Er^{3+}/Yb^{3+} codoped phosphate glass laser end-pumped by laser diode

Shilong Zhao (赵士龙)[1], Shunguang Li (李顺光)[2], Lili Hu (胡丽丽)[2], and Zaixuan Zhang (张在宣)[1]

[1] *College of Information Engineering, China Jiliang University, Hangzhou 310018*

[2] *Shanghai Institute of Optics and Fine Mechanics, Chinese Academy of Sciences, Shanghai 201800*

Received August 26, 2005

An Er^{3+}/Yb^{3+} phosphate laser glass was fabricated and characterized. According to McCumber theory, the stimulated emission cross-section of Er^{3+} ions at 1533 nm calculated by absorption spectrum was 0.84×10^{-20} cm^2, and the fluorescence lifetime of $^4I_{13/2}$ level was 8.5 ms. Continuous wave (CW) laser operation of this Er^{3+}/Yb^{3+} phosphate glass pumped by laser diode (LD) was demonstrated at room temperature. The maximum output power of 80 mW and slope efficiency of 16.5% were obtained.

OCIS codes: 160.5690, 300.6170, 140.3480.

The erbium glass laser attracted much interest since its first operation in the pulsed regime in 1965[1], in particular for telemetry and laser ranging applications due to its emission at the eye-safe wavelength of 1530 nm. More recently, with the development of the InGaAs laser diode (LD) emitting at 980-nm wavelength, continuous wave (CW) laser oscillators based on Er^{3+} doped glasses and optical fibers were actively considered[2]. A LD pumped CW laser operation has been achieved for the first time in 1991[3]. In 1999, Song *et al.*[4] reported a LD pumped Er^{3+}/Yb^{3+} codoped phosphate glass laser with an output of 10.2 mW and a slope efficiency of 5.4%. Recently, Liu *et al.*[5] obtained 43-mW output with the 10.3% slope efficiency in our self-fabricated Er^{3+}/Yb^{3+} codoped phosphate glass. In this letter, we describe an end-pumped Er^{3+}/Yb^{3+} codoped phosphate glass laser with the maximum output power of 80 mW and a slope efficiency of 16.5%.

Er^{3+}/Yb^{3+} codoped phosphate glass with composition of P_2O_5-Li_2O-SrO-Al_2O_3-Yb_2O_3-Er_2O_3 was prepared with high purity chemical materials. Er^{3+} and Yb^{3+} concentrations were 0.99×10^{19} and 1.12×10^{21} cm^{-3}, respectively. It was first melted in a high quality quartz crucible and then proceeded the refining and stirring in a platinum crucible at an appropriate temperature to get homogenous glass. Six surfaces of the glass sample were polished to high optical quality. The refractive index of the glass measured by the prism minimum deviation method was 1.5323. The density determined by the Archimedes methods with distilled water as the immersion fluid was 2.67 g/cm^3. The absorption spectrum of the glass sample was recorded with a PERKIN-ELMER-LANBDA 900UV/VIS/NIR spectrophotometer over a spectral range of 350—1700 nm. The fluorescence spectrum was measured using a TRIAX550 spectrofluorimeter with a spectral resolution of 1 nm under excitation at 970 nm. The fluorescence lifetime for $^4I_{13/2}$ level of Er^{3+} was measured with light pulses of 970-nm laser diode.

The laser experimental configuration is shown in Fig. 1. High-power diode lasers with ended-fiber (LIMO, Germany) was used as pumping source, its maximum output power is 15 W and peak laser wavelength is 978 nm. The pump light was first reshaped by two focal lenses and focused on the glass sample. The spot size was about 50 μm. One face of glass sample was coated for high-reflectivity at 1.53 μm ($R > 99.9\%$) and antireflection coated at 980 nm (92% transmission), and output coupling mirror with 0.88% transmission at 1.53 μm was used. Two filters were used to isolate the pump light leaked out from output coupling mirror. The resonance length is about 10 mm and the output power was measured by a radiometer EPM2000.

The absorption cross-section σ_a was determined from the absorption spectrum and the stimulated emission cross-section σ_e was calculated from McCumber theory[6]. Figure 2 shows the calculated absorption and stimulated emission cross-sections of Er^{3+} ions and the maximum stimulated emission cross-section is

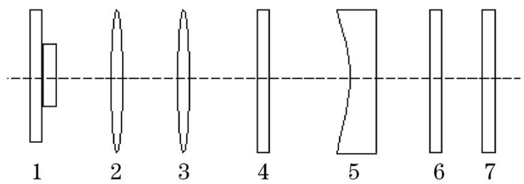

Fig. 1. Schematic diagram of Er^{3+}/Yb^{3+} codoped phosphate glass laser. 1: LD; 2, 3: collimating lens; 4: Er^{3+}/Yb^{3+} codoped glass sample; 5: output coupler; 6, 7: filters.

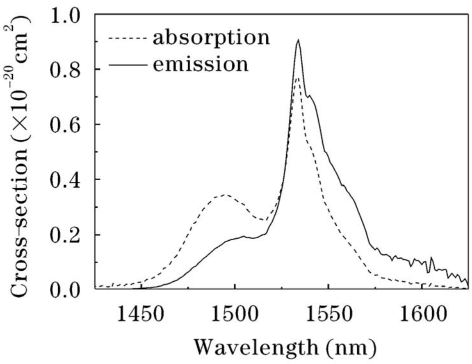

Fig. 2. Absorption and emission cross-sections of Er^{3+} in phosphate glass.

