Concentration-dependent laser performance of Yb:YAG ceramics

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Abstract: Laser performance of Yb:YAG ceramics and single-crystals doped with different Yb concentrations was investigated using two-pass pumping miniature laser configuration. Better laser performance was observed for heavy-doped Yb:YAG ceramic than single-crystal (C_{Yb} = 20 at.%).

OCIS codes: 140.3380 (Laser materials), 140.3480 (Lasers, diode-pumped), 140.3580 (Lasers, solid-state), 140.5680 (Rare earth and transition metal solid-state lasers).

1. Introduction

Transparent laser ceramics [1] fabricated by the vacuum sintering technique and nanocrystalline technology [2] have been proven to be potential replacements for counterpart single crystals because they have several remarkable advantages compared with single-crystal laser materials, such as high concentration and easy fabrication of large-size ceramics samples, multilayer and multifunctional ceramics laser materials. Efficient and high power laser operation in Nd^{3+}- and Yb^{3+}-ions doped YAG ceramics has been demonstrated [1, 3]. The thin disk laser has been demonstrated to be a good way to generate high power with good beam quality owing to the efficiently cooling of gain medium and good overlap of the pump beam and laser beam [4]. The thinner the gain medium, the better the cooling effect, therefore, heavy doped Yb:YAG gain media are the better choice for such lasers. Optical spectra of Yb:YAG ceramics doped with different Yb^{3+}-lasant concentration (C_{Yb} = 9.8, 12, and 20 at.%) and efficient Yb:YAG ceramic microchip lasers [3] and heavy-doped Yb:YAG ceramic lasers[5] have been reported recently. In principle, there is no concentration quenching effect in Yb:YAG, however, the unwanted impurities (such as Er^{3+}, Tm^{3+}, Ho^{3+}, and so on) from raw materials and formation of Yb cluster will be deleterious to the laser performance owing to the high activator doping. Here, we report on the Yb concentration-dependent performance of miniature Yb:YAG (C_{Yb} = 9.8, 12, and 20 at.%) ceramic lasers at 1030 nm with two-pass pumping scheme. The results show that Yb:YAG ceramics are nearly comparable to or better than their counterpart single crystals depending on the Yb doping concentration.

2. Experimental setup

Figure 1 shows a schematic diagram of the experimental setup for laser-diode pumped Yb:YAG miniature laser. Plane-parallel, 1-mm-thick Yb:YAG ceramics (C_{Yb} = 9.8, 12, and 20 at.%) were used as gain medium. One surface of the sample was coated for antireflection both at 940 nm and 1.03 µm. The other surface was coated for total reflection at both 940 nm and 1.03 µm, acting as one cavity mirror and reflecting the pump power for increasing the absorption of the pump power. Plane-parallel fused silica output couplers with transmission (T_{oc}) of 5 and 10% were mechanically attached to the gain medium tightly. A high-power fiber-coupled 940 nm laser diode with a core diameter of 100 μm and numerical aperture of 0.22 was used as the pump source. Optical coupling system with two lenses (M1 and M2) of different focal length was used to focus the pump beam on the ceramic rear surface and to produce a pump light footprint on the ceramic of about 170 μm in diameter. The laser spectrum was analyzed by using an optical spectrum analyzer. Comparable Yb:YAG single crystals single-crystals (C_{Yb} = 10, 15, and 20 at.%) were used to compare the laser characteristics with those of Yb:YAG ceramics.

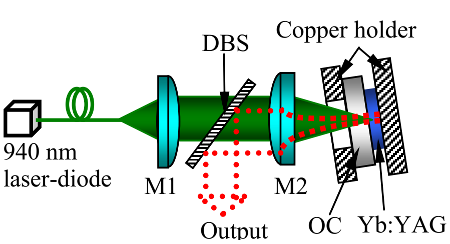

Fig. 1. Schematic diagram of laser-diode pumped Yb:YAG ceramic miniature lasers. DBS, dichroic beam splitter; OC, output coupler; M1, focus lenses with focal length of 8 mm; M2, focus lenses with focal length of 15 mm.

