pulses with an average power of 20 mW have been obtained at a repetition rate of 509 MHz. We believe that this portable, minimal cost Cr:LiSAF laser system might be an attractive source for applications like amplifier seeding that do not require high average output power levels.

Self-induced laser line sweeping and self-pulsing in double-clad fiber lasers in Fabry-Perot and unidirectional ring cavities

Author(s): Pavel Peterka; Petr Navrátil; Bernard Dussardier; Radan Slavík; Pavel Honzátko; Václav Kubecek

Rare-earth doped fiber lasers are subject to instabilities and various self-pulsed regimes that can lead to catastrophic damage of their components. An interesting self-pulsing regime accompanied with laser wavelength drift with time is the so called self-induced laser line sweeping (SLLS). Despite the early observations of the SLLS in solid-state ruby lasers, in fiber lasers it was first time mentioned in literature only in 2009 where such a laser wavelength drift with time was observed in a relatively broad range of about 1076 -1084 nm in ring ytterbium-doped fiber laser (YDFL). The main characteristic of the SLLS is the scanning of the laser wavelength from shorter to longer wavelength, spanning over large interval of several nanometers, and instantaneous bounce backward. The period of this sweeping is usually quite long, of the order of seconds. This spectacular effect was attributed to spatial-hole burning caused by standing-wave in the laser cavity. In this paper we present experimental investigation of the SLLS in YDFLs in Fabry-Perot cavity and ring cavities. The SLLS was observed also in erbium-doped fiber laser around 1560 nm. We present for the first time observation of the laser wavelength sweep in reverse direction, i.e., from longer towards shorter wavelengths. It was observed in YDFL around 1080 nm.

Study of tunable resonances in laser beam divergence and beam deflection

Author(s): A. Koházi-Kis; J. Klebniczki; M. Görbe; P. Nagy

New, fundamental resonant properties of laser resonators are theoretically predicted and experimentally demonstrated. These resonances occur either in the time dependence of the beam width and that of beam radius of curvature of the wavefront or in the time dependent pointing and position stability of the output light beam of a laser resonator. The resonant frequency can be tuned continuously from zero to the round-trip frequency in the first case; and from zero to the half of the round-trip frequency in the second case, by for example, moving one of the mirrors of the resonator. In both cases besides a resonant frequency its complementary frequency to the round-trip frequency is also resonant, and their shifted frequencies by multiples of the round-trip frequency are also resonant. In our experimental demonstration we measured the radiofrequency noise spectrum of the output laser beam, that was partially blocked by a knife-edge. We observed increased noise at the theoretically predicted frequencies. Similar resonances are predicted either in the time dependent pulse-width and phase modulation or time jitter and the central frequency of the ultrashort light pulses of the node-locked lasers because of the analogy between the space description of the light beams and the time-description of the light pulses.

High-efficiency Q-switched and diffraction-limited Nd:YLF side-pumped laser

Author(s): Alessandro M. Deana; Niklaus U. Wetter

This work presents a mode-controlled quasi-CW resonator design based on an Nd:YLF crystal. Up to 47% optical efficiency was obtained and, by passively Q-switching the laser, 209 kW of peak power at 1053 nm was obtained. The new resonator design is capable of delivering 2.3 mJ and 11 ns pulses in a very compact, simple and lightweight set-up.

Current confinement in EP-VECSELs for high power single-mode operation suitable for passive mode-locking

Author(s): Imad Dahhan; Yohan Barbarin; Martin Hoffmann; Wolfgang P. Pallmann; Christian Zaugg; Matthias Golling; Thomas Südmeyer; Ursula Keller; Bernd Witzigmann

One of the main advantages of using VECSEL lasers for mode-locked operation is their power scalability. Best performance data available for mode-locked semiconductor lasers have been achieved with optically

pumped VECSELs, reaching pulses in the femtosecond regime and average powers in the watt regime.1 This advantage is challenging for electrically pumped VECSELs, where a homogeneous carrier injection into the center must be provided in order to maintain a single-mode operation for large diameter devices. In this paper we investigate the current injection from the bottom contact of a VECSEL design, and estimate the leakage of the hole current. Then we introduce two designs that can reduce the leakage current and enhance the injection into the center of the device, thereby increasing the simulated output power by more than 20% in CW-mode while maintaining an optimal gain profile suitable for single-mode operation.

Femtosecond Cr:Colquiriite lasers pumped by a single tapered diode laser
Author(s): Umit Demirbas; Michael Schmalz; Bernd Sumpf; Götz Erbert; Gale S. Petrich; Leslie A. Kolodziejski; James G. Fujimoto; Franz X. Kärtner; Alfred Leitenstorfer
Ti:Sapphire lasers could provide tunable femtosecond pulses in the 680-1180 nm region; however, due to the requirement of expensive green pump sources, its current cost sets a barrier to its widespread adoption. As an alternative, Cr :Colquiriites (Cr:LiCAF, Cr:LiSAF, Cr:LiSGaF) also possess broad gain bandwidths and their total cw tuning range cover the 720-1110 nm region. Moreover, their broad absorption bands around 650 nm enable direct diode pumping by low-cost red laser diodes. However, so far the limited brightness of red diodes required combination of four to six pump diodes to reach reasonable output power levels from Cr :Colquiriites. This complex pumping geometry increases cost and causes stability issues in long-term operation. In this study, we report compact, low-cost and efficient Cr:Colquiriite lasers pumped by a single 1.2 W tapered laser diode at 675 nm. In continuous wave laser operation, output powers of 500 mW and 410 mW together with slope efficiencies of 47% and 41% were demonstrated from Cr:LiSAF and Cr:LiCAF, respectively. In cw mode-locked operation, sub-100-fs pulse trains with average power between 200 mW and 250 mW were obtained at repetitions rates around 100 MHz. These results indicate that tapered diodes in the red spectral region are likely to become the standard pump source for Cr:Colquiriite lasers in the near future. Moreover, the simplified pumping scheme might facilitate efficient commercialization of these low-cost systems, bearing the potential to significantly boost applications of cw and femtosecond lasers in this spectral region.

Efficient high-power narrow-linewidth all-fibred linearly polarized ytterbium laser source
Author(s): Anthony Bertrand; Flavien Liégeois; Yves Hernandez; Domenico Giannone
We report on experimental results on a high power, all-fibred, linearly polarized, mode-locked laser at 1.03 μm. The laser generates pulses of 40 ps wide at a repetition rate of 52 MHz, exhibiting 12 kW peak power. Dispersion in optical fibres is controlled to obtain both high power and narrow spectral linewidth. The average output power reached is 25 W with a spectral linewidth of 380 pm and a near diffraction limit beam ($M2 < 1.2$). This laser is an ideal candidate for applications like IR spectroscopy, where high peak power and narrow linewidth are required for subsequent wavelength conversion.

Optically-induced switching between mode-locked and unmode-locked continuous wave regimes of a femtosecond Cr4+:forsterite laser
Author(s): D. A. Walsh; C. E. Crombie; W. Sibbett; C. T. A. Brown; V. G. Savitski; D. Burns; S. Calvez
The ability to control the temporal output from a femtosecond laser can enable the same laser to be used for multiple functions, for example, the laser used in an optical tweezers system could be used as a constant-intensity source to trap a biological cell and then be temporarily switched to mode-locked operation to effect photoporation. Here, we report the rapid switching of a Cr4+:forsterite laser between mode-locked and unmode-locked continuous wave (CW) regimes via the optical pumping of an intracavity SESAM element. Mode-locking of the laser was initiated by an intracavity quantum well (GaInAsN) SESAM having an anti-resonant design ($\Delta R \sim 0.3\%$, $\lambda PL \sim 1310nm$) that yielded transform-limited 89fs pulses centered around 1296nm with a repetition rate of 162MHz at an average power of 64mW. Upon excitation of the SESAM with 600mW of extra-cavity power from an 808nm semiconductor diode laser, switching could be induced between the unmode-locked and mode-locked regimes. Transitions free of Q-switching or relaxation oscillations were observed with <200μs switching times for both for the initiation and cessation of mode-locking. Periods of mode-locked operation of custom duration could be produced by appropriate control of the SESAM pump diode enabling the generation of bursts of pulses as short as 400μs. Switching was

confirmed to originate from local pump-induced heating of the SESAM by observing the laser going through identical regime switching when the chip temperature of the 'unpumped' SESAM was raised by ~20°C.

