Micro Solid-State Photonics

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Awards
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Keywords Solid-State Lasers, Nonlinear Optics, Micro Solid-State Photonics

"*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.

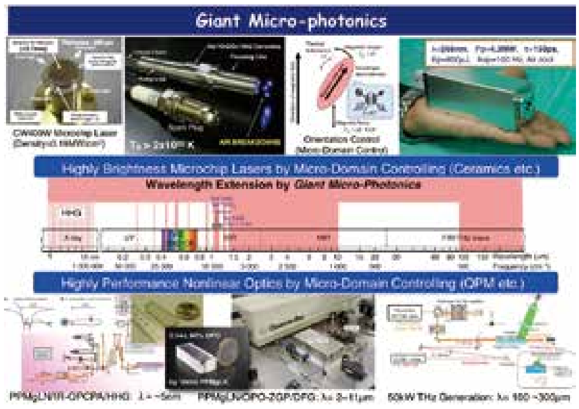

Figure 1. Giant micro-photonics.

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. Thermal Reduction through Distributed Face Cooling (DFC) in a High Power Giant-Pulse Tiny Laser

Sapphire/Nd^{3+}:YAG based DFC chip was obtained with thermal reduction as compared with those from conventional Nd^{3+}:YAG chip. The CW diode laser pumped round-trip cavity loss was 0.51% from a 9-disk DFC chip, which was close to theoretically calculated total Fresnel reflection loss of 0.2% from 8 Sapphire/Nd^{3+}:YAG interfaces. The depolarization ratio from 8-disk DFC chip was 40 times lower than that from YAG/Nd^{3+}:YAG chip. The DFC chip underwent no crack at pump power of 86 W while Nd^{3+}:YAG single chip suffered crystal crack under pump power around 54 W, as shown in Figure 2.

Over megawatt peak power from DFC tiny integrated laser was demonstrated at 1 kHz with 3-pulse burst modes. It is concluded that DFC structure could relieve thermal effects as expected.

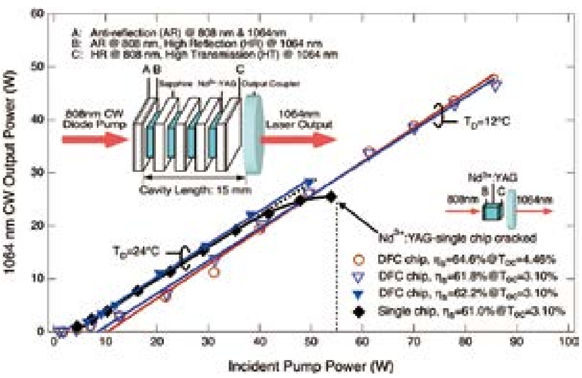

Figure 2. Output power from DFC chip under continuous wave laser pump. T_D is the temperature of diode laser.

2. Q-switching Laser Oscillation of Microdomain-Controlled Yb:FAP Laser Ceramics

The process control of microdomains with quantum mechanical calculations is expected to increase the optical power extracted per unit volume in gain media. Design of extensive variables allows us to evaluate the crystalline magnetic anisotropy in microdomains. Using this process control, we generate over 2 kW laser output from orientation-controlled microdomains made of Yb:Fluoroapatite (FAP).

In Figure 3, we compared the repetition rate and extraction energy density as the figure of merit for Giant-microphotonics, where our microdomain-controlled Yb:FAP laser ceramics showed excellent future possibility of power scaling.

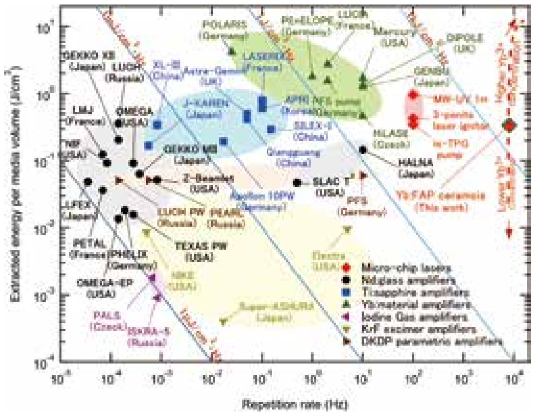

Figure 3. The figure of merit for Giant-microphotonics.

3. Crystal Quartz for High-Intensity, Sub-Nanosecond Wavelength Conversion

Crystal quartz for high-intensity wavelength conversion was evaluated. Pure durability of crystal quartz for sub-ns pulse region at 1.064 μm irradiation was measured as 602 GW/cm^2, which was 2-times higher than undope YAG crystal. QPM-structured quartz constructed by multi-plate stacking was evaluated by a sub-ns high-energy MCL-MOPA pumping. Maximum SH energy of 250 μJ could be obtained at E_p = 52 mJ with conversion efficiency of 0.48% as shown in Figure 4(a). Increasing characteristics of maximum E_{SH} on plate-stacking number N at E_p = 50~55 mJ is shown in Figure 4(b). Our experimental results well fitted the N^2-characteristics of the QPM characteristics.

As a result, availability of crystal quartz for high-intensity wavelength conversion could be demonstrated. QPM quartz is expected for both high-intensity operation and short-wavelength conversion.

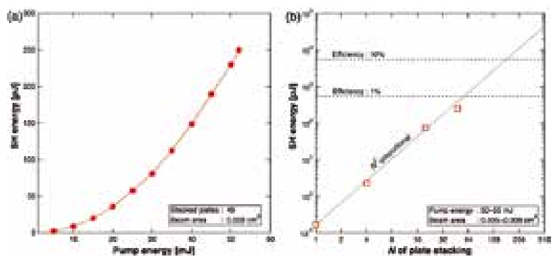

Figure 4. (a) SH energy on pump energy at N = 48, and (b) SH energy on stack number N.

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1) L. H. Zheng, A. Kausas and T. Taira, *Opt. Mater. Express* **7**, 3214–3221 (2017).
2) Y. Sato, J. Akiyama and T. Taira, *Sci. Rep.* **7**, 10732 (2017).
3) H. Ishizuki, V. Yahia and T. Taira, *Opt. Mater. Express* **8**, 1259–1264 (2018).

Award

TAIRA, Takunori; The Commendation for Lazer Advancement of Taizan Prize (2017).

* IMS International Internship Program