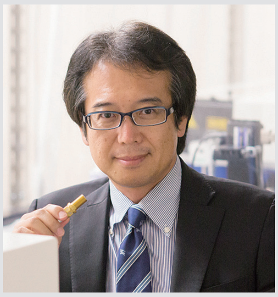
Micro Solid-State Photonics

Division of Research Innovation and Collaboration



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Professional Employment
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Awards
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2012 SPIE Fellow Award, The International Society for Optical Engineering (SPIE)
2014 IEEE Fellow Award, The Institute of Electrical and Electronics Engineers (IEEE)
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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. With the engineered materials of micro ceramic and single-crystal, solid-state 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: The world first laser-ignited car, high efficiency broad frequency conversions from the wavelength of 118nm VUV to 300µm–1mm THz waves, and so on. In addition, the quasi-phase matching (QPM) is an attractive technique for compensating phase velocity dispersion in frequency conversion. Lately, we propose a new architecture to realize a monolithic multi-disk laser by the surface activated bonding (SAB). This multiple thin-disk or chip gain medium for distributed face cooling (DFC) structure can manage the high-power and high-field laser with high-gain compact system. Besides, QPM-structured crystal quartz constructed by multi-plate stacking could be promising as a high-power and reliable VUV frequency conversion devices. These downsized and modularized **tiny integrated lasers** (TILA) promise the extremely high-brightness lasers to open up the new science, such as laser driven electron accelerator toward table-top XFEL, and innovation by the compact power laser (Figure 1).

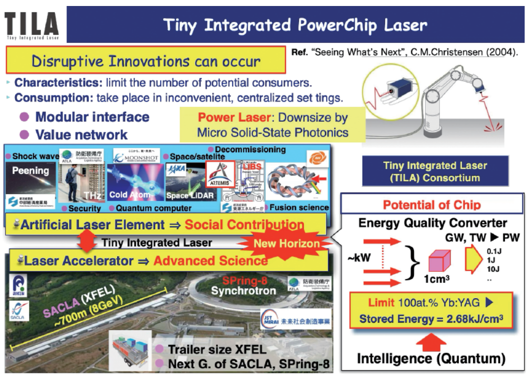

Figure 1. TILA consortium toward "Laser Science and Innovation" by micro solid-state photonics.

Selected Publications

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- T. Taira, *IEEE J. Sel. Top. Quantum Electron.* **13**, 798 (2007).
- T. Taira, *Opt. Mater. Express* **1**, 1040 (2011).
- Y. Sato *et al.*, *Sci. Rep.* **7**, 10732 (2017).
- H. Sakai *et al.*, *Opt. Express* **16**, 19891 (2008).
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- T. Taira *et al.*, *The 1st Laser Ignition Conference '13, OPIC '13, Yokohama, April 23-26*, LIC3-1 (2013).
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- L. Zheng *et al.*, *Opt. Mater. Express* **7**, 3214 (2017).
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- S. W. Jolly *et al.*, *Nat. Commun.* **10**, 1 (2019).
- Y. Sano *et al.*, *Forces in Mechanics* **7**, 100080 (2022).
- V. Yahia *et al.*, *Opt. Express* **32**, 14377 (2024).

1. Scaling Narrowband THz Generation to Large Apertures in $LiNbO_3$ and KTP[1)]

An attractive approach for generating high peak-power multicycle terahertz radiation (MC-THz) pulses is nonlinear optical down-conversion of laser pulses in periodically-poled crystals. A principal limitation to the yield, however, is the small (sub-centimeter) apertures of commercially-available crystals which restrict the amount of laser energy that can be used. Here, we explore MC-THz generation by down conversion in two types of large-aperture media for which periodic poling has been achieved in different ways: (1) extension of traditional, voltage-based poling of bulk material to larger (centimeter) scales; and (2) manual poling by assembly of large aperture sub-millimeter thick wafers in alternating orientations. We explore the dependence of efficiency on laser peak fluence and crystal length for both types of media and extend upon previous work with the wafer approach by increasing the number of wafers in the stack, implementing cryogenic cooling and testing an alternate material: Potassium titanyl phosphate (KTP). Driving with up to 0.2 J, half-picosecond laser pulses centered at 1,030 nm, we obtain conversion efficiencies of up to 0.14%, resulting in ~1% bandwidth MC-THz pulses of up to 207 μJ. (Figure 2).

