Spontaneous Mathieu-Gauss mode oscillation in micro-grained Nd:YAG ceramic lasers with azimuth laser-diode pumping

Shu-Chun Chu
Department of Physics, College of Sciences, National Cheng Kung University
scchu@mail.ncku.edu.tw

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Non-diffractive beams, including Bessel-Gauss and Mathieu-Gauss (BG, MG) modes, are promising for sophisticated micromachining and for trapping microparticles and manipulating them over longer distances than any other optical tweezers. In this study, Mathieu-Gauss mode oscillations were observed in micro-grained isotropic Nd:YAG microchip ceramic lasers with azimuth laser diode pumping.

Figure 1 shows the laser cavity configuration, which was the semi-focal type consisting of a flat mirror $M_1$ (95% transmission at 808 nm; 99.9% reflectance at 1064 nm) and a spherical mirror of 10-mm radius of curvature $M_2$ (99% reflectance at 1064 nm) separated by 5 mm. The 1-mm-thick micrograined Nd:YAG ceramic of 1 at.% Nd concentration was attached to $M_1$ and the cavity was assembled into one body as depicted in Fig. 1. The averaged grain size was measured to be 1.1 μm. The collimated linearly polarized LD beam was passed through an anamorphic prism pair and focused onto the sample by a microscope objective lens of NA= 0.25, where the focused beam diameter was about 60 μm. The laser exhibited a single-frequency TEM00-mode oscillation, which was linearly polarized along the LD pump-beam polarization direction as a result of the reduced thermal birefringence, for the mode- matched pumping condition, where the threshold pump power was 40 mW [4,5].

When the laser cavity was shifted and tilting slightly as depicted by arrows in Fig. 1, i.e., azimuth pumping, and the effective off-axis gain region was controlled as depicted in Fig. 1, a variety of MG mode operations were observed.
observed. Typical far-field patterns, are shown in Fig. 2(a). Numerically reproduced intensity patterns corresponding to Fig. 2(b) and the phase portraits are shown in Fig. 2(c).

We replaced the micro-grained Nd:YAG ceramic by 1 at.%-doped Nd:YAG ceramic samples with average grain sizes of several tens of micrometers, which exhibited spontaneous segregations into local transverse modes possessing different frequencies and polarization states, resulting from spatially dependent thermal birefringence. With azimuth LD pumping, single frequency IG (Ince-Gauss) mode oscillation was achieved as a result of the increased lasing beam diameter with respect to the average grain size [9]. However, as with anisotropic crystals, neither BG nor MG mode oscillations appeared. Examples are shown in Fig. 3.
Laser oscillations in BG and MG modes are usually obtained in cavities with an axicon-type lens or mirror [6, 10] such that interference between conical lasing fields occurs within the laser cavity. In the present experiment, BG MG mode oscillations were produced just by azimuth LD pumping with micro-grained Nd:YAG ceramic laser crystal. Let us offer a plausible explanation for MG mode oscillations in terms of effective off-axis pumping the polarization state is almost completely determined by the polarization of the pump radiation for an isotropic cavity with micro-grained Nd:YAG ceramic [4,5]. For azimuth LD pumping, the laser emission tends to occur such that its polarization direction follows the LD polarization direction within the pumped area. Let us assume a small reflection loss difference at un-coated surfaces of the thermal lens, which possesses a pump-dependent gradient refractive index distribution, between polarizations along radial and azimuth directions. With the two effects combined, the laser polarization state may depend on the pump-beam position and size, i.e., gain area, if the LD polarization direction is fixed. In anisotropic or large-grain Nd:YAG ceramic lasers, the laser polarization state is determined by fluorescence anisotropies or local thermal birefringence independently of the pump polarization, and neither BG nor MG mode oscillations take place.