SHG Laser using YAG Ceramics for Light Source of Photofabrication

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1. Introduction
Since Nd-doped YAG laser material was first discovered by Guesic et al.[1] in 1964, progress in the fabrication technique has rapidly improved its optical quality. In recent years, Nd:YAG (Nd:Y₃A₁₅O₃₀) lasers have been applied with remarkable success to various industrial fields such as medical operation [2,3], metal processing [4], and others. Only single crystals created by the Czochralski (Cz) technique [5,6], however, have been used as laser materials.

Attempts and success to synthesize solid-state laser material from polycrystalline YAG ceramics have been reported only by present authors. Because a solid-state laser demands severe optical requirements, however, synthesizing Nd:YAG laser material of polycrystalline ceramics is technically very difficult. The present work produced polycrystalline, transparent Nd:YAG with optical characteristics nearly equal to those of a single crystal. The green laser using Nd:YAG produced by that method oscillated successfully for the first time by diode laser excitation.

2. Experimental Procedure
To fabricate the specimens [7,8], those starting powders were weighed so that the Nd content in the resultant YAG ceramics would be 4.8 at.%. After the A₁O₃, Y₂O₃, and Nd₂O₃ powders had been mixed with 0.5 mass% of TEOS (Tetraethyl Orthosilicate) as a sintering aid, the mixture was milled for 12 h with high-purity A₁O₃ balls. The milled slurry was dried using a spray dryer. The granulated, spherical powders, measuring less than 50 μm in diameter, were isostatically pressed to disks 16 mm in diameter. The powder compacts sintered at 1750 °C for 20 h under vacuum (1.3x10⁻³ Pa) using a high-vacuum furnace. The fabricating details are similar to those of our previous works [7,8].
Figure 1 shows a schematic diagram of the laser oscillation device. A specimen 8 mm in diameter and 1.6 mm thick was polished on both surfaces below Ra of 0.3 nm microroughness to $\lambda/10$ ($\lambda=633$ nm) flatness, and to a parallelism of 10 s.

![Figure 1 Schematic diagram of the diode pumped SHG laser using Nd:YAG ceramics. The surfaces of Nd:YAG ceramics were only polished.](image)

A reflection mirror, half mirror, and KTP (KTiOPO$_4$) non-linear single crystal situated in parallel on both sides of the specimen. The specimen the was exited continuously with an 809 nm diode laser, and the laser beam of SHG of Nd:YAG (532 nm) emitted from the half mirror was measured using optical power meter.

3. Results and Discussion

Figure 2 shows reflection microscope photographs of 4.8at% Nd:YAG ceramics after thermal etching. The specimens consisted of grains measuring several tens of micrometers, and perfect pore-free structure. The pore density of present ceramics is extremely lower (about several ppm) than that of conventional ceramics, so that the optical scattering loss of polycrystal Nd:YAG ceramics is equivalent to that of high-quality Nd:YAG single crystal by Cz method.

![Figure 2 Surface of transparent Nd:YAG ceramics after thermal etching.](image)

Figure 3 indicates the laser oscillation properties of both specimens. The threshold for the Nd:YAG ceramics and single crystal was nearly equal each other. It exceeded that of the Nd:YAG single crystal with increased exciting power, consequently, the laser power of ceramics is 4 times compared with that of single crystal.

However, YAG single crystals doped with more than 1 at.% of elemental Nd have been very difficult to fabricate by the Cz method because the effective segregation coefficient [9] of Nd for the YAG single crystal is quite low (~0.2). The use of YAG single crystals doped with more than 1.5 at.% of elemental Nd has not been reported for laser devices because of their inferior optical quality. If the Nd content doped into a YAG single crystal surpasses 1 at%, the crystal growth rate of the Nd:YAG single crystal must be maintained at a very low value, below 0.2 mm/h, to eliminate inclusions such as Nd compounds ((NdY)AlO$_3$) [9]. The difficulty in stabilizing YAG single crystals with higher dopings of Nd arises because Nd$^{3+}$ has a larger ionic radius (0.112 nm) than that of Y$^{3+}$ (0.102 nm). The solubility of Nd for polycrystalline ceramics is larger than that of single crystal by Cz method. The chemical composition between single crystal and polycrystal ceramics is different each other. Namely, small amount of Si decomposed from TEOS is doped in the polycrystal ceramics, and is not intentionally doped in single crystal.
When small amount of Si\textsuperscript{4+} ions are displaced with Al\textsuperscript{3+} ions in YAG lattice, the lattice constant of Nd:YAG ceramics slightly decrease. In contrast with this result, the lattice constant of Nd:YAG ceramics increase with increasing Nd content. To form stable YAG structure, the lattice constant of Nd:YAG ceramics must always have constant (ca. 1.20 nm). The doped Si in YAG lattice can be acceptable large distortion, which is introduced by displacement Y\textsuperscript{3+} with Nd\textsuperscript{3+} ions. Role of Si on Nd solid-solution of YAG ceramics is discussed in previous paper.\textsuperscript{[10]}

Figure 4 shows green laser oscillation by intra-cavity optical resonator using KTP non-linear single crystal. The green laser using polycrystalline materials has been oscillated also first case in the world. The output power of SHG (secondary harmonic generation) laser was only 30 mW in present work. High power laser between green and ultra-violet wavelength using the photofabrications will be discussed near future report. The ceramics lasers will provide new optical technology for various industrial capacity in the future.

4. Conclusions

The results of the present works can be summarized as follows.
1) Nd:YAG ceramics with laser grade was fabricated successfully by sintering method.
2) Laser power (fundamental wavelength) of Nd heavily-doped YAG ceramics was higher than that of Nd:YAG single crystal.
3) SHG laser oscillation was performed successfully for the first time using Nd:YAG ceramics.

References