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Focus issue introduction: advanced solid-state lasers

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Abstract: This joint issue of *Optics Express* and *Optical Materials Express* features 28 state-of-the-art articles written by authors who participated in the international "Advanced Solid State Lasers" conference, held in Boston November 4–8, 2018. This review provides a summary of these articles that cover the spectrum of solid state lasers from materials research to sources and from design innovation to applications.

ASSL (advanced solid-state lasers) is the international conference devoted to recent advances in both materials and sources aspects of solid state lasers. Materials encompasses advances in optics, materials science, condensed matter physics and chemistry relevant to the development, characterization and applications of new materials for lasers and photonics. These include crystals, glasses and ceramics, as well as functionalized composite materials, from fibers and waveguides to engineered structures with pre-assigned optical properties. Coherent and high brightness radiation sources include lasers as well as pump and nonlinear devices. Emphasis is on advances in science and technology, for improved power, efficiency, brightness, stability, wavelength coverage, pulse width, cost, environmental impact or other application-specific performance.

We hope readers will enjoy this issue of 30 top-level articles that highlight the state of the art in the field. We are also thankful to all of the authors and reviewers for their nice contributions. And we thank very much Carmelita Washington and John Long from the OSA staff for their outstanding work throughout the launch of this feature issue as well as the review and production processes.

Materials and components processing are at the heart of solid state laser. Z. Pan *et al.* report on the crystal growth, spectroscopy characterization and first laser operation of a new tetragonal disordered "mixed" calcium aluminate crystal, Tm:Ca(Gd,Lu)AlO_4. The introduction of Lu^{3+} leads to an additional inhomogeneous broadening of Tm^{3+} absorption and emission spectra compared to the well-known Tm:$CaGdAlO_4$ [1]. A.A. Bushunov *et al.* used a Yb femtosecond laser to fabricate antireflective microstructures on CdSe single crystal samples. They investigated several microstructure fabrication methods, including direct single pulse ablation using 200 fs pulses, ablation with in-depth focusing, ablation in the presence of additional spherical aberration and ablation with obstruction of peripheral rays [2].

Characterizing new materials is an essential step in the design of future sources. W. Liu *et al.* investigated the thermal-lens induced mode coupling in step-index large mode area fiber laser. They demonstrated that the mode coupling can be induced by the thermal-lens induced waveguide changing along the active fiber [3]. P.F. Moulton *et al.* measured and

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characterized the absorption propertiesof Ti:sapphire crystals. They found significant changes in the spectral shape of the pumping band in Ti:sapphire with increased doping, and explained the results in terms of absorption due to pairs of Ti^{3+} ions. This nice work provides guidance on optimizing designs for InGaN-diode-pumped Ti:sapphire lasers [4].In another article, the same team measured and characterized the UV-near-IR absorption properties of Ti:sapphire crystals. In particular, their data on 800-nm-peak shows a complex line shape, with a lower limit set by Ti^{3+} pair absorption. Thus they demonstrated that the maximum possible Figure-of-Merit for Ti:sapphire reduces as the doping level increases [5].V. Fedorov *et al.* report on the characterization of energy transfer in iron-chromium co-doped ZnSe middle-infrared laser crystals. The room temperature kinetics of the Fe:Cr:ZnSe sample under excitation of chromium ion at 1560 nm shows that energy transfer in Cr-Fe centers could be as fast as 290 ns [6]. In the same group, S.D. Subedi *et al.* performed the spectroscopic and laser characterization of negatively charged nitrogen-vacancy (NV^-) centers in diamond [7].

Modal configuration of the beams is a crucial issue for many applications. S. Pachava *et al.* explore the use of an optical correlation technique to decompose different radial as well as azimuthal order modes of Laguerre Gaussian (LG) beams. They experimentally demonstrate the decomposition of single as well as composite LG beams and compare it with simulations [8]. W.R. Kerridge-Johns *et al.* demonstrated high quality vortex output beams in a diode-pumped Nd:YVO_4 laser using an imbalanced Sagnac interferometer as output coupler [9]. K. S. Abedin *et al.* demonstrated operation of a cladding-pumped hybrid ytterbium-doped HOM fiber amplifier and reconversion of the HOM output to Gaussian-like beam by using an axicon based reconversion system. The amplifier was constructed by concatenating single-mode and HOM ytterbium-doped double clad fibers, and was excited by a common multimode pump source [10].

