Spectral and laser properties of Yb and Ho co-doped $(YLa)_2O_3$ transparent ceramic*

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Highly transparent Yb, Ho doped $(YLa)_2O_3$ ceramic was fabricated by conventional ceramic processing with nanopowders. The absorption and emission spectra of the ceramic was investigated. The energy transfer mechanism between Yb^{3+} and $Ho^{3+}$was also discussed. The strong emission band around 2 μm indicated that the Yb–Ho:$(Y_{0.90}La_{0.10})_2O_3$ transparent ceramic is a promising gain medium for the generation of 2 μm laser emissions. The laser operation of Yb–Ho co-doped $(YLa)_2O_3$ ceramic at 2.1 μm is first reported.

Keywords: Yb–Ho doped $(YLa)_2O_3$, transparent ceramic, spectral properties, 2 μm laser

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1. Introduction

Recently, Ho^{3+} doped laser materials have drawn extensive attention because 2 μm eye-safe lasers are attractive for optical communication, coherent laser radar, atmospheric sensing and medical equipment.[1–4] The trivalent holmium ion (Ho^{3+}) itself is a good candidate for the generation of 2 μm laser emissions due to its ample energy levels, large stimulated emission cross section, and long fluorescence lifetime (8 ms).

However, Ho^{3+}ions have no absorption band near 800 nm or 900–1000 nm, so the direct excitation of Ho^{3+} with common diode lasers is inefficient. The most common sensitizer for Ho^{3+}doped materials is Tm^{3+} or Yb^{3+}, because the absorption band of Tm^{3+} or Yb^{3+} is close to 800 nm or 900–1000 nm and the energy transfer between Yb^{3+} or Tm^{3+} with Ho^{3+} helps to generate 2 μm lasers. The ytterbium-sensitized energy transfer is particularly attractive due to ytterbium's broad absorption band and the availability of high-power InGaAs laser diodes for excitation.

Y_2O_3 is a promising laser material due to its low phonon energy and high thermal conductivity compared to YAG.[5–7] Unfortunately, a single-crystalline yttria is difficult to obtain by using conventional growth methods. Developments in laser ceramic technology have increased the availability of sesquioxide laser host materials.[8,9] Recently, the Ho:Y_2O_3 ceramic fabricated in Japan was used to achieve 2 μm lasers.[10] In our previous work, we found that the sintering temperature can be further decreased with La_2O_3 doped as a sintering additive.[11]

In this paper, we fabricated the Yb–Ho:$(YLa)_2O_3$ transparent ceramic by using commercial nanopowders via a solid-state reaction method and hydrogen-sintering technology. The microstructure and spectral properties of the Yb–Ho:$(YLa)_2O_3$ transparent ceramic were reported. We tried two different pump sources (980 nm and 1910 nm) for the laser experiment, and obtained a laser output under 1910 nm.

2. Experiment

High purity (99.99%) commercial nanopowders of Ho_2O_3, Yb_2O_3, Y_2O_3, and La_2O_3 were used as the starting materials. These powders were weighted according to the stoichiometry of $(Ho_{0.01}Yb_{0.05}Y_{0.84}La_{0.10})_2O_3$, and then ball milled in alcohol for 5 h. After drying, the powder mixture was dry-pressed with low pressure into disks in a steel mold. Then the disks were isostatically pressed at 200 MPa into green bodies. After being sintered for 45 h under a H_2 atmosphere at 1650 °C without pressure, the specimens were polished on both sides for spectral measurements.

The microstructure was observed with an optical microscope (BX60, OLYPMUS, Japan). The absorption spectrum was measured with a spectrophotometer (Model V-570, JASCO) using Xe light as the pump source. The emission spectra were measured with a fluorescence spectral analyzer (Trix-550, Jobin Yvon Spex, France) under the excitation of a 980 nm laser diode (LD), of which the resolution is 1–2 nm.

