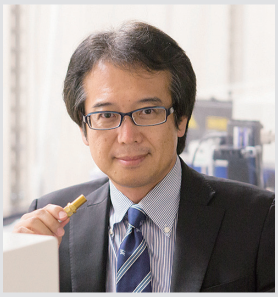
RESEARCH ACTIVITIES

Division of Research Innovation and Collaboration

As the open innovation hub managed by IMS and companies, we conduct the research projects in collaboration with Academia, Industry and Government.

Micro Solid-State Photonics

Division of Research Innovation and Collaboration



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Education

1983	B.A. Fukui University
1985	M.S. Fukui University
1996	Ph.D. Tohoku University

Professional Employment

1985	Researcher, Mitsubishi Electric Corp.
1989	Research Associate, Fukui University
1993	Visiting Researcher, Stanford University (–1994)
1998	Associate Professor, Institute for Molecular Science Associate Professor, The Graduate University for Advanced Studies
2018	Group Director, RIKEN SPring-8 Center
2019	Project Professor, Institute for Molecular Science
2023	Invited Professor, National Institute for Fusion Science
2023	Director, The Amada Foundation

Awards

2004	Persons of Scientific and Technological Research Merits, Commendation by Minister of Education, Culture, Sports, Science and Technology, Japan
2010	OSA Fellow Award, The Optical Society (OSA)
2012	SPIE Fellow Award, The International Society for Optical Engineering (SPIE)
2014	IEEE Fellow Award, The Institute of Electrical and Electronics Engineers (IEEE)
2018	IAPLE (The International Academy of Photonics and Laser Engineering) Fellow
2019	LSJ (The Laser Society of Japan) Fellow

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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. 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).

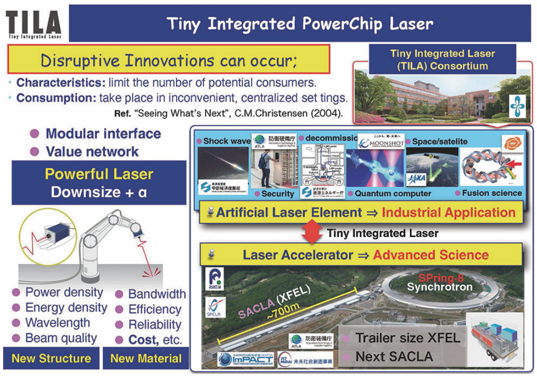

Figure 1. TILA consortium toward "Laser Science and Innovation" by micro solid-state photonics.

Selected Publications

- 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).
- 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. Uncovering Gold Nanoparticle Synthesis Using a Microchip Laser System through Pulsed Laser Ablation in Aqueous Solution[1)]

The synthesis of gold nanoparticles (Au NPs) was carried out by utilising the pulsed laser ablation in liquids (PLAL) method with a microchip laser (MCL) system. This portable system features low power consumption and a giant-pulse laser. Aqueous solutions with and without the surfactant poly(N-vinyl-2-pyrrolidone) (PVP) were used for laser ablation of a bulk gold rod to achieve the successful formation of a colloidal solution of Au NPs. The gas bubbles formed by heating the aqueous medium around the surface of the gold target significantly reduced the efficiency of Au NP ablation. This effect was more pronounced and prolonged in high-viscosity solutions, hindering energy transfer from subsequent laser pulses to the target. Additionally, it was suggested that the chain length of PVP does not affect either the size of the Au NPs or the ablation efficiency. The relatively short pulse duration of the MCL system may contribute to the formation of NPs with consistent size, which were suppressed to grow in significantly smaller cavitation bubbles with short lifetimes.

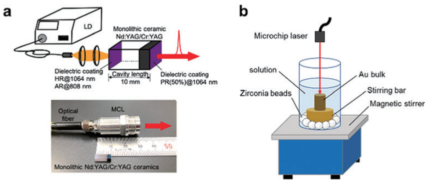

Figure 2. (a) Composition of the MCL system and the scale of the MCL laser head; (b) setup of PLAL system in the present research.

