Micro Solid-State Photonics

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The artistic optical devices should be compact, reliable, efficient and high power light sources. With the approaches of domain structures and boundaries engineering, it is possible to bring the new interaction in their coherent radiation. The high-brightness nature of Yb or Nd doped single crystal or ceramic microchip lasers can realize efficient nonlinear wavelength conversion. In addition, designed nonlinear polarization under coherent length level allows us new function, such as the quasi phase matching (QPM). The development of "***Micro Solid-State Photonics***," which is based on the micro domain structure and boundary controlled materials, opens new horizon in the laser science.

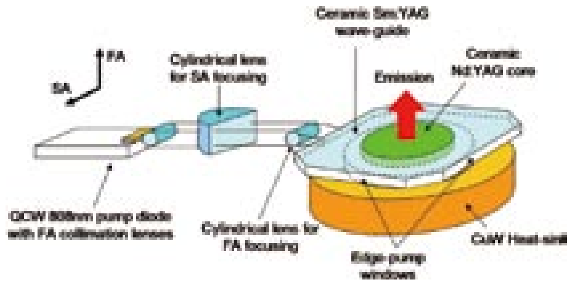

Figure 1. Diode edge-pumped Nd:YAG/Sm:YAG composite all-ceramic microchip laser.

1. Diode Edge-Pumped, Composite Ceramic Nd:YAG/Sm:YAG Microchip Lasers

A diode edge-pump microchip laser has a unique pumping scheme for high power operation. Low thermal distorted, high power operation is possible. The configuration of the edge-pumped microchip laser is more flexible than the well-known, thin-disk laser because there is no need to keep free space in front of the active region for pumping. Then it is possible to arrange an optical switching element such as a Cr:YAG saturable absorber or a nonlinear material close to the core, and a very short laser cavity is possible. Figure 1 shows the schematic of the diode edge-pumped Nd:YAG/Sm:YAG composite all-ceramic microchip laser (active part). The central cylindrical core with a 2mm diameter is 1.5at% Nd doped ceramic YAG. To suppress the parasitic oscillation in the microchip, the core is surrounded by 5at% Sm doped ceramic YAG as an absorber at 1064 nm which is often used as an ASE absorber. The thickness of the microchip is 0.25 mm and bonded on a Cu-W heatsink. In free running operation, the microchip laser emitted 30 mJ at an absorbed pump power of 90 mJ using the output coupler (OC) with a concave curvature of 1 m and 90% reflectivity. In passively Q-switched operation, a pulse energy of 1.76 mJ with a pulse width of 1.5 ns was obtained at an absorbed pump power of 26 mJ by inserting a Cr:YAG saturable absorber with 80% initial transmission into the cavity. The cavity length is 6 mm and the repetition rate is 10 Hz.

2. Laser Oscillation of Nd^{3+}-Doped Photo-Thermo-Refractive Glass under Diode Laser Pumping

The laser action of photo-thermo-refractive glass (PTR) that was the raw material of volume Bragg grating was demonstrated for the first time by introducing Nd^{3+}. An uncoated Nd:PTR generated continuous-wave laser output of 124 mW with a slope efficiency of 25% by laser diode pumping. Nd:PTR has a wide bandwidth of 27.8 nm and 16.0 nm for emission and absorption, respectively. This enabled Nd:PTR to perform wide bandwidth laser action at 1053.9–1063.3 nm, and to hold off the decrease of pump-absorption efficiency below 30% even under 3.5-nm shift of pump wavelength from its absorption center.

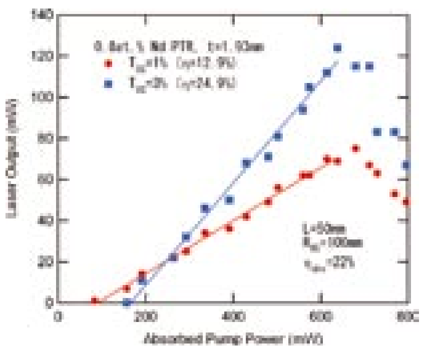

Figure 2. Laser performance of 0.8at.% Nd:PTR with output coupling of 1% and 3%.

3. Development of Anisotropic Transparent Ceramics for Laser Media

Trivalent-rare-earth-ion-doped (RE^{3+}-doped) transparent ceramic materials have attracted much attention as next-generation multifunctional, high-power laser gain media because they have excellent scalability and flexibility. However, fabrication of a laser-grade anisotropic (non-cubic) ceramic medium by the conventional sintering process is not possible because optical scattering occurs at randomly oriented grain boundaries. In this research, we developed a RE^{3+}-assisted magnetic orientation method and applied it for fabrication of ceramic Nd:FAP and Yb:FAP ($Ca_{10}(PO_4)_6F_2$, hexagonal) that have excellent optical properties such as high absorption efficiency, high emission cross-section and long emission lifetime. We successfully improved the transparency of anisotropic ceramics with loss coefficient <1.5 cm^{-1} by optimization of material processing parameters.

