Efficient Laser Operation of Transparent “Mixed” 7 at.% Er:(Lu,Sc)₂O₃ Sesquioxide Ceramics near 2.8 μm

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Erbium lasers emitting at ~2.8 μm according to the $^4I_{11/2} \rightarrow ^4I_{13/2}$ transition are of practical interest for microsurgery, remote sensing and atmosphere pollution monitoring. Among the existing laser gain media for ~2.8 μm lasers, cubic rare-earth sesquioxides Er:A₂O₃ (A = Lu, Y, Sc) appear promising due to their good thermal properties, low phonon energies and high Er³⁺ doping levels [1]. The ceramic technology for sesquioxides offers lower synthesis temperatures (the melting point of Lu₂O₃ is 2450 °C), and the possibility to fabricate in a more straightforward manner “mixed” materials [2]. We report on the synthesis, spectroscopy and first laser operation of a “mixed” ceramic Er:(Lu,Sc)₂O₃.

The ceramic was fabricated using vacuum pre-sintering at 1750 °C followed by hot isostatic pressing (HIPing) at 1750 °C and 200 MPa in argon for 2 h using Er₂O₃, Lu₂O₃ and Sc₂O₃ powders according to the formula (Er_{0.07}Lu_{0.78}Sc_{0.15})₂O₃. The ceramics were transparent with rose coloration, Fig. 1(a). They were of single-phase nature (cubic structure, sp. gr. $T_h - Ia\bar{3}$, $a = 10.198$ Å), according to the XRD data in Fig. 1(b), and had a close-packed microstructure with a mean grain size of 3.2 μm, Fig. 1(c). The 1-mm-thick ceramic sample exhibited high transmission $T = 79.1\%$ at 1.2 μm close to the theoretical value $T_0 = 79.7\%$, Fig. 1(d).

Fig. 1 Er:(Lu,Sc)₂O₃ ceramics: (a) photograph of ceramic samples; (b) X-ray powder diffraction (XRD) pattern, blue bars – reflections for Lu₂O₃, (hkl) – Miller's indices; (c) Scanning Electron Microscope (SEM) image of the polished surface; (d) Transmission spectrum (sample thickness: $t = 1$ mm), black curve – theoretical transmission for undoped material.

The transition probabilities for Er³⁺ were determined using the Judd-Ofelt theory accounting for the intermediate configuration interaction (ICI). The maximum SE cross-section for the $^4I_{11/2} \rightarrow ^4I_{13/2}$ transition σ_{SE} is 1.49×10^{-20} cm² at 2719 nm, Fig. 2(a). The emission spectrum exhibits significant inhomogeneous broadening. Laser operation with a 1.97-mm-thick sample was achieved under Ti:Sapphire laser pumping at 980 nm. A hemispherical cavity with a concave output coupler (transmission $T_{OC} = 1.5\%$, radius of curvature RoC = -75 mm) was used. The pump was focused into the laser element using a 75 mm AR-coated achromatic lens. The ceramic laser generated a maximum output power of 342 mW at 2.71 and 2.85 μm with a high slope efficiency η of 41.7% (exceeding the Stokes limit) and a laser threshold of 125 mW, Fig. 2(b,c). The developed ceramic is attractive for mode-locked lasers near 2.8 μm.

Fig. 2 (a) Stimulated-emission (SE) cross-section, σ_{SE} , spectrum for the $^4I_{11/2} \rightarrow ^4I_{13/2}$ Er³⁺ transition in (Lu,Sc)₂O₃ ceramics; (b,c) Er:(Lu,Sc)₂O₃ ceramic laser: (b) input-output power dependence, η – slope efficiency; (c) typical laser spectrum, inset – laser mode.

References

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