2. Joule-Class Sub-Nanosecond Pulses Produced by End-Pumped Direct Bonded Yag/Sapphire Modular Amplifier[2)]

A Joule-class room-temperature diode-pumped solid-state laser was developed. The energy scaling of the 100 mJ and 1064 nm seed pulse was realized by a series of two diode-pumped amplifiers. The gain medium consists in free combinations of Nd:YAG ceramics bonded to sapphire transparent heat sinks, to relax the thermal load induced by the 34 kW pump power. At low repetition rate, parasitic lasing was the main limitation to energy scaling. By choosing a gain module combination producing a step-like gradual doping concentration profile, mitigation of parasitic oscillations was observed, and the system delivered 2.8 J and 800 ps pulses at 2 Hz (Figure 3).

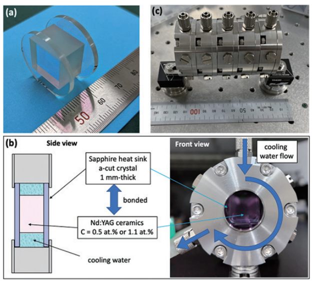

Figure 3. (a) Example of Nd:YAG ceramics with bonded sapphire end-caps that are used for the gain modules. (b) Design of a single independent gain module. (c) Modular gain medium consisting in a series of five modules.

3. Development of a Radiation Tolerant Laser-Induced Breakdown Spectroscopy System Using a Single Crystal Micro-Chip Laser for Remote Elemental Analysis[3)]

For the development of the remote elemental analysis method in a radiation environment based on the laser-induced breakdown spectroscopy (LIBS), the radiation effects on the laser oscillation properties of the single crystal (SC) Nd:YAG MCL were investigated and compared with those of ceramic Nd:YAG MCL. The laser oscillation properties were measured under gamma ray irradiation as a function of dose rate. The effects on the SC MCL properties were very small compared to those on the ceramics, indicating minimal radiation effects on the LIBS signal when using SC MCL. Pulse energy and oscillating build-up time (BUT) were measured for cumulative dose exceeding 1400 kGy. The results indicate that the effects of dose rate and cumulative dose on SC MCL laser properties are minimal. The SC MCL was then integrated into the LIBS system, and the gadolinium signal was successfully measured at a dose rate of 5 kGy/hr. These findings highlight the radiation tolerance of SC MCL for remote LIBS applications in harsh radiation environments (Figure 4).

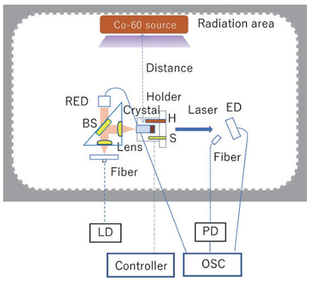

Figure 4. Experimental setup (BS: beam splitter; controller: temperature controller; crystal: YAG crystal; ED, RED: energy detector; fiber: optical fiber; H: heater; holder: specimen holder; LD: laser diode; lens: lens; OSC: oscilloscope; PD: photodiode; S: temperature sensor).

References

1) B. S. Hettiarachchi, Y. Takaoka, Y. Uetake, Y. Yakiyama, H. H. Lim, T. Taira, M. Maruyama, Y. Mori, H. Y. Yoshikawa and H. Sakurai, *Ind. Chem. Mater.* **2**, 340–347 (2024).

2) V. Yahia, A. Kausas, A. Tsuji, M. Yoshida and T. Taira, *Opt. Express* **32**, 14377–14393 (2024).

3) K. Tamura, R. Nakanishi, H. Ohbaa, T. Karino, T. Shibata, T. Taira and I. Wakaidab, *J. Nucl. Sci. Technol.* **61**, 1109–1116 (2024).

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† IMS International Internship Program