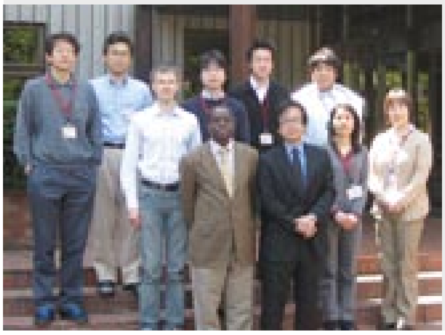
Micro Solid-State Photonics

Laser Research Center for Molecular Science
Division of Advanced Laser Development



TAIRA, Takunori	Associate Professor
ISHIZUKI, Hideki	Assistant Professor
AKIYAMA, Jun	IMS Fellow
TSUNEKANE, Masaki	Post-Doctoral Fellow*
SATO, Yoichi	Post-Doctoral Fellow
SAIKAWA, Jiro	Post-Doctoral Fellow†
OISHI, Yu	Post-Doctoral Fellow‡
MATSUSHITA, Tomonori	Post-Doctoral Fellow
ONO, Yoko	Secretary
INAGAKI, Yayoi	Secretary

The artistic optical devices should be compact, reliable, efficient and high power light sources. With the approaches of domain structures and boundaries engineering, it is possible to bring the new interaction in their coherent radiation. The high-brightness nature of Yb or Nd doped single crystal or ceramic microchip lasers can realize efficient nonlinear wavelength conversion. In addition, designed nonlinear polarization under coherent length level allows us new function, such as the quasi phase matching (QPM). The development of "***Micro Solid-State Photonics***," which is based on the micro domain structure and boundary controlled materials, opens new horizon in the laser science.

1. High Peak Power, Passively Q-Switched Cr:YAG/Nd:YAG Micro-Laser for Ignition of Engines

Our high peak power, micro-laser igniter was first applied for a real automobile engine. A commercial engine of 1AZ-FSE (TOYOTA Motor Corp.) which is a 2.0 L, straight-4 piston engine with a gasoline direct injection system was prepared. The ignition point of a laser is set to be the same point as a spark plug. In this experiment, three of four cylinders (from #1 to #3) were ignited by conventional spark plugs and a #4 cylinder was ignited by our laser. Each ignition timing was carefully controlled and optimized. The repletion rates of the igniters are 13.3 Hz corresponding to an engine speed of 1600 rpm. Schlieren photographies of the early stage of ignition and subsequent combustion in a real engine are shown in Figure 1. The left figure shows the image of a conventional spark plug ignition and the right shows the laser ignition. The A/F is 14.5 which is a stoichiometric mixture of gasoline and air. It should be emphasized that a single laser pulse with an energy of 2mJ can successfully ignite a real engine. We think it will be the lowest energy ever reported for laser ignition of a real automobile engine. High brightness, passively Q-switched micro-laser could reduce the ignition energy dramatically compared to previous ignition lasers and also a spark plug. We further demonstrated the first prototype micro-laser module which had the same dimension as a spark plug as shown in Figure 2.

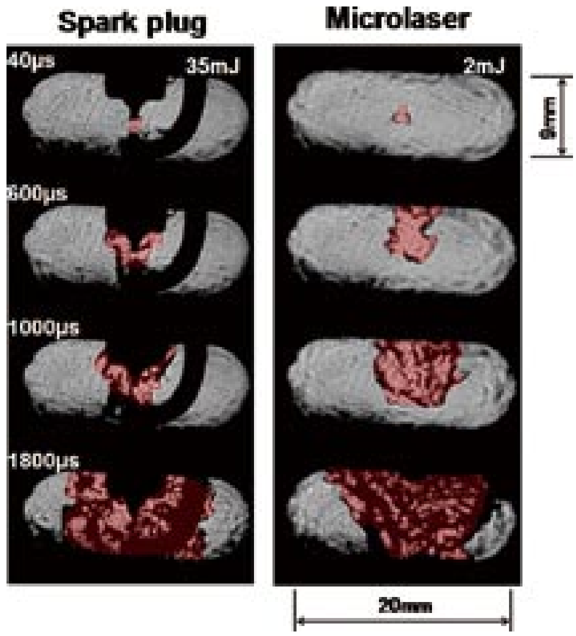


Figure 1. Schlieren photographs of the flame kernel ignited by a spark plug (a) and the micro-laser (b) in a constant volume combustion chamber at 6 ms after ignition trigger.

