Micro Solid-State Photonics

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"*Micro Solid-State Photonics*," based on the micro domain structure and boundary controlled materials, opens new horizon in the laser science. The engineered materials of micro and/or microchip solid-state, ceramic and single-crystal, lasers can provide excellent spatial mode quality and narrow linewidths with enough power. High-brightness nature of these lasers has allowed efficient wavelength extension by nonlinear frequency conversion, UV to THz wave generation. Moreover, the quasi phase matching (QPM) is an attractive technique for compensating phase velocity dispersion in frequency conversion. The future may herald new photonics.

Giant pulse > 10 MW was obtained in 1064nm microchip lasers using micro-domain controlled materials. The world first laser ignited gasoline engine vehicle, giant-pulse UV (355 nm, 266 nm) and efficient VUV (118 nm) pulse generations have been successfully demonstrated. Also, few cycle mid-IR pulses for atto-second pulses are demonstrated by LA-PPMgLN. We have developed new theoretical models for the micro-domain control of anisotropic laser ceramics. These functional micro-domain based highly brightness/brightness-temperature compact lasers and nonlinear optics, so to speak "Giant Micro-photonics," are promising. Moreover, the new generation of micro and/or microchip lasers by using orientation-controlled advanced ceramics can provide extreme high performances in photonics.

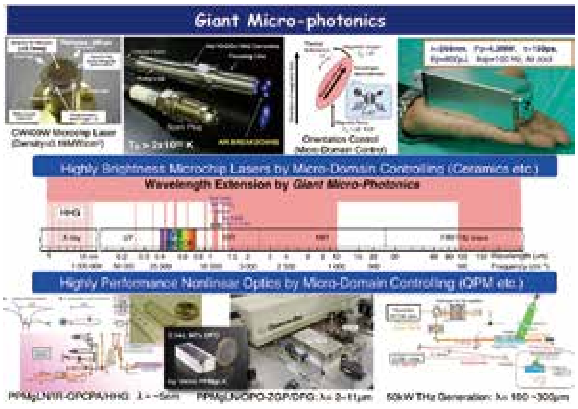

Figure 1. Giant micro-photonics.

Selected Publications

- H. Sakai, H. Kan and T. Taira, ">1 MW Peak Power Single-Mode High-Brightness Passively Q-Switched Nd^{3+}:YAG Microchip Laser," *Opt. Express* **16**, 19891–19899 (2008).
- M. Tsunekane, T. Inohara, A. Ando, N. Kido, K. Kanehara and T. Taira, "High Peak Power, Passively Q-Switched Microlaser for Ignition of Engines," *IEEE J. Quantum Electron.* **46**, 277–284 (2010).
- T. Taira, "Domain-Controlled Laser Ceramics toward Giant Micro-Photonics," *Opt. Mater. Express* **1**, 1040–1050 (2011).
- H. Ishizuki and T. Taira, "Half-Joule Output Optical-Parametric Oscillation by Using 10-mm-Thick Periodically Poled Mg-Doped Congruent $LiNbO_3$," *Opt. Express*, **20**, 20002–20010 (2012).
- R. Bhandari, N. Tsuji, T. Suzuki, M. Nishifuji and T. Taira, "Efficient Second to Ninth Harmonic Generation Using Megawatt Peak Power Microchip Laser," *Opt. Express* **21**, 28849–28855 (2013).

1. Giant-Pulse $Nd:YVO_4$ Microchip Laser with MW-Level Peak Power by Emission Cross-Sectional Control

Giant-pulse generation laser realized by the emission cross-section control of a gain medium in a passively Q-switched $Nd:YVO_4$ microchip laser with a Cr^{4+}:YAG saturable absorber. Up to 1.17 MW peak power and 1.03 mJ pulse energy were obtained with a 100 Hz repetition rate. By combining the $Nd:YVO_4$ crystal with a Sapphire plate, lower temperature difference between a pump region in the gain crystal and a crystal holder was obtained which helped to keep the cavity in stability zone at elevated temperatures and allowed the achievement of the high peak power for this laser system.

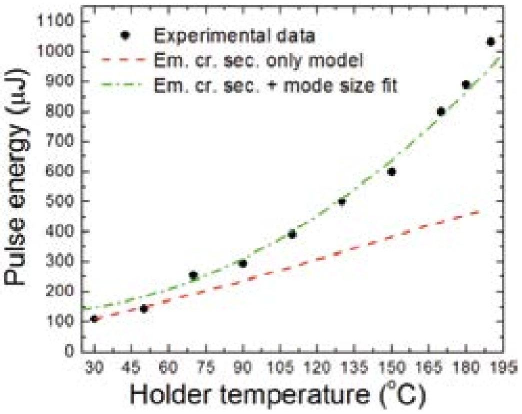

Figure 2. Experimental results of giant-pulse Sapphire/$Nd:YVO_4$ micro-laser.

