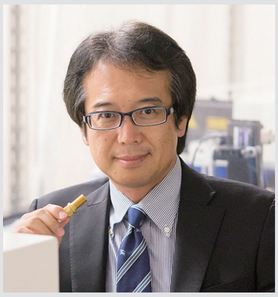
Micro Solid-State Photonics

Division of Research Innovation and Collaboration



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1993 Visiting Researcher, Stanford University (–1994)
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2018 Group Director, RIKEN SPring-8 Center
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Awards
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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: The world first laser ignited car, highly efficiency broad frequency conversions from the wavelength of 118nm VUV until 300–500µm 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).

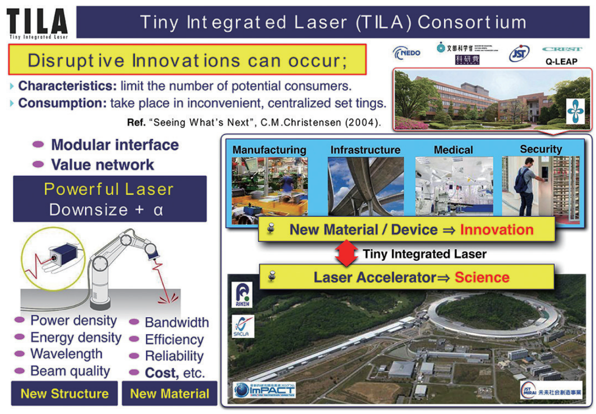

Figure 1. TILA consortium toward "Laser Science and Innovation" by micro solid-state photonics.

Selected Publications

- T. Taira *et al.*, *Opt. Lett.* **16**, 1955 (1991).
- T. Taira *et al.*, *IEEE J. Sel. Top. Quantum Electron.* **3**, 100 (1997).
- 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).
- M. Tsunekane *et al.*, *IEEE J. Quantum Electron.* **46**, 277 (2010).
- T. Taira *et al.*, *The 1st Laser Ignition Conference '13, OPIC '13, Yokohama, April 23-26*, LIC3-1 (2013).
- R. Bhandari *et al.*, *Opt. Express* **21**, 28849 (2013).
- S. Hayashi *et al.*, *Sci. Rep.* **4**, 5045 (2014).
- L. Zheng *et al.*, *Opt. Mater. Express* **7**, 3214 (2017).
- H. Ishizuki *et al.*, *Opt. Mater. Express* **8**, 1259 (2018).
- N. H. Matlis *et al.*, *Nucl. Instrum. Methods Phys. Res., Sect. A* **909**, 27 (2018).
- S.W. Jolly *et al.*, *Nat. Commun.* **10**, 1 (2019).

1. Radiation Dose Rate Effects on the Properties of a Laser-Induced Breakdown Spectroscopy System Developed Using a Ceramics Micro-Laser for Fiber-Optic Remote Analysis[1)]

Radiation dose rate effects on the properties of a compact fiber-optic laser-induced breakdown spectroscopy (LIBS) system with a monolithic Nd:YAG/Cr:YAG composite ceramics were investigated for remote analysis in a hazardous environment. To investigate radiation effects on the LIBS signal, properties related to the Nd:YAG laser operation such as oscillation threshold, output energy, oscillation timing, temporal pulse shape, and beam profile was measured as a function of the radiation dose rate from 0 to 10 kGy/hr in view of their influences to the signal (Figure 2). LIBS spectra of zirconium metal were measured under irradiation. Although signal intensity decreased considerably by irradiation, informative spectra were well obtained even at the maximum radiation dose rate. From the comparison of the LIBS-related parameters among the laser properties, the signal reduction was mainly ascribed to the pulse energy reduction. Scintillation emission spectra were also measured from the ceramics during the irradiation, where the signal intensity increased linearly with the dose rate. The results show that the developed system is applicable to effective remote elemental analysis and monitoring of radiation dose rate in hazardous environments such as nuclear fuel debris inspection.

