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Lasing at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions in $ZrO_2-Y_2O_3-Er_2O_3$ crystals under resonant diode pumping into the $^4I_{13/2}$ level

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Abstract. **Experimental results on lasing in $ZrO_2-Y_2O_3-Er_2O_3$ crystals are presented. Under diode pumping of $ZrO_2-Y_2O_3$ (13.8 mol%)$-Er_2O_3$ (0.2 mol%) crystals into the $^4I_{13/2}$ level of Er^{3+} ions, lasing is obtained at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition with a wavelength of 1648 nm.**

Keywords: *Lasing, $ZrO_2-Y_2O_3-Er_2O_3$ crystal, Er^{3+} ion, resonant pumping.*

1. Introduction

Lasers emitting in the wavelength range 1.6–1.7 μm are used for monitoring some gases (for example, CO_2, NH_3, CH_4) and for designing lidar systems.

Lasing in this spectral range can be obtained at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions in Er^{3+}-doped crystals under resonant pumping into the $^4I_{13/2}$ level.

Lasing at this transition with a wavelength of 1.64 μm was obtained for the first time in $Er:Y_3Al_5O_{12}$ crystal at the temperature T = 77 K [1]. The authors of [2] reported on an efficient solid-state laser based on $Er:Y_3Al_5O_{12}$ crystal, which operated at the wavelength λ = 1645 nm at room temperature under resonant pumping into the $^4I_{13/2}$ level of Er^{3+} ions by a fibre laser with the wavelength λ_p = 1530 nm. Lasing in $Er:Y_2O_3$ ceramics (λ = 1.6 μm, T = 77 K) under resonant pumping by a fibre laser with λ_p = 1535.7 nm was obtained in [3], while lasing in diode-pumped (λ_p = 1477 nm) $Er:Y_3Al_5O_{12}$ crystals (λ = 1.6 μm) at room temperature was achieved in [4].

Despite the available results on lasing of Er^{3+}-doped crystals and ceramics in the range 1.6–1.7 μm, search for new active media for lasers of this spectral range remains important.

The $Y_3Al_5O_{12}$ crystals are characterised by an ordered structure, because of which the spectral lines of active ions in these crystals are mainly homogeneously broadened. At the same time, of interest for laser physics are also crystals with disordered structure, which are characterised by inhomogeneous broadening of the absorption and luminescence lines of dopant ions. This broadening provides the possibility of obtaining tunable lasing and short laser pulses in these crystals. Yttria-stabilised zirconia doped with rare-earth ions belongs to disordered crystals. Crystals of this type have been known for a long time. In particular, lasing in these crystals doped with Nd^{3+}, Ho^{3+}, Tm^{3+} and Er^{3+} at a wavelength of 1.62 μm at room temperature was obtained in [5, 6], while lasing in a crystal with a high concentration of Er^{3+} was obtained in [7] at the $^4I_{11/2} \rightarrow {}^4I_{13/2}$ transition with a wavelength of 2.695 μm under lamp pumping.

The low thermal conductivity of these crystals restricted their application as active media of lamp-pumped lasers. Diode pumping considerably changes requirements to the thermomechanical characteristics of materials, and, therefore, it is of interest to study the possibility of obtaining lasing in yttria-stabilised zirconia crystals doped with rare-earth ions.

In the present work, we report for the first time the experimental results on lasing at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions in $ZrO_2-Y_2O_3$ (13.8 mol%)$-Er_2O_3$ (0.2 mol%) crystals under diode pumping.

2. Experimental results

Yttria-stabilised zirconia crystals doped with Er^{3+} were grown by direct high-frequency heating in a cold container in a Kristall-407 crystal-growth furnace. The crystals of the composition $ZrO_2-Y_2O_3$ (13.8 mol%)$-Er_2O_3$ (0.2 mol%) were grown in a cold container 130 mm in diameter with a growth rate of 10 mm h^{-1}. The spectral and luminescent characteristics of these crystals, which testify to the possibility of obtaining lasing in the spectral range of 1.6–1.7 μm, were published by us in work [8].

The specific features of crystal-field splitting of the $^4I_{13/2}$ and $^4I_{15/2}$ energy levels of Er^{3+} ions in $ZrO_2-Y_2O_3-Er_2O_3$ crystals lead to a long-wavelength shift of the luminescent $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition band with respect to the other oxide crystals, which makes it possible to obtain lasing in the range of 1650–1700 nm.

The spectrum of the $^4I_{15/2} \rightarrow {}^4I_{13/2}$ absorption transition of Er^{3+} ions in $ZrO_2-Y_2O_3$ (13.8 mol%)$-Er_2O_3$ (0.2 mol%) crystals recorded at T = 300 K on a Lambda 950 (PerkinElmer) spectrometer is shown in Fig. 1. The arrow in Fig. 1 denotes the wavelength corresponding to the maximum of the emission spectrum of the laser diode array used for pumping in the reported experiment.

The optical scheme of the laser used to achieve and study lasing at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions in $ZrO_2-Y_2O_3$ (13.8 mol%) $-$ Er_2O_3 (0.2 mol%) crystals is given in Fig. 2.