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3. Results and discussion

Figure 2 shows the output power and optical efficiency of miniature Yb:YAG ceramics and single-crystal lasers as a function of the absorbed pump power for different Yb concentrations and T_{oc}. The absorbed pump power thresholds of Yb:YAG ceramics (C_{Yb} = 9.8, 12, and 20 at.%) were 0.3, 0.33, and 0.64 W for T_{oc} = 5% and 0.33, 0.5, 0.68 W for T_{oc} = 10%. For Yb:YAG ceramics doped with different Yb concentration, the output power increases linearly with absorbed pump power for T_{oc} = 5 and 10%. Maximum output power of 2.54 W was measured for T_{oc} = 5% by using 12 at.% Yb:YAG ceramic as gain medium when the absorbed pump power was 5.3 W. The corresponding slope efficiency was about 55%, optical-to-optical efficiency was about 48%. For T_{oc} = 5%, the output power of 20 at.% Yb:YAG ceramic laser increases linearly with absorbed pump power, but the slope efficiencies will decrease with the absorbed pump power at high pump power level. All analogous parameters for Yb:YAG single crystal lasers [as shown in Fig. 2(b)] were obtained, and were better than those for Yb:YAG ceramics doped with 10 and 12 at.% Yb^{3+}-ions [see Fig. 2(a)]. However, laser performance of 20 at.% Yb:YAG single crystal was much worse than those for Yb:YAG ceramic lasers [see Fig. 2(a)]. The results of conducted experiments show that heavy doped Yb:YAG ceramic is better than its single crystal counterpart although Yb:YAG ceramics doped with 10 and 12 at.% Yb are not as good as their single crystal counterparts. Figure 2(c) and 2(d) shows the optical-to-optical efficiencies of Yb:YAG lasers as a function of absorbed pump power. There is no saturation effect of Yb:YAG lasers with different output couplings for Yb concentration equal to or less than 15 at.% although the optical efficiency increases slowly with the absorbed pump power. However, for 20 at.% Yb:YAG, there is saturation effect of ceramic lasers with T_{oc} = 5% and single-crystal lasers with different output couplings. Maximum optical efficiency of 48% was achieved for Yb:YAG ceramic doped with 12 at.% Yb at the absorbed pump power of 5.3 W. For single crystal doped with 20 at.% Yb lasants, there is a maximum optical efficiency for all output couplings [as shown in Fig. 2(d)]. The optical-to-optical efficiency will decrease with further increase of the pump power.

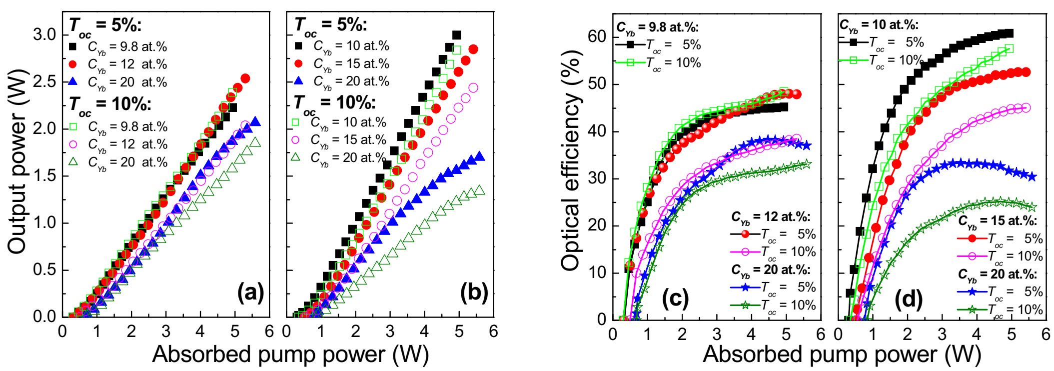

Fig. 2. Output power of (a) Yb:YAG ceramic and (b) Yb:YAG single crystal; and optical efficiencies of (c) Yb:YAG ceramic and (d) Yb:YAG single crystal miniature laser as a function of absorbed pump power for different Yb concentrations and transmissions of the output coupler.

4. Conclusions

In conclusion, the laser performance of Yb:YAG ceramics become worse with Yb concentration, the similar phenomenon was observed in Yb:YAG single crystals. The laser performance of low doping Yb:YAG ceramics is worse than those obtaining from Yb:YAG singly crystals. The laser performance of 20 at.% Yb:YAG ceramics is better than its counterpart single crystal. Heavy-doped Yb:YAG ceramic will be a potential candidate for high-power thin-disk lasers.

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