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3. Results and discussion

Figure 1 is a photograph of Yb–Ho: $(YLa)_2O_3$ transparent ceramic, which has a high transparency. Owing to the doping of La_2O_3 as an additive, the ceramic was obtained at a sintering temperature of 1650° without pressure, about 100° lower than the typical sintering temperature of the Y_2O_3 transparent ceramic. The earlier experiments have shown that there is no influence on the optical properties of the Y_2O_3 transparent ceramic by doping La_2O_3 as the additive.[12,13]

Fig. 1. (color online) Photo of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic (3 mm thick).

Figure 2 displays an optical microscopic photograph of the Yb–Ho:$(YLa)_2O_3$ ceramic. It reveals that the grain size is around 50 μm. The dense microstructure with uniform grains ensures a high optical quality.

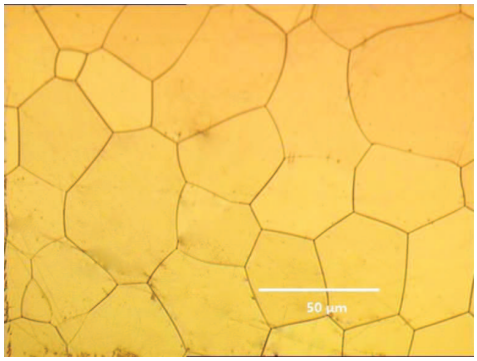

Fig. 2. (color online) Optical microscopic photograph of the Yb–Ho: $(YLa)_2O_3$ ceramic.

The transmittance of the ceramic is shown in Fig. 3. The transmittance reaches above 80% near the infrared range but is relatively low in the visible range. The size of the pores is possibly close to the visible wavelengths, leading to a low transmittance in the visible range. The significant drop of transmittance near 980 nm is due to the strong absorption of Yb^{3+}.

Figure 4 shows the up-conversion emission spectrum of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic in the range of 300–850 nm under the excitation of 980 nm LD. Three emission bands centered at 554 nm, 668 nm, and 755 nm are found. The green emission centered at 554 nm corresponds to the $^5S_2/^5F_4 \rightarrow {}^5I_8$ transition of Ho^{3+} ions. The two-photon energy transfer (ET) process from excited Yb^{3+} ions is the dominant pathway to promote the Ho^{3+} ions to the $^5S_2/^5F_4$ state.[13] The emission around 755 nm is assigned to the $^5S_2/^5F_4 \rightarrow {}^5I_7$ transition. The nonradiative relaxation from the $^5I_6$ state is the other pathway for populating the $^5I_7$ state of Ho^{3+} ions. The relatively weaker red (668 nm) emission is assigned to the $^5F_5 \rightarrow {}^5I_8$ transition. The $^5F_5$ state is populated by the energy transfer (ET) process from Yb^{3+} to Ho^{3+}, $^2F_{5/2}(Yb) + {}^5I_7(Ho) \rightarrow {}^2F_{7/2}(Yb) + {}^5F_5(Ho)$.

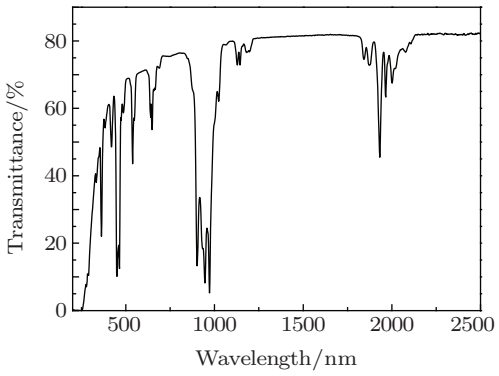

Fig. 3. Transmittance of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic (3 mm thick).