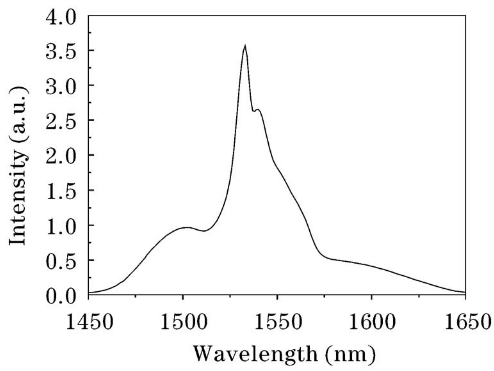

Fig. 3. Fluorescence spectrum of Er^{3+} /Yb^{3+} codoped phosphate glass.

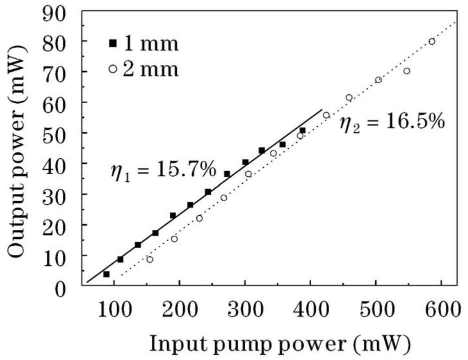

Fig. 4. Output power versus input power for sample L5.

0.84×10^{-20} cm^2 at 1533 nm, which is among the highest value for phosphate glass[7]. The fluorescence spectrum of Er^{3+}/Yb^{3+} codoped phosphate glass was measured in a range of 1400—1650 nm under 970-nm excitation as shown in Fig. 3. The full-width at half-maximum (FWHM) is 22 nm and fluorescence lifetime is 8.5 ms, which is larger than that of Kiger's MM-1 (7.9 ms)[8].

The Er^{3+}/Yb^{3+} codoped phosphate glass with different sample thicknesses realized CW laser oscillations at room temperature. Figure 4 shows the output power versus input power for sample L5. The experimental threshold powers are 88 and 155 mW at 1 and 2 mm, respectively. It is because the resorption increases at laser wavelength with the increase of glass sample thickness. On the other hand, light absorption increases with the increase of glass sample thickness, and the slope efficiency also increases. The maximum output power at 2 mm was approximately 80 mW, which is limited by the maximum input power without producing thermal damage to the glass. So the maximum input power is limited approximately at 600 mW. In order to attain higher output power, cooling equipment is needed. The maximum output power here is nearly twice more than the previous result[5], which may be due to higher slope efficiency and larger output coupling efficiency. The laser spectrum of the Er^{3+}/Yb^{3+} codoped phosphate glass laser at the maximum output power of 80 mW is shown in Fig. 5. Several longitudinal modes were detected and the center wavelength was 1533 nm.

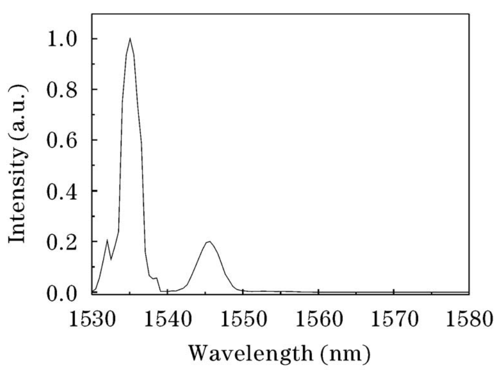

Fig. 5. Laser spectrum of the Er^{3+}/Yb^{3+} codoped phosphate glass laser (at the maximum output power 80 mW).

In conclusion, an Er^{3+}/Yb^{3+} codoped phosphate glass was fabricated. The stimulated emission cross section at 1533 nm calculated by McCumber theory was 0.84×10^{-20} cm^2 and fluorescence lifetime was 8.5 ms. An Er^{3+}/Yb^{3+} codoped phosphate glass CW laser pumped by LD was demonstrated at room temperature. The maximum output power was 80 mW and slope efficiency was 16.5%. By optimizing the laser cavity and the pump wavelength, the output power in excess of 100 mW is expected, which has great potential for optical fiber communication and other applications in which an eye-safe wavelength is required.

S. Zhao's e-mail address is shilong_zhao@hotmail.com.

References

1. E. Snitzer and R. Woodcock, Appl. Phys. Lett. **6,** 45 (1965).
2. M. Okayasu, T. Takeshita, and M. Yamada, Electron. Lett. **25,** 1563 (1989).
3. P. Laporta, S. D. Silvestri, V. Magni, and O. Svelto, Opt. Lett. **16,** 1952 (1991).
4. F. Song, X. Chen, Y. Feng, M. Shang, W. Zhang, G. Zhang, S. Jiang, and M. J. Myers, Chin. J. Lasers (in Chinese) **26,** 790 (1999).
5. Z. Liu, C. Qi, S. Dai, Y. Jiang, and L. Hu, Opt. Mater. **21,** 789 (2003).
6. D. E. McCumber, Phys. Rev. A **134,** 299 (1964).
7. A. F. Obaton, C. Parent, G. Le. Flem, P. Thony, A. Brenier, and G. Boulon, J. Alloy and Compounds **300&301,** 123 (2000).
8. S. Jiang, T. Luo, B. C. Hwang, G. N. Conti, M. Myers, D. Rhonehouse, S. Honkanen, and N. Peyghambarian, Opt. Eng. **37,** 3282 (1998).