Comparative study of Ho:$Y_3Al_5O_{12}$ and Ho:Y_2O_3 transparent ceramics synthesized from laser ablated nanopowders

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Holmium (Ho^{3+}) ions are known for their emission at 2 μm originating from the $^5I_7 \rightarrow {}^5I_8$ transition. Ho lasers find applications in coherent laser radar, atmospheric sensing, surgery and frequency conversion into mid-IR. Among the laser host crystals for Ho^{3+} doping, garnets ($Y_3Al_5O_{12}$) and sesquioxides (A_2O_3, A = Lu, Y, Sc) have attracted attention due to their attractive thermal and spectroscopic properties. Transparent polycrystalline ceramics offer the advantages of lower synthesis temperatures, ease of doping and size-scalable production [1]. We report on a comparative study of Ho:$Y_3Al_5O_{12}$ and Ho:Y_2O_3 transparent ceramics promising for thin-disk ~2 μm lasers.

The 0.94 at.% Ho:$Y_3Al_5O_{12}$ ceramic was fabricated by vacuum sintering at 1780 °C for 20 h using 0.5 wt% TEOS as a sintering aid from Ho:Y_2O_3 and Al_2O_3 nanopowders produced by laser ablation and sedimentation [2]. For the 0.94 at.% Ho:Y_2O_3 ceramics, we used laser-ablated Ho:Y_2O_3 nanopowder with an addition of ~2 wt% ZrO_2 as a sintering aid to avoid exaggerated grain growth. They were uniaxially pressed and vacuum sintered at 1780 °C for 20 h. The obtained ceramics were transparent with yellowish coloration, Fig. 1(a).

The ceramics were of single-phase nature. The Ho:$Y_3Al_5O_{12}$ one exhibited a cubic structure (sp. gr. $Ia\bar{3}d$, a = 10.010 Å), Fig. 2(a), and a mean grain size D_{grain} of 32 μm. The Ho:Y_2O_3 ceramics was also cubic (sp. gr. $Ia\bar{3}$, bixbyite (C-type) structure, a = 10.569 Å) with smaller D_{grain} of 6.8 μm. Both ceramics exhibited a close-packed microstructure with clean grain boundaries and a lack of pores, Fig. 1(c).

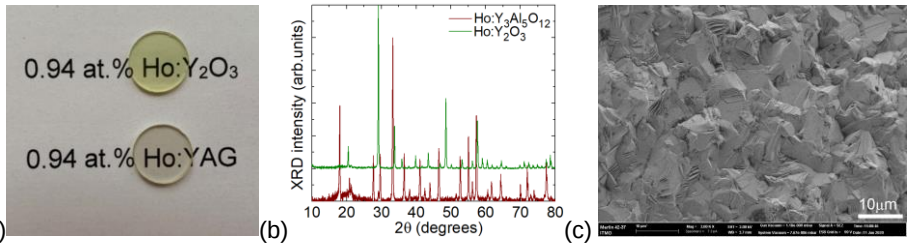

Fig. 1 (a) Photograph of the laser-grade polished ceramic disks; (b) X-ray powder diffraction (XRD) patterns of ceramics; (c) Scanning Electron Microscope (SEM) image of the fracture surface of the Ho:Y_2O_3 ceramics.

The ceramics exhibited high transmission in the visible and IR, Fig. 2(a). For the Ho:Y_2O_3 ceramics at 1.0 μm, T_0 = 80.0% which is close to the theoretical limit set by Fresnel losses, T_{Fr} = 81.6%. The transition intensities were analysed within the Judd-Ofelt theory. Absorption, σ_{abs}, and stimulated-emission (SE), σ_{SE}, cross-sections, Fig. 2(b), for the $^5I_7 \leftrightarrow {}^5I_8$ Ho^{3+} transition were determined and the luminescence lifetimes of several Ho^{3+} excited-states were measured. The multi-phonon non-radiative (NR) relaxation rates were estimated. For the Ho:$Y_3Al_5O_{12}$ ceramics, $\tau_{lum}(^5I_7)$ = 6.85 ms, Fig. 2(c), which is close to the estimated radiative lifetime (7.82 ms).

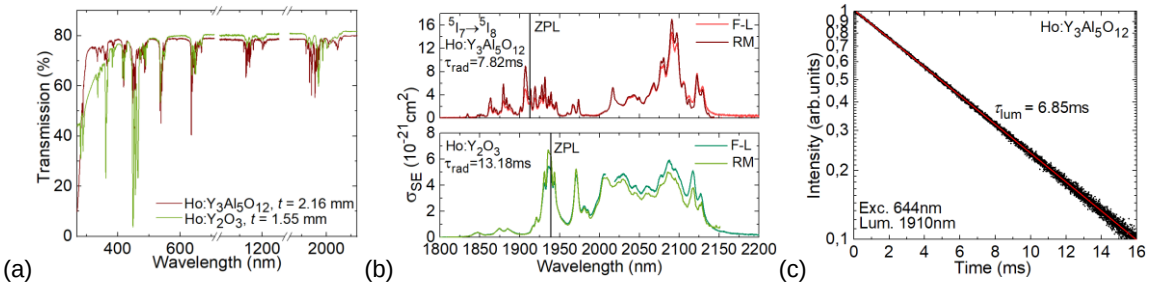

Fig. 2 Spectroscopy of Ho:$Y_3Al_5O_{12}$ and Ho:Y_2O_3 transparent ceramics: (a) in-line transmission spectra; (b) stimulated-emission, σ_{SE}, cross-sections for the $^5I_7 \rightarrow {}^5I_8$ transition calculated by the Füchtbauer–Ladenburg (F-L) equation and reciprocity method (RM); (c) luminescence decay curve from the $^5I_7$ Ho^{3+} state for the Ho:$Y_3Al_5O_{12}$ ceramics.

References

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