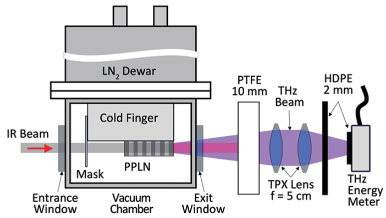

Figure 2. Optical layout showing the periodically-poled device mounted to the cold finger inside the cryostat.

2. Enhanced Thermal Conductivity of Distributed Face-Cooled Composite Laser Medium Included Thermal Resistance at the Bonding Interface[2)]

A new concept of the effective thermal conductivity (κ_{eff}) of the laser gain medium with the distributed face-cooled composite synthesized by the inter-layer surface activated bonding (il-SAB) has been proposed. The thermal resistances at the bonded interface (R) between 1at.% Nd:YAG and a c-cut sapphire single crystal in several composites were experimentally confirmed, and it was found that il-SAB brings negligibly small R. On the contrary, R in the bi-layer composite of 1at.% Nd:YAG and sapphire sandwiching indium foil fabricated by 6.0-kN uniaxial pressing reached 1.4×10^{-5} m^2K/W at 25 °C. In the case of the simple contact of 1at.% Nd:YAG and a sapphire single crystal, R at 25 °C was 4.3×10^{-4} m^2K/W. Consequently, effective thermal conductivities in bi-layered composites with 1at.% Nd:YAG and c-cut sapphire with the same thickness fabricated by il-SAB, sandwiching indium foil, and simple contacting without bonding were evaluated to be 15.3 W/mK, 13.9 W/mK, and 3.65 W/mK, respectively. Negligible R of composite gain media by il-SAB indicates that κ_{eff} of 1at.% Nd:YAG will be improved from 10 W/mK to more than 30 W/mK if sapphire parts are thicker than 12.2 times of YAG parts in composite gain media with the distributed face-cooling structure. (Figure 3).

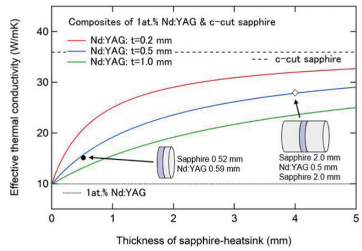

Figure 3. The dependence of κ_{eff} on the ratio of the thickness between Nd:YAG single crystal and sapphire heatsink in DFC-PowerChip.

3. Generation of High-Energy Laser Pulses at 266 nm with Sub-Nanosecond Pulse Duration and 20 Hz Repetition Rate[3)]

We developed a high-energy laser system using a microchip laser with a sub-nanosecond pulse duration and power amplifiers employing Distributed Faced Cooling, achieving pulse energies exceeding 2 J at a repetition rate of 20 Hz. This report presents the results of wavelength conversion based on this laser, achieving 266 nm in the Deep UV (DUV) range. Using KD*P crystals for wavelength conversion, we obtained a maximum pulse energy of 235 mJ at 2 Hz. However, the short pulse duration of approximately 580 ps from the microchip laser seed source causes nonlinear absorption in the crystal, challenging the conversion to 266 nm. That is why, we generated 532 nm through second harmonic generation (SHG) in LBO1, then 355 nm by SFG of the 532 nm pulse and the residual fundamental wave in LBO2, and finally 266 nm by SFG of the 355 nm and the residual fundamental wave in LBO3. We developed a high-energy UV laser system using LBO crystals, achieving 266 nm DUV pulses with a maximum pulse energy of 111 mJ and peak power of 190 MW at a 20 Hz repetition rate. (Figure 4).

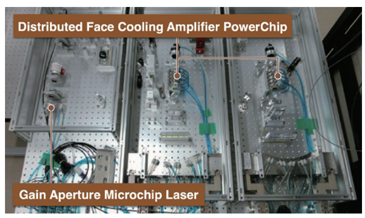

Figure 4. Experimental setup of compact Deep-UV sub-nanosecond pulsed laser system with world-class output power.

References

1) N. H. Matlis *et. al.*, *Opt. Express* **32**, 33875–33893 (2024).
2) Y. Sato and T. Taira, *Opt. Express* **33**, 24039–24049 (2025).
3) K. Hirosawa *et al.*, *CLEO/Europe-EQEC 2025*, CA-6 (2025).

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