Mode-locked femtosecond all PM Yb fiber laser delivering linearly chirped pulses
Author(s): Claude Aguergaray; Neil G. R. Broderick; Miro Erkintalo; Jocelyn S. Y. Chen; Vladimir Kruglov
We report on a new design for a passively mode locked bre laser employing all normal dispersion polarisation maintaining bres operating at 1 μm. The laser produces linearly polarized, linearly chirped pulses that can be recompressed down to 344 fs. Compared to previous laser designs the cavity is mode-locked using a nonlinear amplifying bre loop mirror that provides an additional degree of freedom allowing easy control over the pulse parameters. This is a robust laser design with excellent reliability and lifetime.

Medium-gain erbium doped fiber amplifier ring laser passively mode-locked by graphite nano-powder adhered thin PVA film
Author(s): Yung-Hsiang Lin; Gong-Ru Lin
A direct brushing process of graphite nano-powder adhered on the single-mode fiber end-face with the use of an ultrathin PVA film is demonstrated, such a graphite nano-powder adhered ultra-thin PVA film is introduced to passively mode-lock a medium-gain Erbium-doped fiber laser (EDFL). The structural property of the graphite nano-powder is investigated by Raman spectroscopy. Numerous structural defects induced when abrading the graphite into nano-powder are found to broaden the 2D band Raman scattered signal and attenuate its peak intensity. The graphite nano-powders exhibit the featureless transmittance to show the potential as being a broadband tuning saturable absorber. In addition, the modulation depth of 0.43 is comparable with the graphene saturable absorber. The central wavelength of the passively mode-locked medium-gain EDFL is at 1561.2 nm with the full width at half maximum (FHWM) of 1.62 nm, and the pulsewidth is 1.58 ps. Under the limited intra-cavity power of 18 dBm, a nearly transform-limited passively mode-locking EDFL with TBP of 0.32 is generated.

Top-hat beam output from a large mode area microstructured fiber for beam delivery
Author(s): Pierre Calvet; Constance Valentin; Yves Quiquempois; Géraud Bouwmans; Laurent Bigot; Marc Douay; Arnaud Mussot; Emmanuel Hugonnot
We present a new passive air/silica microstructured optical fiber designed to be single mode and which delivers a flat-top intensity profile at 1 μm. By inclusion of a raised index ring surrounding the central core, the refractive index profile of the fiber flattens the intensity distribution of the fundamental mode. Experimental results clearly demonstrate the feasibility of all-fibered top-hat beam delivery systems with one spatial mode suitable for many applications.

Applying refractive beam shapers for spectral beam combining with volume Bragg gratings
Author(s): Alexander Laskin; Derrek Drachenberg; Sergiy Mokhov; George Venus; Leonid Glebov; Vadim Laskin
The technique of combining the laser beams with proximate wavelengths by a train of volume Bragg gratings operating as narrow band spectral mirrors allows reaching extremely high resulting power. Performance of these volume Bragg gratings in terms of reflectivity, stability of spectral characteristics depends on their temperature, especially on the temperature profile being a result of interaction of the incident or passing through radiation of powerful laser with material of the grating. The most dangerous effect of thermal lensing appears as a result of heating by laser radiation. The temperature profile in a grating is determined by the intensity profile of a laser beam applied, conditions of thermal conductivity, and energy exchange with environment. The Gaussian intensity distribution in typical laser beams leads to higher temperature in the central part of a grating and, hence, causes nonuniform shift of Bragg wavelength across the aperture and thermal lensing. Homogenizing of the temperature profile over the working field of a volume Bragg grating would mitigate radial gradient of temperature and increase brightness of a combined beam. This can be realized through applying the beam shaping optics, for example refractive field mapping beam shapers. They provide high flexibility in building various optical setups due to their unique features: almost lossless intensity profile transformation, providing flattop, super-Gauss or inverse Gauss profiles. Different profile shapes can be achieved with the same beam shaper, saving of the beam consistency, high transmittance and flatness of intensity profile, extended depth of field, capability to adapt to real intensity

profiles of TEM00 and multimode laser sources. Combining of the refractive field mapping beam shapers with other optical components, like beam-expanders, relay imaging lenses, anamorphic optics makes it possible to generate the laser spots of necessary shape, size and intensity distribution. This paper describes a comparison of quality (M2) of Gaussian and super-Gaussian beams diffracted and transmitted by reflecting volume Bragg gratings used for spectral beam combining. Both, mathematical modelling of thermal lensing and experimental results with high density spectral beam combining of 150 W laser beams are described. It was found that the use of super-Gaussian beams results in smaller gradient of temperature across the aperture and, therefore, smaller thermal lensing.

Low speckle line generation using a semiconductor laser source
Author(s): Gordon Craggs; Youri Meuret; Jan Danckaert; Guy Verschaffelt
In this contribution we show that we can design a low speckle line generator based on the reduced spatial coherence of a broad-area vertical-cavity surface-emitting laser (BA-VCSEL). This type of semiconductor laser can be driven into a special operation regime, a regime of low spatial coherence, which has already been shown to have a speckle reducing eect for image projection applications. However, the eectiveness of reducing speckle strongly depends on the line generating optics. Therefore we compare dierent line generating optical systems on their potential to use spatially incoherent laser emission for speckle reduction. These systems are: a single cylindrical lens, a tandem cylindrical lens array or a diuser based line generator. We also compare these results with the speckle occurring if we replace the partial spatially coherent VCSEL with a single mode laser or with a multi-mode VCSEL. We nally draw conclusions on the design of the most optimal optical system. The results of our study are also valid for other sources of partial spatially coherent emission.

Beam shaping in high-power laser systems with using refractive beam shapers
Author(s): Alexander Laskin; Vadim Laskin
Beam Shaping of the spatial (transverse) profile of laser beams is highly desirable by building optical systems of high-power lasers as well in various applications with these lasers. Pumping of the crystals of Ti:Sapphire lasers by the laser radiation with uniform (flattop) intensity profile improves performance of these ultrashort pulse high-power lasers in terms of achievable efficiency, peak-power and stability, output beam profile. Specifications of the solid-state lasers built according to MOPA configuration can be also improved when radiation of the master oscillator is homogenized and then is amplified by the power amplifier. Features of building these high power lasers require that a beam shaping solution should be capable to work with single mode and multimode beams, provide flattop and super-Gauss intensity distributions, the consistency and divergence of a beam after the intensity re-distribution should be conserved and low absorption provided. These specific conditions are perfectly fulfilled by the refractive field mapping beam shapers due to their unique features: almost lossless intensity profile transformation, low output divergence, high transmittance and flatness of output beam profile, extended depth of field, adaptability to real intensity profiles of TEM00 and multimode laser sources. Combining of the refractive field mapping beam shapers with other optical components, like beam-expanders, relay imaging lenses, anamorphic optics makes it possible to generate the laser spots of necessary shape, size and intensity distribution. There are plenty of applications of high-power lasers where beam shaping bring benefits: irradiating photocathode of Free Electron Lasers (FEL), material ablation, micromachining, annealing in display making techniques, cladding, heat treating and others. This paper will describe some design basics of refractive beam shapers of the field mapping type, with emphasis on the features important for building and applications of high-power laser sources. There will be presented results of applying the refractive beam shapers in real installations.

