

Mid-infrared emission of Dy³⁺-doped transparent yttria ceramic

Meryem Bakbir¹, Roman Maksimov², Vladislav Shitov², Vladimir Osipov², Elena Dunina³, Liudmila Fomicheva⁴, Alexey Kornienko³, Patrice Camy¹, Alain Braud¹, and Pavel Loiko^{1*}

¹Centre de Recherche sur les Ions, les Matériaux et la Photonique (CIMAP), UMR 6252 CEA-CNRS-ENSICAEN, Université de Caen Normandie, 6 Boulevard Maréchal Juin, 14050 Caen, France

²Institute of Electrophysics, Ural Branch of the Russian Academy of Sciences, 106 Amundsena St., 620016 Ekaterinburg, Russia

³Vitebsk State Technological University, 72 Moskovskaya Ave., 210035 Vitebsk, Belarus

⁴Belarusian State University of Informatics and Radioelectronics, 6 Brovka St., 220027 Minsk, Belarus

Abstract. 1 at.% Dy³⁺-doped Y₂O₃ transparent ceramic was fabricated by vacuum sintering at 1750 °C from laser-ablated nanoparticles and its structure and mid-infrared emission were studied. For the ⁶H_{13/2} → ⁶H_{15/2} Dy³⁺ transition, the stimulated-emission cross-section is 0.39×10⁻²⁰ cm² at 3.3 μm corresponding to an emission bandwidth of 173 nm.

1 Introduction

Dysprosium ions (Dy³⁺) are promising for generating mid-infrared (MIR) laser emission at wavelengths beyond 3 μm, thereby avoiding structured water vapor absorption. Cubic yttria (Y₂O₃) is a well-established laser host material due to its high thermal conductivity, low phonon energy, broad optical transparency, and easy rare-earth doping. In recent years, transparent yttria ceramics have attracted increasing attention, as they enable the fabrication of large-scale, high-optical-quality, and homogeneously doped laser elements at processing temperatures significantly lower than the compound's high melting point (~2420 °C) [1]. In this work, we report on the fabrication and spectroscopic properties of Dy³⁺-doped Y₂O₃ transparent ceramics for MIR laser applications.

2 Results and discussion

The ceramic was fabricated through solid-state vacuum sintering of nanoparticles produced by co-evaporation of a solid target prepared from high-purity oxide powders in the molar ratio (Dy_{0.01}Y_{0.99})₂O₃ with an addition of 5 mol% ZrO₂ as a grain growth inhibitor. Following an annealing step to ensure a complete monoclinic-to-cubic phase conversion, the powder was uniaxially dry-pressed at 200 MPa into the green body. The compact was sintered under vacuum (10⁻³ Pa) at 1750 °C for 20 h. The Scanning Electron Microscopy (SEM) image of the polished and chemically-etched ceramic surface shows a dense microstructure consisting of closely packed grains with an average size of 7 μm, Fig. 1(a). The Raman spectrum

*Corresponding author: pavel.loiko@ensicaen.fr

confirms the cubic C-type bixbyite structure of yttria, Fig. 1(b). The most intense peak, assigned to F_g vibrations, is found at 378 cm^{-1} . The ceramic features broad transparency range ($0.25\text{--}8.5\text{ }\mu\text{m}$) with a high transmittance of 82.8% at $2\text{ }\mu\text{m}$, and displays the characteristic absorption bands of Dy^{3+} ions, Fig. 1(c). The $f\text{--}f$ transition probabilities of Dy^{3+} ions were calculated using the Judd-Ofelt theory, Fig. 1(d). The radiative lifetime τ_{rad} of the ${}^6\text{H}_{13/2}$ manifold is 10.74 ms . The absorption, σ_{abs} , and stimulated-emission, σ_{SE} , cross-sections of Dy^{3+} ions around $3\text{ }\mu\text{m}$ are shown in Fig. 1(e). The peak σ_{SE} value for the ${}^6\text{H}_{13/2} \rightarrow {}^6\text{H}_{15/2}$ transition calculated via the Füchtbauer-Ladenburg equation amounts to $0.39 \times 10^{-20}\text{ cm}^2$ at 3322 nm . The corresponding emission bandwidth (FWHM) reaches $\sim 170\text{ nm}$. Overall, the MIR emission of Dy^{3+} ions is very broad spanning $2.4\text{--}3.6\text{ }\mu\text{m}$. The luminescence lifetime of the ${}^6\text{H}_{13/2}$ Dy^{3+} state is $28\text{ }\mu\text{s}$ indicating significant multiphonon non-radiative relaxation, Fig. 1(f).

