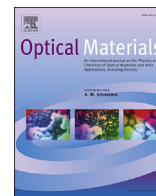




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Diode-pumped high power 2.7 μm Er:Y₂O₃ ceramic laser at room temperature

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ABSTRACT

Investigation of room temperature laser performance of the polycrystalline Er:Y₂O₃ ceramic at 2.7 μm with respect to dopant concentrations was conducted. With 7 at.% Er³⁺ concentration Er:Y₂O₃ ceramic as laser gain medium, over 2.05 W of CW output power at 2.7 μm was generated with a slope efficiency of 11.1% with respect to the absorbed LD pump power. The prospects for improvement in lasing efficiency and output power are considered.

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1. Introduction

Laser sources operating in the 2–5 μm spectral range have attracted considerable attention because of their emission lines coincide with numerous molecular fingerprints, relating to strong rotational-vibration absorption of molecular gases, liquids and solids [1]. Specifically, the emphasized 3 μm wavelength is resonant with symmetric stretch vibrations in OH, and hence laser emitting around this spectral region can be strongly absorbed by water. High-quality cutting or ablation has been demonstrated in biological tissue by use of 2.7 μm erbium ZBLAN fiber lasers [2]. In recent years, there have been enormous improvement research efforts for the laser performances emitting around 3 μm , mainly because of their potential applications for using in laser surgery and materials processing [3–5].

With commercially available laser diodes (LD) at ~970 nm, laser sources based on Er³⁺ emitting at 2.7–3 μm wavelength range have been widely studied. Lifetime of the upper laser level, ⁴I_{13/2}, for

3 μm erbium transition is generally shorter than the lower laser level ⁴I_{13/2}. Concentration dependent upconversion of the lower laser level (⁴I_{13/2} + ⁴I_{13/2} → ⁴I_{9/2} + ⁴I_{15/2}) is essential for removing the population bottle-neck and for the establishment of continuous-wave (CW) laser inversion. Slope efficiency exceeding quantum defect limit was thus obtained by the energy recycling upconversion mechanism [4,6], and laser emissions around 3 μm have been demonstrated successfully by directly pump the terminal laser level [7,8]. High doping concentration, however, also lead to series of detrimental effect for the 3 μm erbium lasing. For example, concentration dependent upconversion depopulates the upper laser level as well, thermal conductivity of the gain medium decreases with the increasement of active ions dopant concentration [9,10]. Besides, severe thermal problems in the gain media would strengthen the nonradiative decay rate and degrade the output beam qualities, and hence preventing the laser from further brightness scaling [11,12]. Therefore, optimize erbium doping concentration is essential for high efficient and high power 3 μm erbium laser operation. This has been demonstrated with Er:YSGG, Er:YAG, Er:YLF and Er:BYF crystal, and their optimized erbium concentration was ~30 at.%, ~50 at.%, ~15 at.% and ~12–15 at.%, respectively [12–15].

Polycrystalline Er:Y₂O₃ ceramic has recently shown an

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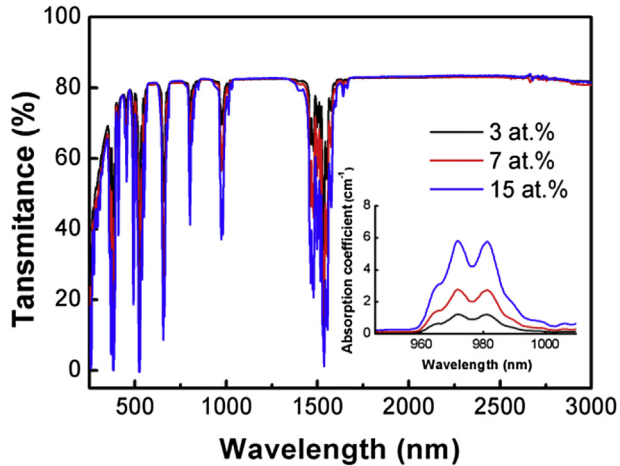


Fig. 1. Transmittance spectra of 1.33 mm thick Er:Y₂O₃ ceramic samples with 3 at.%, 7 at.%, and 15 at.% Er³⁺-doping concentration. Inset: absorption spectra of the Er:Y₂O₃ ceramics in the region of Er³⁺ ⁴I_{15/2} absorption.

promising laser gain medium for high power 2.7 μm laser operation. It possess the advantages of lower phonon energy, higher thermal conductivity, and larger $\sigma\tau$ product (where σ is the strongest peak emission cross section, and τ is upper laser level lifetime) compared to the most spread used Er:YAG crystal [10,16,17]. Additionally, it can be fabricated with large size and high concentration while keeping low cost and short fabrication period, which is very challenging for Y₂O₃ single crystal because of its extremely high melting point (above 2400 °C) [18,19]. Efficient and high power laser operation at 2.7 μm have been demonstrated at liquid nitrogen temperature (77 K) with the Er:Y₂O₃ ceramic gain medium [3,20]. However, room temperature laser performance and the erbium concentration have as yet not been optimized.