Development of a laser-based process chain for manufacturing free form optics
Author(s): S. Heidrich; A. Richmann; E. Willenborg
This paper presents the development of a laser based process chain for manufacturing fused silica optics. Due to disadvantages of conventional methods concerning costs and time when manufacturing optics with nonspherical shape, this process chain focuses on aspherical and free form surface geometries, but it is also capable of producing spherical optics. It consists of three laser based processing steps, which in combination produce the optics. In a first step, fused silica is ablated with laser radiation to produce the geometry of the

optics. A subsequent laser polishing step reduces the surface roughness and a third step uses laser micro ablation to remove the last remaining redundant material. Most of the conducted experiments are carried out using CO2 laser radiation, but it is also possible to ablate material with ultra short pulse laser radiation. Besides describing the experimental setup and the mechanisms of the ablation and polishing step, the paper presents and discusses results achieved to date. Although the process chain is still under development, the single process steps already reach promising results for themselves and moreover, first elements are manufactured using the first two process steps together.

Laser processing of GaN-based LEDs with ultraviolet picosecond laser pulses
Author(s): Rüdiger Moser; Michael Kunzer; Christian Goßler; Ralf Schmidt; Klaus Köhler; Wilfried Pletschen; Ulrich T. Schwarz; Joachim Wagner
Picosecond (ps) lasers provide a universal tool for material processing. Due to the short pulse length material is removed by a process called "cold ablation", with minimal thermal damage to neighbouring regions. As a result, better defined structures with smother and cleaner side walls can be fabricated than with nanosecond (ns) laser pulses. This offers new possibilities for laser processing in semiconductor technology for both semiconductor materials as well as contact and bond metallizations. The fabrication of optoelectronic devices such as light-emitting diodes (LEDs) typically involves photolithography steps, requiring specific lithography masks be fabricated which, in particular for prototyping, is expensive and time consuming. Therefore it would be attractive for a range of applications to replace these steps by direct writing techniques such as laser processing, which will speed up e.g. the development and prototyping of new devices. We report on fully laser processed planar GaN-based LEDs fabricated without any photolithography steps. On the bare semiconductor wafer, isolation trenches and mesa structures are formed directly by ultraviolet ps laser pulses. For the direct deposition of patterned ohmic contact metallizations, the ps laser fabrication and subsequent use of high resolution shadow masks is presented, which exhibit a significantly reduced sidewall roughness compared to masks produced by ns laser pulses. Due to the higher precision of the laser defined masks it becomes possible to deposit multiple layers, through the use of alignment marks, similar to multiple mask level photolithography. Finally, the ps laser processed LEDs are electrically and optically characterized and their characteristic compared with that of conventionally fabricated mesa LEDs.

Investigations of the temperature regimes of the selective laser melting
Author(s): Yu. Chivel
The principles of measuring the surface temperature of powder bed in the focal spot of the laser radiation while scanning the surface using galvoscanner with F-teta lens have been elaborated. Investigation of the melting of overhang layers has been conducted under full temperature monitoring. Temperature regimes of the selective laser melting process of the 3D object from steel 316L powder have been investigated.

Monitoring of the protective glass during laser cladding with active fiber laser
Author(s): Bruno Valsecchi; Barbara Previtali
This paper deals with the monitoring of the protective glass in a laser cladding head specifically designed for high power active fiber laser beams. The available high power density that can be focused on the workpiece surface is not only one of the most well known positive features of the fiber laser sources but becomes a very critical thermal load acting on the optical elements of the cladding head, in particular in dirty processes such as the laser cladding. The cladding powder indeed coming from the powder cone is likely to interact with the optical elements of the cladding head. As a result the optical elements become locally opaque and absorb the laser beam, with consequent thermal deformation, coating damage and lens breakage. The protective glass, that divides the focusing and collimation lenses from the dirty work area, has the fundamental role to protect the entire optical chains and represents the element whose life has to be continuously monitored in order to avoid unexpected and unpleasant lens damages. The paper presents the study of a monitoring device aimed at monitoring the life of the protective glass making use of the scattered light from the protective glass. The developed monitoring device is able to recognize both small (i.e. cracks) and big defects (i.e. diffuse opacity) on the surface of the protective glass. In order to test the developed monitoring system a real industrial case is investigated making use of a new prototypal laser head assisted by the monitoring device.

Laser transmission welding of Acrylonitrile-Butadiene-Styrene (ABS) using a tailored high power diode-laser optical fiber coupled system

Author(s): E. Rodríguez-Vidal; I. Quintana; J. Etxarri; D. Otaduy; F. González; F. Moreno

Laser transmission welding (LTW) of polymers is a direct bonding technique which is already used in different industrial applications sectors such as automobile, microfluidic, electronic and biomedicine. This technique offers several advantages over conventional methods, especially when a local deposition of energy and minimum thermal distortions are required. In LTW one of the polymeric materials needs to be transparent to the laser wavelength and the second part needs to be designed to be absorbed in IR spectrum. This report presents a study of laser weldability of ABS (acrylonitrile/butadiene/styrene) filled with two different concentrations of carbon nanotubes (0.01% and 0.05% CNTs). These additives are used as infrared absorbing components in the laser welding process, affecting the thermal and optical properties of the material and, hence, the final quality of the weld seam. A tailored laser system has been designed to obtain high quality weld seams with widths between 0.4 and 1.0mm. It consists of two diode laser bars (50W per bar) coupled into an optical fiber using a non-imaging solution: equalization of the beam quality factor (M2) in the slow and fast axes by a pair of micro step-mirrors. The beam quality factor has been analyzed at different laser powers with the aim to guarantee a coupling efficiency to the multimode optical fiber. The power scaling is carried out by means of multiplexing polarization technique. The analysis of energy balance and beam quality is performed in two linked steps: first by means ray tracing simulations (ZEMAX®) and second, by validation. Quality of the weld seams is analyzed in terms of the process parameters (welding speed, laser power and clamping pressure) by visual and optical microscope inspections. The optimum laser power range for three different welding speeds is determinate meanwhile the clamping pressure is held constant. Additionally, the corresponding mechanical shear tests were carried out to analyze the mechanical properties of the weld seams. This work provides a detailed study concerning the effect of the material microstructure and laser beam quality on the final weld formation and surface integrity.

Stabilization of laser welding processes by means of beam oscillation

Author(s): Christiane Thiel; Axel Hess; Rudolf Weber; Thomas Graf

Welding with high-brightness laser beams suffers from increased sensitivity of both, the process itself and the laser beam shaping optics[1]. Laser beam oscillations create comparably large melt pool surfaces while maintaining the high laser beam brightness. Fast laser beam oscillation is known to be favourable for joining of dissimilar materials[2][3]. In our work we use such oscillations to stabilize high-quality laser welding processes. Comparison of the cross sections for different oscillation properties clearly showed that the welding depth is determined by the static beam properties, i.e. high brightness, while the weld width is given by the oscillation amplitude. The width corresponds to the width which is obtained by a static, lower brightness beam that has parameters equal to the time averaged oscillating high-brightness beam. We denote the time averaged oscillating beam as "virtual lower quality beam". It follows that in many cases the process efficiency given by the amount of melt is improved by oscillation since we combine the welding depth - and hence increased coupling efficiency - achieved with the high-brightness beam with the width of the time-averaged oscillation High-speed videos show that motion patterns have to be chosen carefully in order to minimize unwanted effects such as e.g. melt ejection. However, the aim of the present investigations is to improve process stability, in particular to make the welding process less sensitive to focal shift. Therefore the results of welding with an oscillating laser beam in different focus positions are discussed with respect to process stabilization.