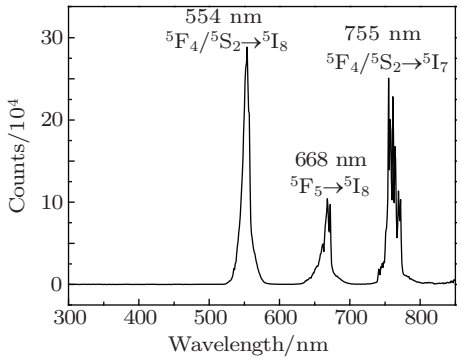

Fig. 4. Up-conversion luminescence spectrum of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic ($\lambda_{ex} = 980$ nm).

Figure 5 is the emission spectrum of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic in the range of 1800–2200 nm which is diode-pumped at 980 nm. The emission peaks centered at 1939 nm, 1974 nm, 2014 nm, and 2083 nm are due to the stark energy level splitting of $^5I_7$ in Ho^{3+}. The broad emission band around 2 μm indicates that the Yb–Ho: $(YLa)_2O_3$ transparent ceramic is a promising gain medium for the generation of 2 μm laser emissions.

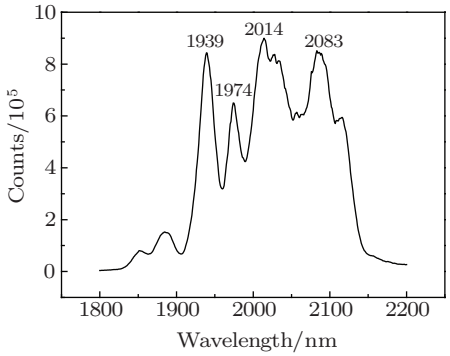

Fig. 5. Infrared emission spectrum of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic ($\lambda_{ex} = 980$ nm).

Figure 6 shows the laser performance of the Yb–Ho: $(YLa)_2O_3$ transparent ceramic (uncoated) pumped by a Tm:YLF laser at 1.91 μm. The maximum output power of 138 mw is obtained with a slope efficiency of 2.7%. The central laser wavelengths are 2077 nm and 2095 nm.[14] The 980 nm LD was also used as the pump source but failed to obtain any laser output. In our future work, we will optimize the doping concentrations of Ho^{3+} and Yb^{3+} to minimize the up-conversion and then enhance the 2 μm emission of Ho^{3+}.

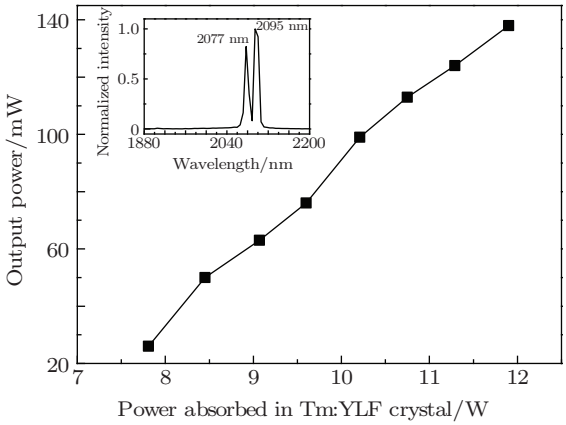

Fig. 6. (color online) Laser output power versus the absorbed pumped power ($\lambda_{ex} = 1910$ nm). The output spectrum is shown in the inset.

4. Conclusion

In summary, a highly transparent Yb–Ho: $(YLa)_2O_3$ transparent ceramic was fabricated by a solid-state reaction. The microstructure and spectral properties of the ceramic were examined. Three emission peaks (554 nm, 668 nm, and 755 nm) at the up-conversion area were observed. The strong emission band around 2 μm indicated that the Yb–Ho: $(YLa)_2O_3$ transparent ceramic is a promising gain medium for the generation of 2 μm laser emissions. The Yb–Ho: $(YLa)_2O_3$ transparent ceramic (uncoated) had a maximum output power of 31.1 mW at 2100 nm under a Tm: YLF laser at 1910 nm. The Yb–Ho: $(YLa)_2O_3$ transparent ceramic is a promising mid-infrared laser material.

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