2. Optical Gain in the Anisotropic Yb:FAP Laser Ceramics

Currently well-aligned anisotropic laser ceramics can be produced by only the orientation control by slip-casting under the magnetic field, therefore our methods should be the solution for appreciating advantages of anisotropic laser gain media and ceramic gain media, simultaneously. We fabricated Yb:FAP fluorapatite (FAP) ceramics by means of 1.4-T rotational magnetic field. If it can perform the optical amplification, it can be the best candidate of the gain medium for lasers with the extreme high brightness.

The experimental setup is shown in Figure 3. Uncoated *c*-cut Yb:FAP ceramic sample with the thickness of 0.6 mm was positioned with Brewster angle to the optical path. The fluorescence from the sample was detected by the spectrometer through the pump-cut filter (both of setup-a and -b) and the mirror-2 (only setup-b). As a result, fluorescence from anisotropic Yb:FAP laser ceramics was amplified to 2.8 times by constructing an optical resonator.

This amplification indicates that the laser-diode pumping formed the optical gain comparable to the optical loss in Yb:FAP ceramics. We are now expecting we can realize laser oscillation by use of the optical gain in Yb:FAP ceramics.

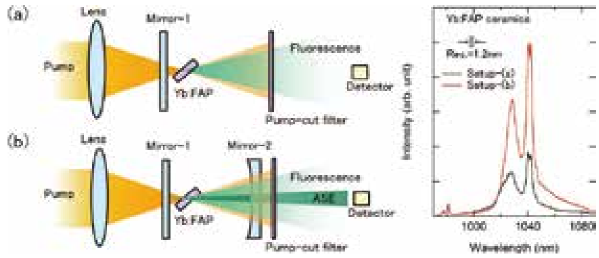

Figure 3. Experimental setup for the detection of fluorescence from Yb:FAP ceramics and their signals. (a) Without output coupler. (b) With output coupler.

3. Periodic Laminar Structured Quartz for Quasi-Phase Matched Wavelength Conversion

Crystal quartz, used in the first second harmonic generation (SHG) by Franken *et al.* in 1961, is one of major nonlinear material. Although its excellent optical properties, such as short absorption edge and high laser-damage threshold, its small birefringence has limited practical applications by conventional birefringent phase matching scheme.

Recent progress of laser-system development enabled to use intense short pulses with narrow spectra between ps and sub-ns pulse region, and periodic laminar structure (PLS) quartz pumped by the intense laser have became practical choice for next-generation wavelength-conversion device.

Figure 4(a) shows improvement of SHG-green output energy by PLS quartz. Resulting SHG by 48-plates stacking was increased 500 times higher than single-plate, non-phase matched SHG. Figure 4(b) shows SHG output on input pump energy of 48-plates PLS quartz. Maximum output energy of 8 μJ with 0.54 ns pulse duration could be obtained. Wavelength conversions such as third and forth harmonic generation by PLS quartz pumped by intense MCL can be also expected.

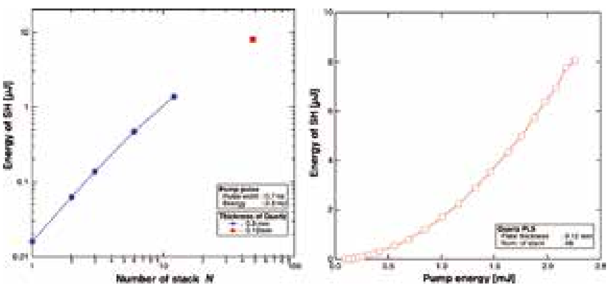

Figure 4. (a) Improvement of SHG output by PLS, (b) SHG output on input pump energy at 48-plates PLS.

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1) A. Kausas and T. Taira, *Opt. Express* **24**, 3137–3149 (2016).

2) Y. Sato, J. Akiyama and T. Taira, *CLEO/Europe 2015*, CA-P.8 (June 21–25, 2015).

3) H. Ishizuki and T. Taira, *The 63rd JSAP Spring meeting 2016*, 21a-S611-4 (Mar. 19–22, 2016).