In this paper, laser performances of polycrystalline Er:Y₂O₃ ceramic at 2.7 μm with respect to erbium dopant concentration were evaluated and compared using a narrow-bandwidth wavelength stabilized 976 nm LD pump source. With 7 at.% Er³⁺ concentration Er:Y₂O₃ ceramic as laser gain medium, over 2.05 W of CW output power at 2.7 μm was generated with a slope efficiency of 11.1% with respect to the absorbed LD pump power.

2. Materials and experimental setup

Gain media evaluated are Er:Y₂O₃ ceramics fabricated using solid-state reactive sintering under vacuum condition, with Er³⁺-doping concentrations of 3 at.%, 7 at.%, and 15 at.%. Mirror polished ceramic samples with thickness of 1.33 mm were used to measure the optical transmittance by a UV/VIS/NIR spectrophotometer (Lambda 950, PerkinElmer). Fig. 1 shows the in-line transmission spectra of the Er:Y₂O₃ ceramics over the wavelength range of 250–3000 nm at room temperature. The Er:Y₂O₃ ceramics have an optical transmittance of about 82% in the nonabsorption spectral range. Absorption bands centered at 654 nm, 800 nm, 972 nm, 1536 nm are attributed to the transitions of Er³⁺ ions from its

ground state of ⁴I_{15/2} to the excited states of ⁴F_{9/2}, ⁴I_{9/2}, ⁴I_{11/2} and ⁴I_{13/2}, respectively. The absorption spectra of the Er:Y₂O₃ ceramics for the three doping concentration, derived from the measured transmittance spectra, from 945 nm to 1010 nm are shown in the inset of Fig. 1.

The experimental arrangement is schematically shown in Fig. 2. A simple two mirror cavity was employed, which consist of a plane input coupler (IC) with high reflectivity at lasing wavelength and high transmission (>85%) at the pump wavelength and a plane output coupler (OC) with transmittance of 2% for the lasing wavelength. Pump source used in the experiment was a volume Bragg grating (VBG) stabilized, fiber coupled diode (LD), and the beam quality factor M² of the pump source was around 30. Center wavelength of the LD was fixed at 976 nm with a bandwidth less than 0.3 nm. The delivery fiber has a core diameter of 105 μm, and the numerical aperture (NA) is 0.22. Ceramic samples used in the experiment were cut and polished to have dimensions of 2 mm × 3 mm in cross section, and 9.0 mm, 11.7 mm, and 5.6 mm in length, respectively. Both end faces of the ceramic were uncoated. The corresponding single-pass small-signal pump absorption of the 3 at.%, 7 at.% and 15 at.% samples, under nonlasing and unbleaching conditions, were 55.1%, 90.4%, and 90.5%, respectively. Shorter length of 3 at.% Er:Y₂O₃ ceramic samples were used in the experiment, so that it eliminates the influence of overlap between the pump and lasing mode. The ceramic samples were wrapped with indium foil and mounted on a water-cooled copper heat sink maintained at a temperature of 10 °C for efficient heat removal. Real-time temporal behavior of the laser output was monitored by a HgCdZnTe infrared detector (VIGO system model, PDI-4) with rise time of ~15 ns, and a digital oscilloscope (Agilent, MSOS804A) of 8 GHz electrical band width. Laser output power is measured by a thermopile power meter (OPHIR 30A-BB-18). Emission spectra of the Er:Y₂O₃ ceramic laser are analyzed using a 0.55 m monochromator (Omni-λ5005, Zolix).

3. Results and discussion

Firstly, a comparative study was conducted to evaluate the laser performance of the Er:Y₂O₃ ceramic with Er³⁺-doping concentration range between 3 at.% and 15 at.%. Pump spot diameter of ~360 μm was employed for the investigation. The confocal parameter ($2\pi n\omega_p^2/\lambda M^2$) of the pump beam inside Er:Y₂O₃ was estimated to be ~13 mm. The resonator was adjusted for the highest output power. No self-termination or self-pulsing phenomenon was observed during the laser oscillation. Fig. 3 shows the laser output performance of the Er:Y₂O₃ ceramics in terms of output power and slope efficiency. A strong dependence of the laser performance on the doping level is obvious. The best performance was achieved with 7 at.% Er³⁺ concentration. The slope efficiency with respect to the absorbed LD pump power is 12.2%, and the threshold is located at 0.55 W. The slope efficiencies diminish at lower as well as at higher doping concentration.

For the 3 at.% Er:Y₂O₃ ceramic, as shown in Fig. 3, the laser had a threshold of about 0.66 W and a slope efficiency of 8.1%. With absorbed pump power of 9.4 W, output power of 710 mW at 2.7 μm was obtained. Lower concentration demand for establishment of

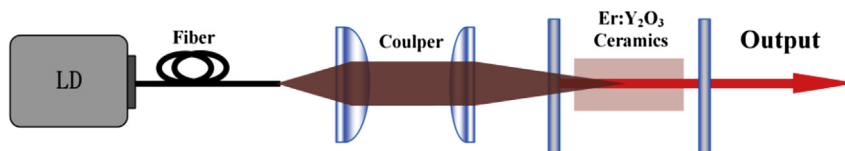


Fig. 2. Experimental setup for LD end-pumped Er:Y₂O₃ ceramic lasers.

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