Pyrometry diagnostic in laser cutting technology

Author(s): Alexander V. Dubrov; Vladimir D. Dubrov; Yury N. Zavalov; Elena S. Makarova; Nickoly G. Dubrovin

The measurement data of temporal temperature fluctuation on the cut front while laser cutting of sheet metal (3 mm, 6 mm and 10 mm thickness) are obtained using two-color multi-channel pyrometer. Measurements were carried out for several values of cutting speed and pressure of assisted gas (oxygen), using a 1500W CO2 laser radiation and 1800W Ytterbium fiber laser. The relationship between the temperature fluctuations and the deformation of the melt flow surface on the cutting front in the frequency range above 3 kHz was proven. It is shown that in the case of CO2 laser cutting the temperature fluctuations RMS is greater than 10 K in the range of sub-millimeter capillary waves, but in the case of Fiber Laser cutting the temperature

fluctuations RMS is less than 3 K. The spectrum of capillary waves in case of Fiber- Laser cutting is formed under the effect of forced surface deformation at lower frequencies, in particular related to the assisted gas jet. It is shown, that thermo-capillary effect with capillary-wave turbulence generation can be observed in the locations, where exposition intensity of melt surface to CO2 laser radiation exceeds 1 MW/cm2. Thus, an additional mechanism of the anomalous absorption on the front of cutting can compensate the low absorption of the metal in case of 10.6 ìm laser in comparison with the absorption of the metal in the near infrared range.

Optimum power consumption at high-quality laser-oxygen cutting
Author(s): A. M. Orishich; V. B. Shulyatyev; A. G. Malikov
This report presents the results of the experimental investigation of the interaction between energy and mechanical characteristics of the laser cut for thick sheets. The aim is to optimize the energy consumptions in of the process of high-quality oxygen-assisted laser cutting of low-carbon steel.

Regression modeling to predict the geometrical features of Ti6Al4V thin sheets butt joints welded by disk laser
Author(s): Fabrizia Caiazzo; Ernesto Mastrocinque; Gaetano Corrado; Vincenzo Sergi
The aim of this work is to investigate the effects of power, welding speed, defocusing on geometric features and on defects of 1 mm Ti6Al4V laser welded butt joints by a new generation disk laser with 2 kW of maximum power. Them active gain is a Yb:YAG disk instead of traditional Nd:YAG rods. Disk geometry allows to keep the nominal beam quality also at high power because there is no thermal lensing effect, typical of rod geometry. A three level Box-Behnken experimental design with three repetitions is carried out for a total of 45 tests. Linear and quadratic regression equations are developed to relate the input factors to the output variables in order to predict the geometric features of butt joints.

Characterization of lap joints laser beam welding of thin AA 2024 sheets with Yb:YAG disk-laser
Author(s): Fabrizia Caiazzo; Vittorio Alfieri; Francesco Cardaropoli; Vincenzo Sergi
Lap joints obtained by overlapping two plates are widely diffused in aerospace industry. Nevertheless, because of natural aging, adhesively bonded and riveted aircraft lap joints may be affected by cracks from rivets, voids or corrosion. Friction stir welding has been proposed as a valid alternative, although large heat affected zones are produced both in the top and the bottom plate due to the pin diameter. Interest has therefore been shown in studying laser lap welding as the laser beam has been proved to be competitive since it allows to concentrate the thermal input and increases productivity and quality. Some challenges arise as a consequence of aluminum low absorptance and high thermal conductivity; furthermore, issues are due to metallurgical challenges such as both micro and macro porosity formation and softening in the fused zone. Welding of AA 2024 thin sheets in a lap joint configuration is discussed in this paper: tests are carried out using a recently developed Trumpf TruDisk 2002 Yb:YAG disk-laser with high beam quality which allows to produce beads with low plates distortion and better penetration. The influence of the processing parameters is discussed considering the fused zone extent and the bead shape. The porosity content as well as the morphological features of the beads have been examined.

Holographic lithography for biomedical applications
Author(s): E. Stankevicius; E. Balciunas; M. Malinauskas; G. Raciukaitis; D. Baltriukiene; V. Bukelskiene
Fabrication of scaffolds for cell growth with appropriate mechanical characteristics is top-most important for successful creation of tissue. Due to ability of fast fabrication of periodic structures with a different period, the holographic lithography technique is a suitable tool for scaffolds fabrication. The scaffolds fabricated by holographic lithography can be used in various biomedical investigations such as the cellular adhesion, proliferation and viability. These investigations allow selection of the suitable material and geometry of scaffolds which can be used in creation of tissue. Scaffolds fabricated from di-acrylated poly(ethylene glycol) (PEG-DA-258) over a large area by holographic lithography technique are presented in this paper. The PEG-DA scaffolds fabricated by holographic lithography showed good cytocompatibility for rabbit myogenic stem cells. It was observed that adult rabbit muscle-derived myogenic stem cells grew onto PEG-DA scaffolds. They were attached to the pillars and formed cell-cell interactions. It demonstrates that the fabricated structures have potential to be an interconnection channel network for cell-to-cell interactions,

flow transport of nutrients and metabolic waste as well as vascular capillary ingrowth. These results are encouraging for further development of holographic lithography by improving its efficiency for microstructuring three-dimensional scaffolds out of biodegradable hydrogels

High-precision measurements of reflectance, transmittance, and scattering at 632.8 nm
Author(s): Humbat Nasibov; Izmir Mamedbeili; Dadash Riza; Ertan Balaban; Fikret Hacizade
Progresses in the optical coatings and optical material fields require an increase in the sensitivity and accuracy of the optical parameters' measurement methods and systems. In this work we describe a flexible and high-accuracy system for measuring the main optical characteristics at 632.8 nm wavelength. The system comprises two methods: a laser ratio-metric measurement method for absolute measurement of the transmittance and the specular reflectance, and an integrating-sphere method for assessment of the total integrated scattering. The system utilizes an intensity stabilized He- Ne laser as a light source. Two four-element trap detectors are used: the first for monitoring of laser power, the second (fixed on a motorized stage) for the measurement of reflectance and transmittance, one after another. A PMT mounted to the exit port of a 40 cm diameter integrating hemisphere, is used for measuring the total integrated scattering. A series of measurements with several reference mirrors showed that the system is able to measure the specular reflectance with a reproducibility of <0.005%, transmittance of 0.005% with a reproducibility <0.005%, and total integrated scattering about 10 ppm, with a reproducibility of < 5 ppm at 2 sigma. The system allows characterizing of optical components with diameters between 5 mm and 50 mm.

Airborne laser systems for atmospheric sounding in the near infrared
Author(s): Roberto Sabatini; Mark A. Richardson; Huamin Jia; David Zammit-Mangion
This paper presents new techniques for atmospheric sounding using Near Infrared (NIR) laser sources, direct detection electro-optics and passive infrared imaging systems. These techniques allow a direct determination of atmospheric extinction and, through the adoption of suitable inversion algorithms, the indirect measurement of some important natural and man-made atmospheric constituents, including Carbon Dioxide (CO2). The proposed techniques are suitable for remote sensing missions performed by using aircraft, satellites, Unmanned Aerial Vehicles (UAV), parachute/gliding vehicles, Roving Surface Vehicles (RSV), or Permanent Surface Installations (PSI). The various techniques proposed offer relative advantages in different scenarios. All are based on measurements of the laser energy/power incident on target surfaces of known geometric and reflective characteristics, by means of infrared detectors and/or infrared cameras calibrated for radiance. Experimental results are presented relative to ground and flight trials performed with laser systems operating in the near infrared (NIR) at λ = 1064 nm and λ = 1550 nm. This includes ground tests performed with 10 Hz and 20 KHz PRF NIR laser systems in a variety of atmospheric conditions, and flight trials performed with a 10 Hz airborne NIR laser system installed on a TORNADO aircraft, flying up to altitudes of 22,000 ft above ground level. Future activities are planned to validate the atmospheric retrieval algorithms developed for CO2 column density measurements, with emphasis on aircraft related emissions at airports and other high air-traffic density environments.

