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.

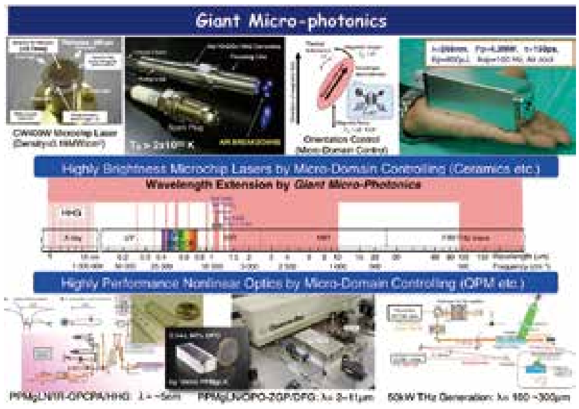

Figure 1. Giant micro-photonics.

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. >MW Peak Power at 266 nm, Low Jitter kHz Repetition Rate from Intense Pumped Microlaser

Intense pulse pumped microlaser is proposed for high peak power and low timing jitter at high repetition rate. It is based on Intense and Fast Pulse Pump (IFPP) technique, in which fast pulse pumps up the upper-level population and then dumps it rapidly by Q-switching. That could come close to complete pumping efficiency to reduce thermal problems and contribute to suppress the timing jitter of passively Q-switched laser. In this work, linearly polarized 1064 nm beam from [100]-cut YAG/Nd^{3+}:YAG and [110]-cut Cr^{4+}:YAG passively Q-switched microlaser is directly guided into nonlinear crystals to obtain 532 nm and 266 nm output. By implementing IFPP concept, over 1 MW peak power, 215 ps pulse duration, 1 kHz pulses at 266 nm with reduced standard deviation timing jitter of 37 ns were obtained.

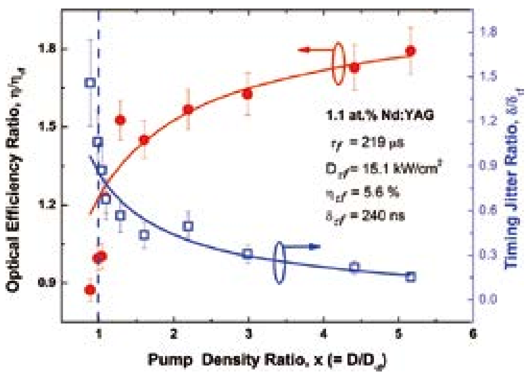

Figure 2. Optical efficiency ratio $\eta/\eta_{\tau f}$ and timing jitter ratio $\delta/\delta_{\tau f}$ as a function of pump power density ratio $D/D_{\tau f}$ at 1 kHz.

2. Sub-Nanosecond Laser Induced Air-Breakdown with Giant-Pulse Duration Tuned Nd:YAG Ceramic Micro-Laser by Cavity-Length Control

Laser induced breakdown (LIB) in air has been explained by different ways along pulse duration τ. Cascade ionization (CI) is considered as the mechanism for long pulse durations of over 1 ns. On the other hand, laser filamentation is alternative mechanism for fs pulses. However, for intermediate ps pulse, the mechanism is unclear due to a lack of knowledge about air-breakdown in sub-ns region and a contribution of multi-photon ionization. In addition, the knowledge about pulse duration dependence of breakdown energy in gas is practically useful for laser ignition. We first demonstrated a continuously giant-pulse duration tunable (0.5–9 ns) laser based on a short monolithic Nd:YAG/Cr:YAG ceramic by cavity-length control. LIB in laboratory air was investigated as a function of τ in sub-ns region using the developed laser. Air-breakdown threshold intensity I_{th} was measured using three different focusing conditions (Figure 3). We confirmed that (1) the measured I_{th} was almost constant at the longer τ than τ_{CI} named as limit-pulse-duration of CI, (2) I_{th} had ~τ^{-2} scaling for $\tau < \tau_{CI}$, (3) the increase of I_{th} is not connected to a specific intensity level, and (4) τ_{CI} was not constant and depended on focusing conditions.

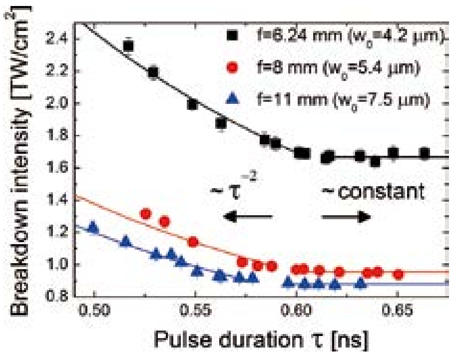

Figure 3. Measured breakdown threshold intensities as a function of pulse duration in laboratory air for three focusing conditions.

3. Damage Threshold Evaluation by Bulk-Shaped Nonlinear and Laser Materials

Laser-induced damage threshold (LIDT) of various optical materials, such as crystal quartz, YAG, and glass at sub-nanosecond pulse duration are evaluated. Bulk-shaped materials are used in the LIDT evaluation as shown in Figure 4, which can eliminate surface effects, such as adhesive dirt and polishing quality.

Evaluation were demonstrated using a laser source with 0.7-ns pulse-duration of 1.064 μm wavelength. LIDT of crystal quartz for piezoelectric and optical purpose were measured around 700 GW/cm^2 and 900 GW/cm^2, respectively. Also, LIDT of Nd:YAG and borosilicate glass were measured around 400 GW/cm^2 and 610 GW/cm^2, respectively.

Although conventional plate-shape measurement should be affected by its plate-surface condition, measurement using the bulk-shaped material can evaluate pure material characteristics.

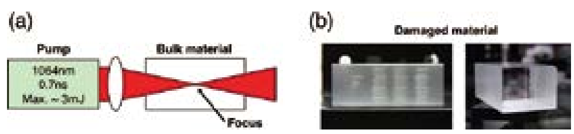

Figure 4. Laser-induced damage threshold evaluation using bulk-shaped material. (a) Set up of evaluation, (b) Example of damaged material.

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2) H. H. Lim and T. Taira, *Opt. Express* **25**, 6302–6310 (2017).
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* IMS International Internship Program