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EDITORIAL

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Frontiers in laser science—cryogenically cooled lasers: editorial

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In this Special Issue on Cryogenically Cooled Lasers, we capture a snapshot of the state-of-the-art laser systems that capitalise on the benefits of operating the gain material at cryogenic temperatures. The principle of operating a solid-state laser with the active medium held at extremely low temperatures is not new, as the second laser ever reported was based upon this technique [1]. However, it appears that the complexity of cryogenic, coupled with, laser engineering, has dampened significant uptake of the technology. Reasons to overcome the challenges were realised at the dawn of the "modern era" of cryogenically cooled lasers, as coined by D.C. Brown [2]. This modern era was heralded, incongruently, by Lacovara et al. [3], with the authors diode-pumping an ytterbium-doped Yttrium Aluminium Garnet (Yb:YAG) laser to demonstrate its potential for room-temperature operation. At the same time, they proved Yb:YAG is an exemplar active medium for power-scaling, epitomised soon after in the form of a thin disk [4]. In the process, also showing the spectroscopic and laser-performance advantages derived from cooling the crystal to cryogenic temperatures. Since that time, Yb:YAG has been the mainstay in power-scaling diode-pumped cryogenically cooled lasers [2, 5].

While ytterbium is the active ion of choice, for its simple energy scheme and suitability for efficient diode-pumping configurations, in the collection of papers in this special issue, we have reports for systems covering nearly all of the key rare earth ions and a semiconductor diode laser. Starting with the lightest of the reported lanthanide ions, Fibrich et al. present a systematic study of praseodymium in the Yttrium Orthoaluminate ($YAlO_3$) perovskite-like host.

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In addition to a rigorous study of its spectroscopy at cryogenic temperatures, the authors demonstrate 0.5 W of output power operating at 493-nm, from an in-band GaN-diode-pumped monolithic laser [6]. Next in the line of the lanthanides, a neodymium-doped YAG cryogenic laser in-band diode-pumped is reported, producing 60 W at 946 nm with an optical to optical efficiency approaching 50% [7]. Moving toward the other end of the series for commonly used rare earth ions, holmium is next. Again, as a dopant of the YAG host, in this case in a slab geometry. The reported laser was also in-band-pumped, exploiting a high-power Tm-fibre laser, with the Ho:YAG laser operated in Q-switching mode, it generated > 130 mJ pulses with a > 60% slope efficiency for repetition rates over 200 Hz [8]. The final selection of papers on rare-earth-ion lasers is all based upon alternate host media, that is sesquioxides and Yttrium Lithium Fluoride (YLF). First, there is a study of the spectroscopy and diode-pumped operation of thulium-doped yttria ($Tm:Y_2O_3$) [9], highlighting the key spectroscopic implications associated with cooling the crystal. Also from the HiLase Centre in the Czech Republic and for the same host material, efficient performance of a cryogenic ceramic-$Yb:Y_2O_3$ laser is also reported [10]. This laser was operated in CW and in passively Q-switched configurations, demonstrating significant improvements in output power associated with operating at cryogenic temperatures. Perevezentsev et. al. also investigate $Yb:Y_2O_3$ in [11], recommending its potential for replacing the workhorse Yb:YAG for cryogenically cooled disk amplifiers for ps-pulses. Furthermore, they report a demonstration of a multi-pass amplifier scheme and show that the gain spectral bandwidth is almost double that of Yb:YAG at liquid nitrogen temperatures. In the last sesquioxide host presented, Brown et. al. report a comprehensive study of the absorption spectroscopic properties of $Yb:Lu_2O_3$ at sub-ambient temperatures [12]. In this paper, critical changes in the electronic–vibronic transitions in function of the crystal temperature are observed and discussed, with parallels in comparable Yb-doped sesquioxide hosts, whether fabricated in single- or poly-crystal (ceramic) forms. As the last cryogenic ytterbium-doped system, an invited contribution by Demirbas et al. from Deutsches Elektronen-Synchrotron (DESY), the authors provide a comparative study of Yb:YLF in both laser and amplifier configurations [13]. Their paper details CW laser powers up to 375 W and 90 W for a regenerative amplifier, from a single gain crystal and explores the power-scaling limits for this gain medium. Exploiting the carefully characterised spectroscopy of the trivalent ytterbium ion in this host, the authors are able to map the temperature inside the gain crystal during different stages of the pump cycle. Coupling the laser and amplifier performance and local temperature rise in the crystals, kW-class single-rod cryogenic Yb:YLF lasers are proposed. Lastly, the performance of cryogenically cooled micro-pin heatsinks for a laser-diode array are characterised and compared with a standard diode heatsinking configuration [14]. The design study shows a reduction in the heat sink thermal impedance by a factor of 2–3 utilising flowing liquid nitrogen coolant, along with an enhancement in the diode-laser output power by ~ 20%. These gains would be expected to provide significant efficiency advantages for future power-scaled semiconductor lasers designed for operation at these cryogenic temperatures.

In conclusion, we hope you enjoy reading these papers in this special issue, paving the way for future advancement of the Frontiers in Laser Science, particularly in the high average and peak power regimes.

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