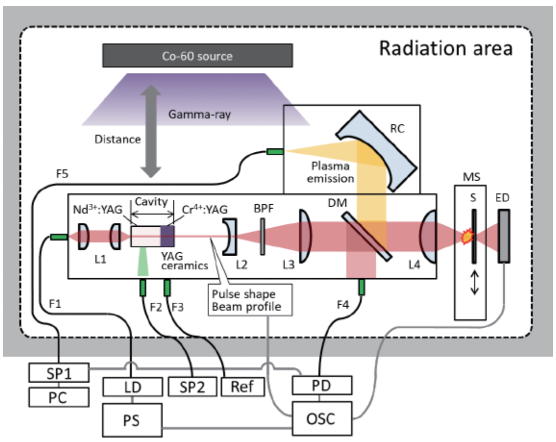

Figure 2. Experimental setup to study the properties of the FO-MC LIBS system in radiation environment.

2. Deformation Properties of Laser Peen Forming Using Sub-Nanosecond Microchip Laser[2)]

A high-power pulsed microchip laser, which has a pulse duration of sub-nanosecond order, had been developed. A focused microchip laser pulse can induce an effective shock wave for deforming the irradiated metal surface plastically. When a sheet metal is scanned by the laser, dieless sheet forming, called laser peen forming, is achieved through the accumulation of such plastic deformations. The authors have applied the method to sheet metal bending (Figure 3). A tamping layer, such as water, on a target surface encourages laser-induced shock waves. Therefore, the sheet metals were irradiated in water. Several materials were bent, and the feasibility of the process was confirmed. Fundamental deformation properties in teams of forming parameters, such as defocusing, pulse energy, material hardness, and thickness, were examined. It was confirmed that, qualitatively, the process had similar deformation modes to those obtained by peen forming. However, when fluence was greatly increased by focusing the pulse energy, laser absorption by water reduced the bending deformation.

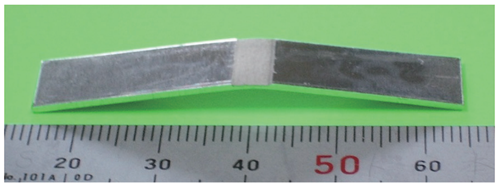

Figure 3. Example of bend workpiece (A1100, t = 1 mm).

3. Study on the Specific Heat of $Y_3Al_5O_{12}$ between 129 K and 573 K[3)]

We measured the isopiestic specific heat (C_P) of $Y_3Al_5O_{12}$ (YAG) by the differential scanning calorimetry aiming to obtain thermal parameters under cryogenic and room-temperature (RT) conditions. It was also found that the applicable temperature range of our numerical model for C_P of YAG was updated to the range between 129 K and 573 K with below 3% error. Obtained parameters were verified by the comparative study with the first principles calculations. Discrepancy between the calculation value and measured value at 273 K was 0.017 J/gK in C_P. Figure 4 also shows the reason why reported ΘD of YAG has been variated from 500 K to 900 K. ΘD shows the dependence to gradually decrease T towards 0 K and to gradually increase ΘD over 800 K, and to gradually increase T over 600 K under the isopiestic condition and to gradually decrease ΘD toward below 500 K.

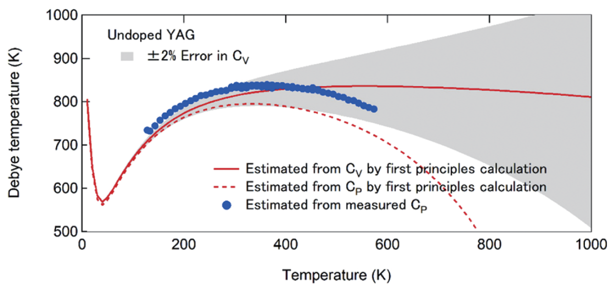

Figure 4. Temperature dependence of ΘD by our model.

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1) K. Tamura, H. Ohba, M. Saeki, T. Taguchi, H. H. Lim, T. Taira and I. Wakaida, *J. Nucl. Sci. Technol.* **58**, 405 (2020). DOI: 10.1080/00223131.2020.1854880

2) Y. Sagisaka, T. Kawasaki, V. Yahia, T. Taira and Y. Sano, *Journal of the JSTP* **62**, 8 (2021). (in Japanese). DOI: 10.9773/sosei.62.8

3) Y. Sato and T. Taira, *Opt. Mater. Express* **11**, 551 (2021). DOI: 10.1364/OME.416480