Figure 2. First prototype micro-laser module (right), which has the same dimension as a spark plug (left).

2. Spectroscopic Characteristics of Nd^{3+}-Doped Photo-Thermo-Refractive Glass

Considering recent spreading of laser resonator control that uses volume Bragg diffraction grating (VBG), it is convenient for VBG to have an ability of laser action. VBG is made of photo-thermo-refractive (PTR) glass, therefore we have evaluated the spectroscopic properties of Nd^{3+}-doped photo-thermo-refractive glass (Nd:PTR). From absorption characteristics we can estimate radiative lifetime of Nd:PTR by Judd-Ofelt analysis to be 861 µs while quantum efficiency of 0.8at.% Nd:PTR is considered to be 57.6%. Authors assures that Nd:PTR is the promised laser medium due to wide absorption and emission bandwidth, long fluorescent lifetime.

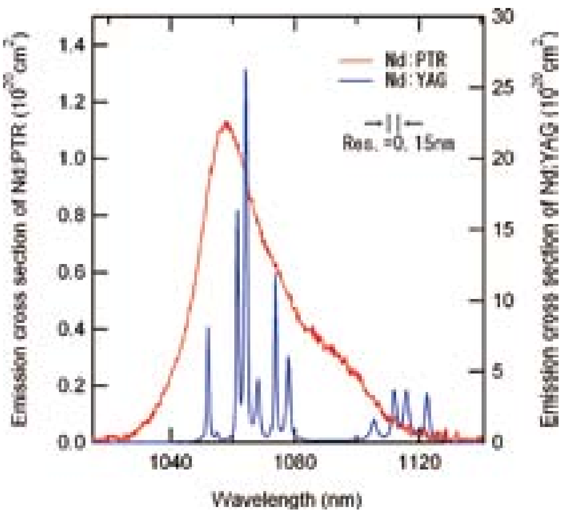


Figure 3. Emission cross section of Nd:PTR. Center wavelength of fluorescence is 1058 nm with a very wide emission bandwidth of 28nm that is useful for tuning by Bragg grating.

3. Broadly and Continuously Tunable, High-Energy Optical Parametric System by Angular Tuning of Tilted QPM Structures

We proposed a broadly and continuously tunable high-energy colinear optical parametric systems by using a periodically poled Mg-dpoped $LiNbO_3$ (MgLN) device with tilted quasi-phase matching (QPM) structures as shown in Figure 4, and experimentally demonstrated expanded tuning characteristics of the tilted QPM devices. The resulting tuning ranges of signal wave were 0.22 µm (1.50 µm ~ 1.72 µm), 0.13 µm (1.45 µm ~ 1.58 µm), for tilted QPM device with QPM period Λ_0 = 28.0, 29.0 µm, in device-rotation angle θ_1 from –10° to +10°. Combination of angular rotation and tilted QPM structure is effective for compact and broadband-tunable coherent light source, especially for high refractive index crystals, as MgLN.

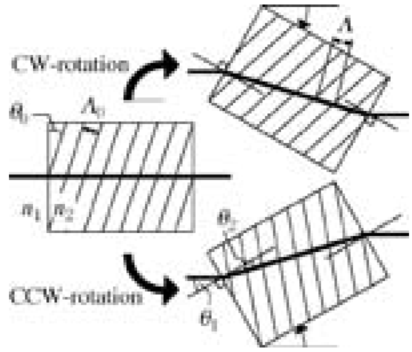


Figure 4. Broad and continuous tuning of optical parametric system by angular tuning of tilted QPM device.

4. Formation of Anisotropic Laser Ceramics

Rare-earth doped transparent ceramics (polycrystalline materials) have attracted considerable attentions as the next generation laser gain media due to their capability for engineered structure and improved mechanical properties. In this study, we have newly established "Rare-earth assisted electromagnetic material processing" which is a precise grain orientation controlling method for transparent *anisotropic* laser ceramics. We applied it for fabrication of rare-earth doped FAP ($Ca_{10}(PO_4)_6F_2$) materials and successfully obtained the uniaxially oriented laser grade Nd^{3+}:FAP ceramics as shown in Figure 5 by imposition of a feeble (1.4 tesla) static magnetic field during slip-casting process.

Figure 5. Macro photograph of Nd^{3+} doped transparent FAP ceramics.

References

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* from JST Innovation Plaza Tokai
† from Tokyo Institute of Technology
‡ from RIKEN