Numerical simulation of a laser-acoustic landmine detection system
Author(s): Ion I. Lancranjan; Sorin Miclos; Dan Savastru; Roxana Savastru; Constantin Opran
The preliminary numerical simulation results obtained in the analysis of a landmine detection system based on laser excitation of acoustic - seismic waves in the soil and observing its surface vibration above the embedded landmine are presented. The presented numerical simulations comprise three main parts: 1) Laser oscillator and laser beam propagation and absorption in soil; a laser oscillator operated in Q-switched regime is considered; different laser wavelengths are investigated. 2) Acoustic - seismic wave generation by absorption in soil of laser pulse energy; 3) Evaluation of acoustic - seismic wave generation by the buried in soil landmine; 4) Comparison of Distributed Feed- Back Fiber Laser (DFB-FL) and Laser Doppler Vibrometer (LDV) detector used for soil vibrations evaluation. The above mentioned numerical simulation is dedicated for evaluation of an integrated portable detection system.

Laser-plasma accelerators-based high energy radiation femtochemistry and spatio-temporal radiation biomedicine
Author(s): Y. A. Gauduel; O. Lundh; M. T. Martin; V. Malka

The innovating advent of powerful TW laser sources (~1019 W cm-z) and laser-plasma interactions providing ultra-short relativistic particle beams (electron, proton) in the MeV domain open exciting opportunities for the simultaneous development of high energy radiation femtochemistry (HERF) and ultrafast radiation biomedicine. Femtolysis experiments (Femtosecond radiolysis) of aqueous targets performed with relativistic electron bunches of 2.5-15 MeV give new insights on transient physicochemical events that take place in the prethermal regime of confined ionization tracks. Femtolysis studies emphasize the pre-eminence of ultra-fast quantum effects in the temporal range 10-14 - 10-11 s. The most promising advances of HERF concern the quantification of ultrafast sub-nanometric biomolecular damages (bond weakening and bond breaking) in the radial direction of a relativistic particle beam. Combining ultra-short relativistic particle beams and near-infrared spectroscopic configurations, laser-plasma accelerators based high energy radiation femtochemistry foreshadows the development of real-time radiation chemistry in the prethermal regime of nascent ionisation clusters. These physico-chemical advances would be very useful for future developments in biochemically relevant environments (DNA, proteins) and in more complex biological systems such as living cells. The first investigation of single and multiple irradiation shots performed at high energy level (90 MeV) and very high dose rate, typically 1013 Gy s-1, demonstrates that measurable assessments of immediate and reversible DNA damage can be explored at single cell level. Ultrafast in vivo irradiations would permit the development of bio-nanodosimetry on the time scale of molecular motions, i.e. angstrom or sub-angstrom displacements and open new perspectives in the emerging domain of ultrafast radiation biomedicine such as pulsed radiotherapy.

Power balance on the SG-III prototype facility
Author(s): Ping Li; Feng Jing; Dengsheng Wu; Runchang Zhao; Hai Li; Honghuan Lin; Jingqin Su
With the methods of time-division multiplexing in Frontend and angle detuning in FOA, each beam pulse on SG-III prototype facility is controlled independently and so the systematic variations of power imbalance are eliminated entirely.

Tapered fiber phase conjugator for high-power all-solid lasers with high repetition rate
Author(s): Chun Tang; Lixin Tong; Gang Xie; Qingsong Gao; Lingling Cui; ZhiGang Zhao; Chong Liu; Jun Chen
A high power multi-pass diode-pumped solid-state MOPA system with large core diameter tapered quartz fiber as phase conjugator is experimentally investigated. The results of the effects of laser longitudinal mode characteristic, laser pulse width and fiber surface optical quality on SBS reflectivity are presented. Maximum SBS reflectivity of 69.7% is obtained with the repetition rate of 1000 Hz, input pulse energy of 38mJ and pulse width of 24 ns. The phase conjugator is made from a taper shaped quartz fiber with the diameter of 1mm at the input end and 0.4mm at the other end. It has good application prospects in improving the beam quality and compressing the pulse width for high power laser system with high repetition rate.

Development of Φ500mm array-lens beam sampler
Author(s): Hong-lai Xu; Yong Peng; Wen-chao Zhou; Yi-dong Ye; Xiao-yang Hu
Wavefront sampling is important for beam parameters measurement. A new method to perform the large aperture beam sampling with array-lens was put forward. A 25×25 array-lens of wavefront distortion measurement was designed, and an experimental system was settled up. The perfect parallel beam is used to demarcate the large aperture array-lens beam sampler. And a large aperture wavefront of distortion was measured by the set. That the experiment result is in accordance with the theoretical calculation.

Grating waveguide structures for intracavity generation of beams with azimuthal polarization in an Yb:YAG thin-disk laser
Author(s): Martin Rumpel; Marwan Abdou Ahmed; Andreas Voss; Thomas Graf
We report on the design, fabrication, and spectroscopic characterization as well as on the intra-cavity employment of grating waveguide structures (GWS) for the generation of beams with azimuthal polarization in an Yb:YAG thin-disk laser. Two different GWS concepts are used for the polarization shaping: the first is based on a resonant reflection (RR) behavior whereas the second uses the coupling mechanism to a leaky-mode (LM) similar to what was published for the generation of radially polarized beams1. In both cases the structure combines a multilayer coating and a sub-wavelength grating. The RR structure comprises a partial

reflector (R ≈ 88%) and a wave guiding layer. The parameters of the grating (which is integrated into all layers) are designed in order exploit the abnormal reflection caused by constructive interference and was designed with a nominal peak reflectivity higher than 99.99% at the laser wavelength of 1030 nm and within a narrow spectral bandwidth of 2-3 nm FWHM. The LM structure is composed of a standard HR mirror and a grating which was designed to excite a leaky mode of the plane structure. This leads to a reduction of the reflectivity for one polarization at the design wavelength of 1030 nm whereas the orthogonal polarization is not affected and experiences an unchanged high reflectivity. By fabricating these elements with circular grating lines one can generate beams with either radial or azimuthal polarization. Here we discuss the latter case, where azimuthally polarized beams with a laser output power of up to 145 W, an optical laser efficiency of 43%, and high polarization purity were generated. The beam quality factor M2 of the emitted beams was measured to be ≈ 2.3. Moreover, the effect of the heat load in the GWS on its performance will be discussed.

Spectroscopic properties of newly flux grown RE2O3:Yb3+ (RE=Y,Lu) laser crystals for high-power diode-pumped systems

Author(s): Gabriel Buse; M. Velázquez; Philippe Veber; Véronique Jubera; Yannick Petit; Stanislav Péchev; Oudomsack Viraphong; Rodolphe Decourt; Anaël Jaffres; Patrick Aschehoug; Gérard Aka

Developing large laser grade cubic rare-earth sesquioxides (RE2O3, RE=Y,Sc,Lu) single crystals doped with Yb3+ ions stands as one of the most challenging endeavours of today's crystal growth1,2. Recent studies on cubic RE2O3 single crystals have demonstrated their laser potential and highlighted the extreme thermodynamic conditions in which their growth takes place1-3. In particular, the laser performances of Lu2O3:Yb3+ crystals make them likely to outperform betterknown rivals such as YAG:Yb3+ or KY(WO4)2:Yb3+ for 976 nm diode-pumped systems4. Several mm3-sized Yb3+-doped Y2O3, Gd2O3 and Lu2O3 single crystals were recently grown by a newly designed high-temperature solution growth method5, and characterized by means of X-ray diffraction, Fourier transformed infrared (FTIR) spectroscopy and electron probe microanalysis (EPMA). Spectroscopic characterizations (absorption and emission cross sections, visible anti-Stokes emission, fluorescence decays) of these new cubic RE2O3:Yb3+ (RE=Y,Lu) single crystals are presented.