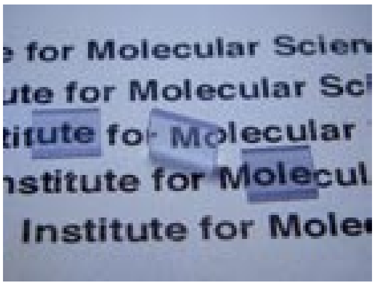

Figure 3. Highly oriented Nd^{3+} doped fluorapatite transparent ceramics (0.5mm thickness) obtained by slip casting under 1.4T magnetic field and subsequent sintering process

4. High Energy Quasi-Phase Matched Optical Parametric Oscillation Using Mg-Doped Congruent $LiTaO_3$ Crystal

We report on high energy optical parametric oscillation of 118 mJ output with ~70% slope efficiency in 10 ns duration of 30 Hz operation by using Mg-doped congruent composition $LiTaO_3$ (MgLT). The periodically poled MgLT device with ~30 µm period for quasi-phase matching (QPM) in 5-mm-thick crystal are prepared. MgLT crystal could become a candidate for high-energy and higher durability material of QPM device, compared to conventional Mg-doped congruent composition $LiNbO_3$.

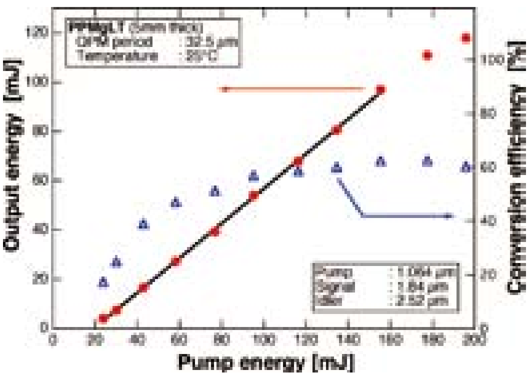

Figure 4. Dependence of total OPO output energy and conversion efficiency on input pump energy.

5. Passively Q-Switched Nd:YAG/Cr^{4+}:YAG Laser with Performances Controlled a Volume Bragg Grating

The large peak emission cross-section of Nd:YAG limits the maximum energy of a passively Q-switched Nd:YAG/Cr^{4+}:YAG laser equipped with a normal output coupler (OCM), which typically has a reduced wavelength selectivity. We demonstrated a diode end-pumped, high-peak power, passively Q-switched Nd:YAG/Cr^{4+}:YAG laser and controlled its performances with a volume Bragg grating (VBG). The laser pulse energy was increased significantly (by a factor of two or more) by elevating Nd:YAG temperature and locking the emission wavelength (λ_{em}) with the VBG. Furthermore, wavelength λ_{em} was tuned by changing the VBG temperature, while maintaining ns-order short laser pulses of mJ-level energy.

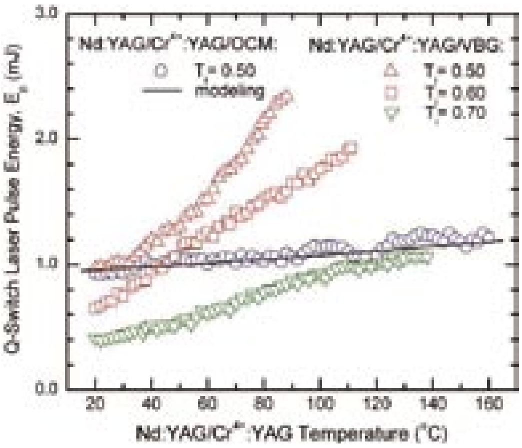

Figure 5. Q-switch laser pulse energy versus temperature of Nd:YAG/Cr^{4+}:YAG crystals. Cr^{4+}:YAG of various initial transmission T_i; output coupling mirror with transmission T = 0.70; VBG at 20 °C.

References

1) M. Tsunekane and T. Taira, *Tech. Digest of Europhoton 2010* WeP8 (2010).
2) Y. Sato, T. Taira, V. Smirnov, L. Glebova and L. Glebov, *Tech.Digest of Conf. on Lasers and Electro-Optics (CLEO2010)* CTuJ-4 (2010).
3) J. Akiyama and T. Taira, *OSA Topical Meeting on Advanced Solid-State Photonics 2010* AtuB3 (2010).
4) H. Ishizuki and T. Taira, *Opt. Express* **18**, 253–258 (2010).
5) N. Pavel, M. Tsunekane and T. Taira, *Opt. Lett.* **35**, 1617–1619 (2010).