Enhancement of the laser emission efficiency of Yb:Y_2O_3 ceramics via multi-step sintering method fabrication

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Y_2O_3 sesquioxide is a promising host material for solid-state lasers due to its high thermal conductivity (~13.5 $Wm^{-1}K^{-1}$), wide transparency range (0.2 ÷ 8 μm), high refractive index (1.9 to 2.1 in the 300 ÷ 800 nm spectral range), or its low cut-off phonon energy (380 cm^{-1}) [1]. Furthermore, Yb^{3+}-doped Y_2O_3 ceramics have attracted great attention due to their relatively long fluorescence lifetime, high quantum efficiency and broad absorption and emission bands [1,2]. However, the growth of large Y_2O_3 crystals from the melt is a difficult task due to the high melting point (>2400ºC). By using ceramic processing technology, Y_2O_3 ceramics can be fabricated at about two-thirds of the melting temperature, which greatly reduces the cost and fabrication period.

In this work, 5.0 at.% Yb:Y_2O_3 transparent ceramics were obtained by solid-state reaction and multi-step sintering (MSS) method using an optimal selected content of 9.0 at.% La_2O_3 and 2.0 at.% ZrO_2 as sintering additives. Based on the chemical formula $(Yb_{0.05}La_{0.09}Zr_{0.02}Y_{0.84})_2O_3$, the raw powders were blended and ball milled in ethanol with agate balls and then dried and sieved. The powder mixture was pressed into green bodies using a stainless steel die set, and then isostatically pressed at 250 MPa to enhance the green body's strength. The two-step intermediate sintering was conducted in air, as follows [3]. First, the temperature was increased from room temperature to a relatively high-temperature of 1450ºC, with a heating rate of 10°C/min and maintained at this temperature for 1 h. After that, the temperature was rapidly decreased to 1000°C where it was held for 40 h. Finally, the samples were sintered at 1760ºC for 12 h under vacuum (10^{-4} Pa) in a furnace with a tungsten-molybdenum chamber. For comparison, the compacted green bodies were also densified by the normal vacuum sintering method, at 1760ºC. The as-sintered ceramics were further annealed in air at 1300ºC, for 20 h, to remove oxygen vacancies. Finally, the ceramic samples were mirror-polished to a thickness of 1.5 mm.

The phase identification revealed that all sintered ceramics have a cubic structure similar to pure Y_2O_3. The microstructure presents a good homogeneity for all ceramic samples, with the average grain size of about 15 μm. Furthermore, it was observed that the grains become more uniform in the case of Yb:Y_2O_3 ceramic obtained by the MSS method. As a result, a high transmission of 78.5% at the wavelength of 1100 nm was recorded for the Yb:Y_2O_3 ceramic fabricated by the MSS method (Fig. 1). Laser emission at 1.03 μm was obtained in all 5.0 at.% Yb:Y_2O_3 uncoated ceramic media under quasi-continuous wave pumping at 971 nm with a fiber-coupled (100-μm diameter and NA = 0.22) diode laser. The optical resonator was a short (10-mm length) plane-plane mirror configuration. As shown in Fig. 2, laser pulses with 1.12 mJ energy for absorbed pump pulse energy E_{abs} = 6.35 mJ at 971 nm, were obtained from the Yb:Y_2O_3 ceramic densified by the MSS method; the slope efficiency, with respect to E_{abs}, reached 33%. The Yb:Y_2O_3 ceramic fabricated by the normal sintering method yielded laser emission with a lower slope efficiency of 29%.

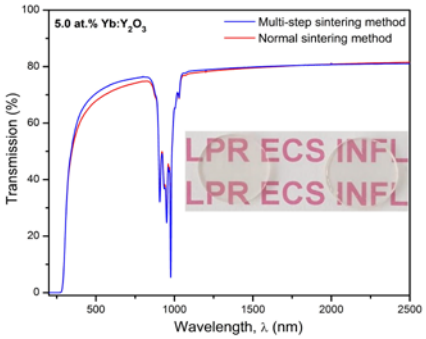

Fig. 1 Transmission spectra of the mirror-polished 5.0 at.% Yb:Y_2O_3 transparent ceramics.

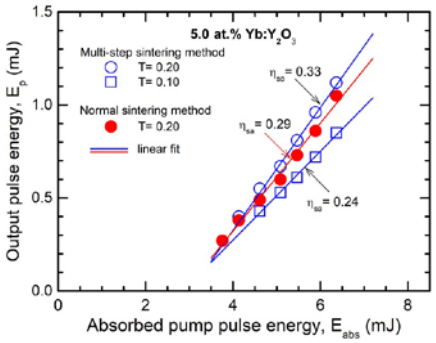

Fig. 2 Laser pulse energy, E_p versus absorbed energy of the pump pulse energy, E_{abs}. T: out-coupling mirror transmission.

Next investigations will focus on obtaining Yb:Y_2O_3 ceramics with better laser emission efficiency, as well as on the evaluation of their laser emission performances in different operating regimes.

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References

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