Ytterbium-doped Sc2SiO5 in thin-disk laser configuration

Author(s): K. S. Wentsch; L. Zheng; J. Xu; B. Weichelt; M. Abdou Ahmed; Th. Graf

We present first experimental investigations on Ytterbium-doped Sc2SiO5 as a promising gain medium for thin-disk lasers. This oxyorthosilicate laser material combines good thermo-mechanical properties and a broad emission bandwidth suitable for high-power cw and mode-locked laser operation. The demonstrated average output powers of up to 75 W with a not yet optimized thin-disk crystal confirm the power capability of this new material and preliminary tests on passive mode-locking indicate the high potential for future ultrafast thin-disk laser oscillators.

High-efficiency wavelength and polarization selective grating-waveguide structures for Yb:YAG thin-disk lasers

Author(s): Martin Rumpel; Marwan Abdou Ahmed; Andreas Voss; Thomas Graf

We report on Grating Waveguide Structures (GWS) with a high diffraction efficiency used in Littrow configuration to select (and tune) the wavelength of an Yb:YAG thin-disk laser. The structures are composed of a multilayer HR coating, on which an additional low index layer (SiO2) and high index layer (Ta2O5) was deposited. A binary grating with a period of 580 nm is etched on top of the structure with a groove depth of 87 nm for GWS 1 and 72 nm for GWS 2. The simulation results show that the diffraction efficiency in the -1st order can reach a value of 99.99% for TE polarization, whereas it is only about 20% for TM polarization at 1030 nm. The grating was fabricated by standard interference lithography followed by a dry etching process to the desired groove depth. The spectroscopic measurement exhibited a diffraction efficiency of 99.6% for GWS 1 at 1030 nm and 99.7% for GWS 2 at 1048 nm. The devices were placed as end-mirror into the resonator of a Yb:YAG thin-disk laser. An output power of up to 110 W could be obtained from the laser in fundamental-mode operation (M2 ≈ 1.2) with GWS 1, corresponding to an optical efficiency of ηoo = 36.2%. In multi-mode operation (M2 ≈ 6) a power of 325 W with ηoo = 53.2% could be extracted. The spectral bandwidth of the emitted beam was measured using an Optical Spectrum Analyzer

(OSA) to be less than 20 pm in fundamental-mode. We also showed a continuous wavelength tuning range of 46 nm for GWS 1 and of 38 nm for GWS 2. With a commercially available Stokes polarimeter the degree of linear polarization (DOLP) was measured to be higher than 98.6% over the whole power and wavelength tuning range.

Eye-safe pulsed kW-peak power high-repetition rate all-fiber MOPA source
Author(s): J. Swiderski; M. Maciejewska; W. Pichola; J. Kwiatkowski; M. Mamajek
The 1.5 μm pulsed 3-stage all-fiber MOPA source seeded by a directly modulated DFB laser was developed. It operated at the repetition rate ranging from 400 kHz to 2 MHz and delivered up to 6.5 μJ in 1-ns pulse. The total signal gain of up to 57 dB and the maximum average output power of over 2.8 W (at 2 MHz) were demonstrated when the total pump power of the MOPA was 10.64 W. The amplified pulses were very stable and did not reveal either duration and shape change in relation to input pulses generated by the seed.

Millijoule-level 20 ps Nd:YAG oscillator-amplifier laser system for investigation of stimulated Raman scattering and optical parametric generation
Author(s): Michal Jelínek; Vàclav Kubecek
We report on quasi-continuously pumped oscillator-amplifier laser system. The laser oscillator was based on highly 2.4 at.% doped crystalline Nd:YAG in a bounce geometry and passively mode locked by a semiconductor saturable absorber mirror. Using the cavity dumping technique, 19 ps pulses with the energy of 20 μJ and Gaussian spatial beam profile were generated directly from the oscillator at the repetition rate up to 50 Hz. For applications requiring more energetic pulses the amplification was studied using either an identical highly doped Nd:YAG module in bounce geometry or flashlamp pumped Nd:YAG laser rod. Using compact all diode pumped oscillator-amplifier system, 130 μJ pulses were generated. The flashlamp pumped amplifier with 100 mm long Nd:YAG enabled to obtain higher energy. In the single pass configuration the pulse was amplified to 4.5 mJ, using the double pass configuration the pulse energy was further increased up to 20 mJ with the duration of 25 ps at 10 Hz. The developed laser system was used for investigation of stimulated Raman scattering in Strontium Barium Niobate and optical parametric generation in CdSiP2.

Transfer capability of 3-5 μm radiation by hollow glass waveguide
Author(s): Michal Nemec; Helena Jelínková; Mitsunobu Miyagi; Hiroyuki Takaku; Katsumasa Iwai; Yuji Matsuura; Maxim Doroshenko
The aim of this work was the delivery investigation of 3 - 5 μm laser radiation by a hollow glass waveguide. The waveguide was formed by a supporting fused silica glass capillary tube with a silver layer deposited on the inside wall. As an inner dielectric material film, a cyclic olefin polymer (COP) was used. The primary parameters of the sample investigated were the inner/outer diameter 700/850 μm and the length of up to 110 cm. As radiation sources, three lasers generating in mid-infrared spectral region were designed and constructed. The flash-lamp-pumped Er:YAG laser operated at 2.94 μm wavelength. The second system was 4.3 μm Dy:PbGa2S4 laser. Its coherent pumping was performed by the flashlamp pumped Er:YLF laser generating at 1.73 μm wavelength. The third laser emitting at 4.45 μm was based on Fe:ZnSe active medium pumped by electro-optically Q-switched Er:YAG laser radiation (2.94 μm). The study presented describes a transfer capability of 3 - 5 μm radiation by COP/Ag hollow glass waveguide. The delivery efficiency and spatial structure were investigated. The transmission measured reached 84 %, 58 %, and 64 % for Er:YAG (2.94 μm), Dy:PbGa2S4 (4.3 μm), and Fe:ZnSe (4.45 μm) laser systems, respectively. The spatial beam structure transferred was similar for all systems. The laser delivery system based on COP/Ag hollow glass waveguide can be useful for some mid-infrared radiation applications.

Tunable Fe,Cr:ZnMgSe gain-switched mid-IR laser operating at room temperature
Author(s): Helena Jelínková; Maxim E. Doroshenko; Jan Sulc; Michal Jelínek; Michal Nemec; Miroslav Cech; Tasoltan T. Basiev; Y. A. Zagoruiko; N. O. Kovalenko; A. S. Gerasimenko; V. M. Puzikov; V. K. Komar
The goal of this work was to design and investigate the gain switched new Fe,Cr:ZnMgSe laser operating at the room temperature. The pumping was provided by the electro-optically Q-switched Er:YAG laser with the oscillation wavelength of 2.937 μm which matching the absorption line of the Fe,Cr:ZnMgSe crystal. The Q-switched operation was obtained by the Brewster angle cut LiNbO3 Pockels cell placed between the

rear mirror and the laser active medium. The output radiation parameters were: the energy of 10 mJ, pulse duration of 120 ns, and repetition rate 1 Hz. The pump radiation was directed into the Fe,Cr:ZnMgSe crystal placed inside the 16 mm long hemi-spherical cavity formed by the dichroic pumping mirror (T = 86 % at 2.94 μm and R = 100% for 4 - 5 μm) and the output coupler with the reflectance R = 95 % at 4 - 5 μm and radius of curvature r = 500 mm. The maximum output Fe,Cr:ZnMgSe laser energy was 160 μJ corresponding the slope efficiency 4 % (with respect to absorbed energy). The generated radiation wavelength was 4.8 μm with the linewidth of 100 nm (FWHM). The output beam spatial profile was approximately Gaussian in both axes. Laser tuning properties were investigated by the Lyot filter (MgF2 plate, 2 mm thick) inserted into the resonator providing the tuning range from 4.5 to 4.9 μm. The results were compared with the Fe:ZnSe crystal operated at the same conditions.