The active element was pumped by a laser diode array (*1*) with the wavelength λ_p = 1.46 μm. The diode array radiation from an output fibre (*2*) (diameter 400 μm) was projected by

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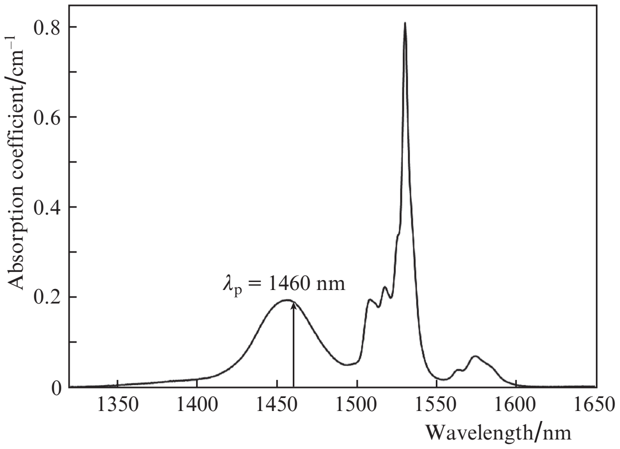

Figure 1. Absorption spectrum of ZrO_2–Y_2O_3 (13.8 mol %) – Er_2O_3 (0.2 mol %) crystal at T = 300 K.

a lens (*3*) into the active element with a magnification of 1 : 1.5. An active element (*5*) measuring 3×3× 15 mm was cut of a ZrO_2–Y_2O_3 (13.8 mol%) – Er_2O_3 (0.2 mol%) crystal. The active element faces were antireflection coated for the lasing wavelength (1.65 μm). The cavity used in the experiment was formed by a spherical mirror (*4*) (radius of the working surface curvature 500 mm, transmittance at the pump wavelength $\tau \geqslant 90\%$, reflectance at the lasing wavelength exceeding 99%) and a plane output mirror (*6*) with a transmittance at the lasing wavelength below 1%.

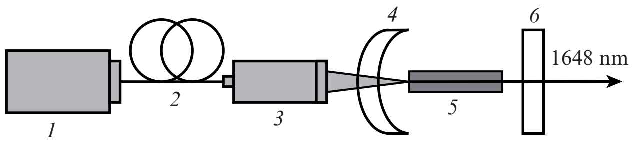

Figure 2. Optical scheme of the laser.

A temperature stabilisation system ensured a constant temperature (~18 °C) of the copper holder of the active element. The laser signal on the crystal was controlled using an FD-7G photodiode, whose signal was fed to a GDS 720C digital oscilloscope. The spectrum of the ZrO_2–Y_2O_3 (13.8 mol%)– Er_2O_3 (0.2 mol%) laser was recorded by a Horiba FR 1000 spectrometer.

Lasing at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions in ZrO_2–Y_2O_3 (13.8 mol%)– Er_2O_3 (0.2 mol%) crystals was obtained at the wavelength λ = 1648 nm. The lasing threshold with respect to the absorbed pump power was 2.75 W. The luminescence and lasing spectra at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions are shown in Fig. 3.

With the use of a plane mirror with a transmittance $\tau \approx 7\%$ instead of the plane highly reflecting output mirror ($\tau < 1\%$) (see Fig. 2), lasing at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition did not occur. However, when the plane highly reflecting output mirror was replaced by a spherical mirror with a radius of curvature r = 300 mm and a transmittance $\tau \approx 0.5\%$, the output laser power was about 20 mW.

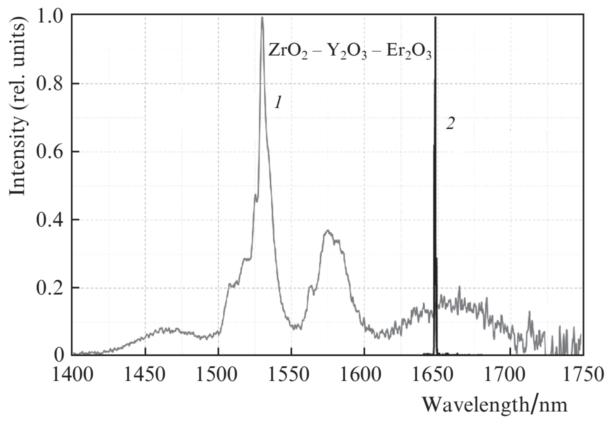

Figure 3. (*1*) Luminescence and (*2*) lasing spectra of Er^{3+} ions in ZrO_2–Y_2O_3 (13.8 mol %) – Er_2O_3 (0.2 mol %) crystals at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition.

3. Conclusions

In this work, lasing at the $^4I_{13/2} \rightarrow {}^4I_{15/2}$ transition of Er^{3+} ions in ZrO_2–Y_2O_3 (13.8 mol%) – Er_2O_3 (0.2 mol%) crystals was obtained for the first time under diode pumping into the $^4I_{13/2}$ level. The laser wavelength was 1649 nm, and the radiation power did not exceed 20 mW.

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