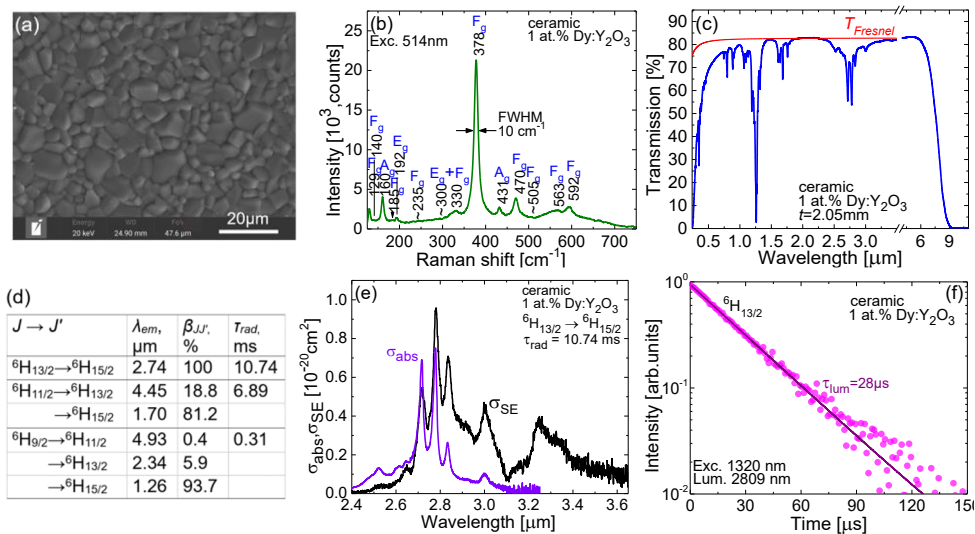


Fig. 1. Dy^{3+} -doped yttria transparent ceramic: (a) SEM image of the polished and chemically-etched ceramic surface; (b) Raman spectrum; (c) in-line transmission spectrum, red curve – limit set by Fresnel losses; (d) probabilities of spontaneous radiative transitions for Dy^{3+} ions calculated using the Judd-Ofelt theory; (e) absorption, σ_{abs} , and stimulated-emission (SE), σ_{SE} , cross-sections for the ${}^6\text{H}_{13/2} \rightarrow {}^6\text{H}_{15/2}$ transition; (f) luminescence decay curve from the ${}^6\text{H}_{13/2}$ Dy^{3+} manifold.

3 Conclusion

To conclude, Dy^{3+} -doped yttria transparent ceramic combine high transmittance close to the theoretical limit, intense absorption at 1.3 and $1.7\text{ }\mu\text{m}$, and broadband emission beyond $3\text{ }\mu\text{m}$ owing to the ${}^6\text{H}_{13/2} \rightarrow {}^6\text{H}_{15/2}$ transition, making it appealing for mid-infrared lasers. The relatively short luminescence lifetime of Dy^{3+} ions despite the low-phonon-energy behavior of the host matrix could be enhanced by cooling the ceramic to cryogenic temperatures. *Funding.* Agence Nationale de la Recherche (project ANR-25-CE08-4202 (DUPLEX); Région Normandie, France (Contrat de plan État-Région (CPER)).

References

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