A highly efficient resonantly pumped Ho:YAG laser
Author(s): Jacek Kwiatkowski; Jan K. Jabczynski; Waldemar Zendzian; Jacek Swiderski; Mateusz Kaskow; Lukasz Gorajek
An efficient high-peak-power Ho:YAG hybrid laser resonantly pumped by a 20 W linearly polarized Tm:fiber laser at the wavelength of 1908 nm was developed. At room temperature a maximum continuous output power of 10.7 W with a slope efficiency of over 55% with respect to the incident pump power was achieved. In Q-switching regime an acousto-optic modulators were applied. The research was conducted for normal and Brewster's angle Q-switches respectively. In CW pumping regime the repetition rate was changed from 500 Hz to 5000 Hz. For the best case, for 5 kHz repetition rate, pulses of 1.6 mJ energy and 123 kW peak-power were achieved at the wavelength of 2090.2 nm with an M2 ≈ 1.6.

Ion argon-krypton laser for medical applications
Author(s): Wojciech Kaminski; Jan Kasprzak; Jerzy Kesik; Piotr Warda
Ion gas lasers filled with pure argon or krypton are often used in medicine. The number of possible medical laser applications are still increasing. Every type of application requires specific wavelength range. Due to number of available laser wavelengths of argon and krypton lasers, laser filled with mixture of both gases could be interesting universal medical laser source. However output power value of some interesting in medical point of view laser wavelengths may be insufficient in laser filled with mixture. Developed by authors quasi-continuous ion laser supply regime in connection with observed and described by authors the effect of laser power increase in presence of noble gas admixtures allows to achieve laser power satisfactory for certain medical applications but unavailable in typical ion lasers operated with standard continuous power supply regime.

Influence of noble gas additions on the output power of krypton ion laser
Author(s): Wojciech Kaminski; Jerzy Kesik; Piotr Warda
In this paper authors will present the phenomenon of advantageous influence of noble gas additions on the output parameters of krypton ion lasers. Authors have observed that small additions of argon to the krypton discharge causes increase of laser output power of certain krypton laser lines. The power change depends on laser line wavelength, mixture composition, gas pressure and discharge current values. Authors will present measurement results and explanation of this phenomenon.

Pr,Ce:YAlO3 crystal properties under UV-radiation exposure
Author(s): Martin Fibrich; Helena Jelínková; Jan Sulc; Karel Nejezchleb; Václav Skoda
As came out in one of our past experiments concerning the Pr:YAlO3 (Pr:YAP) active material, UV-radiation had an adverse effect for lasing action due to the crystal solarization. So, co-doping of this material by Ce3+-ions having broad absorption-bands in the UV-region has been proposed for crystal property improvement in terms of color-center formation. The Pr,Ce:YAP absorption-spectrum investigation under UV-radiation exposure, in comparison to the Pr:YAP one, is reported in this contribution. Moreover, lasing properties of these two materials under the GaN-diode pumping are summarized.

Laser turn-on behavior in organic vertical-external cavity surface-emitting lasers
Author(s): Sébastien Chénais; Oussama Mhibik; Tatiana Leang; Hadi Rabbani-Haghighi; Alain Siove; Sébastien Forget

Organic lasers offer the promise to build compact, inexpensive, broadly tunable solid-state lasers in the visible range, with potential applications in spectroscopy, bio/chemo sensing or short-haul data telecommunications. Among existing laser architectures of optically-pumped organic lasers, external-cavity resonators enable the highest conversion efficiencies, excellent beam quality, power scalability and versatility due to the open cavity. Recently, we reported on an open-cavity laser architecture using a thin film of dye-doped polymer as the gain medium, named Vertical External Cavity Surface-emitting Organic Laser (VECSOL). The very high gain of organics make these lasers highly efficient even for macroscopic cavities, even though the pulse buildup time must be short enough to fit within the gain time window defined by the pump pulse duration and the fluorescence lifetime. In this paper we analyze the laser turn-on dynamics of organic VECSELs. A simple theoretical framework is presented, based on the Statz-DeMars coupled rate equations. Simulations are compared to the experimental pulse shapes of the pump and laser beams, recorded with the same fast photodiode. We observe that the laser pulse is both shifted and broadened with respect to the 0.5-ns-long pump pulse when the cavity length is increased, together with a drop of efficiency. Efficiency curves are presented, showing a higher threshold and lower slope efficiency when the cavity length increases, which is well accounted by the model. Finally, an optimized VECSOL is presented, with a 25 ns-pulsewidth pump source, enabling reaching conversion efficiencies up to 61%.

Tunability of laser based on Yb-doped hot-pressed CaF2 ceramics

Author(s): Jan Sulc; Maxim E. Doroshenko; Helena Jelínková; Tasoltan T. Basiev; Vasilii A. Konyushkin; Vyacheslav V. Osiko

The aim of presented study was an investigation of tunability of diode pumped laser based on hot-pressed Yb:CaF2 ceramics. The tested Yb:CaF2 sample was in the form of 3.5mm thick plane-parallel face-polished plate (without AR coatings). The Yb3+ concentration was 5.5 %. A fiber (core diameter 200 μm, NA= 0.22) coupled laser diode (LIMO, HLU25F200-980) with emission at wavelength 976 nm, was used for longitudinal Yb:CaF2 pumping. The laser diode was operating in the pulsed regime (4 ms pulse length, 20 Hz repetition rate). The duty-cycle 8% ensured a low thermal load even under the maximum diode pumping power amplitude 10W (crystal sample was only air-cooled). This radiation was focused into the crystal (pumping beam waist diameter ~ 170 μm). The 145mm long semi-hemispherical laser resonator consisted of a flat pumping mirror (HR @ 1.01 − 1.09 μm, HT @ 0.97 μm) and curved (r = 150mm) output coupler with a reflectivity of ~ 98% @ 1.01 − 1.09 μm. Tuning of the ytterbium laser was accomplished by using a birefringent filter (single 1.5mm thick quartz plate) placed inside the optical resonator at the Brewster angle between the output coupler and the laser active medium. The extremely broad and smooth tuning was obtained. The laser was continuously tunable over ~ 66nm (from 1015nm to 1081 nm) and the tuning band was mostly limited by free spectral range of used birefringent filter. The tunability FWHM was 40 nm corresponding bandwidth 10 THz results in Fourier limited gaussian pulse width ~ 40 fs (FWHM). The maximum output power amplitude 0.68W was obtained at wavelength 1054nm for absorbed pump power amplitude 6W. The laser slope efficiency was 15%.

Bulk Er:YAP and Er:Yb:YAP optical emission studies for eyesafe laser applications

Author(s): Efstratios Georgiou; Jean-Pierre Boquillon; Olivier Musset

Emission and excitation spectra of Er-doped YAP crystals reveal a broad emission band in the eyesafe region with peaks around 1545-nm and 1608-nm and pump-bands suitable for common 800-nm and 970-nm diode lasers, suggesting YAP as a candidate crystalline host for diode-pumped laser in the 1.5-μm eyesafe regime. Erbium-doped YAP-crystal results are comparable with analogous measurements on Er:Yb:YAG, which has already demostrated efficient lasing action in the eyesafe region.