Pushing the limits of sources in terms of energy and spectral performance is a major challenge for current research. B. Yang *et al.* have constructed a monolithic tapered ytterbium-doped fiber laser oscillator and investigated the laser oscillator performance with respect to 976 nm and 915 nm pump, especially on the aspects of the TMI. They report the highest average power for the tapered ytterbium-doped fiber lasers [11]. N. Dalloz *et al.* conceived a bidirectional 793 nm diode-pumped actively Q-switched Tm^{3+}, Ho^{3+}-codoped silica polarization-maintaining (PM) double-clad (DC) fiber laser. With this laser, they obtained 55 W of average output power at 2.09 µm with 100 ns pulse width at 200 kHz repetition rate [12]. V. Balaswamy *et al.* demonstrated a high-power, cascaded Raman fiber laser with near complete wavelength conversion over a wide wavelength and power range. They achieved this by culmination of two recent developments in this field [13]. V. Agrez and R. Petkovsek presents a highly adaptable fiber laser with pulse-on-demand and precision pulse-duration tuning. It is based on a compact optical design combining the gain-switching technique with the all-fiber master oscillator and pump-recovery amplifier architecture [14]. Y. Zhao *et al.* report on a mode-locked Tm,Ho:CLNGG laser emitting in the 2 µm spectral range using single-walled carbon nanotubes as a saturable absorber (SA). Pulses with duration of 98 fs are generated at 99.28 MHz repetition rate with an average output power of 123 mW, yielding a pulse energy of 1.24 nJ. Using a 0.5% output coupling, pulses as short as 67 fs are produced after extracavity compression with a 3-mm-thick ZnS plate [15]. V. Fedorov *et al.* designed a room temperature gain-switched and Q-switched Fe:ZnSe lasers tunable over 3.60-5.15 µm pumped by radiation of 2.94 µm Er:YAG laser. The maximum output energy was measured to be 5 mJ under 15 mJ of pump energy in gained-switch regime. They also demonstrated mechanically Q-switched regime of oscillation of Fe:ZnSe lasers [16]. U. Sheintop *et al.* presents a KGW Raman laser with an external-cavity configuration at the 2 µm region, which is the first demonstration in this range. The Raman laser is pumped by an actively Q-switched Tm:YLF laser emitting at 1880 nm. Due to the KGW biaxial properties, the Raman laser is able to emit separately at 2197 nm and 2263 nm [17]. T. Kawasaki *et al.* realized a Nd:YAG Micro-MOPA, based on a microchip master oscillator and power amplifier system with gain aperture beam cleaning leading to 100 Hz operation, with a pulse brightness of 11 PW/sr.cm^2 by optical compensation of thermal lensing [18]. H. Kawase and R. Yasuhara demonstrated continuous-wave laser operation of a diode-pumped 5.0 at % Er-doped $YAlO_3$ (YAP) single-crystal lasing at 2.92 µm with near-quantum-defect slope efficiency at room temperature. A high slope efficiency of 31% is achieved with a maximum output power of 0.674 W. This efficiency is 94% of the theoretical quantum-defect efficiency [19]. Q. Tian *et al.* achieved a 1.8-µm laser generation based on a 885-nm diode laser in-band pumping of conventional Nd:YAG bulk crystal. With a Cr:ZnSe saturable absorber, passively Q-switched operation has been demonstrated with pulse width, maximum pulse energy and peak power of 54 ns, 125.9 µJ and 2.27 kW, respectively. The results are very competitive to many reported Tm^{3+} lasers at 1.9 µm [20]. R. Sun et *al.* developed VO_2-based metamaterial emitter enabling broadband thermal-switching light to mid-infrared atmospheric windows. At room temperature, the emitter radiates light in both 3-5µm and 8-14µm atmospheric windows. At high temperature, the radiation peaks move out of the atmospheric windows and enable a strong radiation at 5-8µm [21]. A. Golinelli *et al.* present a Ti:Sa-based 1 kHz TW-class laser delivering 17.8 fs pulses with 350 mrad shot-to-shot CEP noise based on an original 10 kHz front-end design. It is also possible to tune the output wavelength of the front end within a 90-nm range around 800 nm [22]. M. Jackle *et al.* demonstrated tunable green lasing between 541 and 552 nm from a bromide-based organic-inorganic per-ovskite thin-film. The optical feedback required for laser emission is provided by a circular gratingthat forms a disk Bragg resonator inside a spin-coated 200 nm thin-film of methylammoniumlead tri-bromide ($CH_3NH_3PbBr_3$) [23]. M. K. Tarabrini *et al.* report on a 2.3 W continuous-wave single-mode room-temperature operation of Cr:CdSe lasers pumped by a Tm-doped fiber lasers and study quenching and thermal lensing effects [24].

Saturable absorbers (SA) are key points for pulse laser generation. Qi Yang *et al.* fabricated few-layer MXene $Ti_3C_2T_x$ utilized as a SA to realize passively Q-switched visible bulk laser covering the spectral range of orange (607 nm), red (639 nm), and deep red (721 nm). The performances that were achieved indicate that MXene $Ti_3C_2T_x$ SA are promising optical modulators in the visible domain [25]. Z. Li *et al.* demonstrated high-repetition-rate fundamentally Q-switched mode-locked Nd:YAG waveguide laser modulated by platinum diselenide ($PtSe_2$) saturable absorber. The waveguide laser could operate at ~8.8 GHz repetition rate and ~27 ps pulse duration, while maintaining a relatively high slope efficiency of 26% and high stability with signal-to-noise ratio (SNR) up to 54 dB [26].

Concerning nonlinear optics, Y. Kaneda *et al.* present a novel approach for generation at 213 nm, corresponding to the fifth harmonic of the common 1064 nm laser. The approach is scalable in output power. Starting from two infrared fiber laser sources, they demonstrated 0.456 W output at 213 nm [27]. S. Wicharn and P. Buranasiri report on the enhancement of nonlinear cross-polarized wave (XPW) generation in a one-dimensional photonic band-gap structure, composed of two periodic arrangements of barium-fluoride and silicon-dioxide through numerical simulations [28]. N. Hiroumemura *et al.* worked at the determination of accurate Sellmeier equations which reproduces their experimental results for the quasi phase-matching in $LaBGeO_5$ at 22°C with several configurations of polarization over the 0.2660 – 1.0642 µm spectral range [29]. Finally, D. Martyshkin *et al* demonstrated that silicon nitride waveguide can be used for efficient supercontinuum generation spanning more than 1.5 octaves over the 1.2-3.7 µm range when pumped by at 2.35 µm femtosecond oscillator [30].

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