Energy transfer analysis of Tb3+ and Yb3+ ions doped in borosilicate glass

Author(s): Takenobu Suzuki; Kento Mizuno; Yasutake Ohishi

We investigated the spectroscopic properties of borosilicate glass co-doped with Tb3+ and Yb3+, focusing our attention on studying the possibility of the cooperative up-conversion process in the Tb3+-Yb3+ co-doped system as a pumping scheme for Tb3+. A rate equation model for the Tb3+-Yb3+ co-doped system were analyzed. The model could reproduce the up-conversion emission dynamics well for all the samples co-doped with different Tb3+ number densities.

Simulation of the influence of atmospheric conditions on low-cost optical free space link
Author(s): Jan Latal; Petr Koudelka; Jan Vitasek; Petr Siska; Jan Skapa; Andrej Liner; Martin Papes; Vladimir Vasinek
The team of authors was concerned in the development and construction of low-cost free space optical link and simulations of the influence of atmospheric conditions on this link. The article contains description of electronic design and attention is also dedicated to simulations of atmospheric conditions. Gradually, the most frequently occurring atmospheric conditions and their impact on the available bit rates were tested. An integral part of the article is calculation of the energy balance of the whole link. At the end are shown images of the measured eye diagrams and samples of measured distribution of optical power using a digital camera and its processing in MATLAB.

Laser-induced shock waves from structured surfaces
Author(s): Ch. Leela; V. Rakesh Kumar; Surya P. Tewari; P. Prem Kiran
We present our results on the expansion dynamics of laser induced plasma created shock wave from stainless steel alloy propagating into ambient air that are characterized by time resolved shadowgraphic imaging. A machinist's scale with periodic surface structures of 30 μm depth and 240 ± 20 μm width having 25 and 64 lpi (lines per inch) is used as a target surface. Laser pulses from frequency doubled Nd:YAG (7ns, 532 nm) with 45 mJ energy per pulse focused to a beam diameter of ~ 1 mm on the target surface are used to generate laser induced shock waves. A fast ICCD camera (DH-734U, ANDOR) with 1.5 ns gating resolution is used to capture the time evolution of SWs into air. The properties of shock waves from structured surfaces are compared to that from a flat surface to understand the contribution of structured surface to shock wave dynamics. The SWs from a flat surface are observed to follow Sedov-Taylor solution during time delay of 0.2 to 20 μs. Contact front discontinuity dynamics were studied at different time scales for flat and structured surfaces The maximum velocity of the SWs has increased from 2.75 to 4 km/s with increasing number of surface structures from 25 to 64 lpi. From the measured radius of curvature of SW's (RSW), the velocity, pressure and temperature associated with the micro explosion of metal surface is estimated using Counter Pressure Corrected Point Strong Explosion Theory.

The investigation of transient thermal effects in optical elements under high laser intensities
Author(s): Mateusz Kaskow; Jan Tarka; Jacek Kwiatkowski; Waldemar Zendzian; Lukasz Gorajek; Jan K. Jabczynski
The most important limitations in development of high energy and high power lasers based on solid state technology are thermal effects occurring under high intensity and high heat loads. The thermo-optical effects occurring inside output couplers, folding mirrors, output windows can significantly diminish the beam quality of high power lasers and therefore have to be investigated. The knowledge on transient thermal effects occurring inside bulk laser elements exposed on laser intensities of several dozens of kW/cm2 is of special interest for some specific applications (e.g. heat capacity lasers). The aims of work were theoretical analysis of those effects occurring inside the laser mirrors and its experimental verification. The hints for choice of the best materials (from the point of view of thermal limitations) for laser windows and output couplers were pointed out. The special laboratory setup enabling simultaneous registration of thermo-optical effects applying shearing interferometry and wavefront sensing by means of Shack-Hartmann test was worked out. The transient as well as averaged in time thermal-optical effects occurring inside the volume of examined element as a result of surface absorption in the coatings and bulk absorption in the material can be resolved and measured. The resolution of measurements: less than 0.1 K temperature difference and thermally induced optical power of about 0.1 D were demonstrated.

Large aperture plasma electrodes Pockels cell for multi-pass amplified scheme of SGII upgrading laser
Author(s): Dengsheng Wu; Feng Jing; Ping Li; Xiongjun Zhang; Jun Zhang; Xiaolin Tian
The multi-pass amplified scheme of SGII upgrading laser is similar as that of NIF. Large aperture plasma electrodes Pockels cell (PEPC) is the key unit of this amplified scheme. The transit time that laser beam passes through the PEPC for the first time and second time is about 270ns. PEPC should switch the state between ON and OFF in 270ns. The response time of the PEPC driven by positive-negative switching pulses can not satisfy the demand of SGII upgrading laser due to the higher generator impedance. In the single-

pulse-process, the low-impedance high voltage generator based on double Blumlein pulse-forming line is used to drive the PEPC. The amplitude of single pulse is up to 21kV, while the impedance of the generator is only 6.25Ω. The theoretical charge time of the PEPC with 350mm×350mm aperture is about 54ns, and the response time of PEPC is less than 170ns in the single-pulse-process. The response time is reduced greatly. The switching efficiencies with full aperture are higher than 99.7%. The extinction contrast exceeds 381. The top width of the time window is larger than 160ns, and the bottom width is about 400ns. All the experimental results can meet the specification of SGII upgrading laser.

Dynamic response of metals and alloys to laser-induced shock waves
Author(s): E. Manikanta; P. Venkateshwarlu; S. Sai Shiva; V. Rakesh Kumar; Ch. Leela; Surya P. Tewari; G. Manoj Kumar; P. Prem Kiran
We present the measurements on the propagation characteristics of the laser generated acoustics shock waves and the vibrations inside material targets from laser-metal interaction in real time. Laser pulses (7 ns) from second harmonic of a Nd: YAG laser (532 nm) were used to launch compression waves inside the solid samples. The acoustic measurements were carried out using a calibrated microphone, while the vibrations induced within the material before getting converted into ASW in the atmosphere were measured using vibration transducers (piezoelectric accelerometer). The arrival time of the vibration transducer was used to measure the particle velocity within the material that increased with increasing laser energy. The measurement of the arrival time of the ASW as a function of the microphone distance from the source of explosion was carried out. The shock velocity with respect to distance from the source of explosion followed an exponential decay. The arrival time of the ASWs was found to be increasing with the distance. The shock arrival time with respect to incident laser energy showed an exponential decay where as the shock velocity was found to be linearly increasing with the incident laser energy. Overall, acoustic energy has increased with increasing density of the material.

Stability analysis of solid-state lasers regarding thermal lensing effect
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The stability of solid-state lasers is influenced by the thermal lensing effect in the crystal. This effect is based on the deformation of the end faces of the crystal and the temperature dependence of the refraction index. It also depends on the photoelastic effect produced by thermal induced stress in the crystal. The analysis of the photoelastic effect is important for high power lasers and for lasers with a radially polarized laser beam. In this work, we use FE model to calculate the deformation, heat and stress distribution in the laser crystal with high accuracy. We also simulated the refraction index anisotropy with respect to the crystal orientation using the calculated stress distribution. As a result of our simulation, we can study stability of laser resonators for both radially and azimuthally polarized laser beam.

Photodarkening measurements in Yb-doped silica fibers in correlation with cooperative luminescence
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In this study, detailed investigation of photodarkening in Yb - doped aluminosilicate fibers is reported. The cooperative luminescence loss influenced by photodarkening is measured simultaneously with 633 nm probe loss. The quadratic dependence of photodarkening and cooperative luminescence versus dopant concentration was observed. The results indicated lower cooperative luminescence loss at 513 nm than expected and provided new pieces of information to the photodarkening mechanism description.