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Efficient lasing in a Fe^{2+} : ZnSe crystal at room temperature

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***Abstract*. Efficient room-temperature lasing is obtained in a Fe^{2+} : ZnSe crystal pumped by 2.9364-μm giant pulses from an Er : YAG laser. The slope efficiency of a Fe^{2+} : ZnSe laser with respect to the absorbed pump energy is 13 %. The laser with a dispersion resonator can be continuously tuned from 3.95 to 5.05 μm. The luminescence lifetime of the $^5T_2$ level of the Fe^{2+} ion in a ZnSe matrix at room temperature is measured to be 355 ± 15 ns.**

Keywords: *IR lasers, tunable solid-state lasers, Fe^{2+} : ZnSe crystals.*

1. Introduction

A ZnSe crystal doped with Fe^{2+} ions attracts attention as a broadband laser medium emitting in the mid-IR spectral range. Laser action in this crystal was first observed in [1], where pulsed lasing was obtained in a Fe^{2+} : ZnSe crystal in the temperature range from 15 to 180 K and the temperature tuning of the laser was demonstrated in the spectral region between 3.98 and 4.54 μm. The crystal was pumped by 48-μs laser pulses.

In our previous paper [2], the upper limit of the operating temperature of the laser was 255 K for 200-μs pump pulses. This allowed us to abandon liquid nitrogen cooling and to obtain efficient lasing in a Fe^{2+} : ZnSe crystal cooled by a two-stage thermoelectric cooler. However, it is obvious that the operating conditions remain rather inconvenient upon such cooling as well.

Lasing in a Fe^{2+} : ZnSe crystal occurs at the $^5T_2 - {}^5E$ transition in the Fe^{2+} ion. The Fe^{2+} : ZnSe crystal pumped by long pulses should be cooled to obtain lasing because the lifetime of the upper $^5T_2$ laser level of the Fe^{2+} ion in a ZnSe matrix decreases with increasing temperature from 105 μs at 120 K to 5 μs at 200 K [1] due to an increase in the nonradiative relaxation rate, and its estimated value at room temperature should not exceed a few microseconds. Therefore, the threshold pump energy at room temperature can be reduced by pumping the crystal by pulses of duration smaller than the nonradiative relaxation time.

Indeed, the authors of [3] obtained lasing at room temperature in polycrystalline ZnSe samples grown by the chemical vapour deposition method and doped then with Fe^{2+} ions by the diffusion method. The samples were pumped by 5-ns pulses; however, the maximum output energy estimated in [3] was only ~1 μJ and the lasing efficiency did not exceed 0.01 %.

In this paper, we obtained efficient lasing at room temperature in a Fe^{2+} : ZnSe crystal pumped by 2.9364 μm pulses from a *Q*-switched Er : YAG laser.

2. Experimental setup

An active element of the Fe^{2+} : ZnSe laser was made of a Fe^{2+} : ZnSe single crystal grown by the method of free vapour growth to a single-crystal seed by using the chemical transport in hydrogen with the technology close to that developed earlier for growing single crystals of the solid solutions of II – VI compounds [4]. Doping with Fe^{2+} ions up to a concentration of $\sim 1 \times 10^{18}$ cm^{-3} was performed during the crystal growing. The active element had a length of 10 mm and transverse dimensions of 17×10 mm. We obtained earlier an output energy of ~0.2 J with a slope efficiency of 43 % for a Fe^{2+} : ZnSe laser with such active elements cooled to liquid nitrogen temperature [2] and demonstrated a continuous tuning of the laser from 3.77 to 4.40 μm by using a dispersion element in the resonator [5].

Figure 1 shows the optical scheme of our setup. The Fe^{2+} : ZnSe laser resonator is formed by a rear spherical mirror M1 (with the radius of curvature of 50 cm) and a plane output mirror M2 with interference coatings deposited on CaF_2 substrates. The transmission spectra of the resonator mirrors are presented in Fig. 2. The transmission of these mirrors at 4.4 μm was 0.25 % and 9.5 %, respectively. The resonator length was 17 cm. The Fe^{2+} : ZnSe crystal was mounted near the output mirror at the Brewster angle to the optical axis of the resonator.

The Fe^{2+} : ZnSe laser was pumped by a flashlamp-pumped *Q*-switched Er : YAG laser at 2.9364 μm. The Er : YAG laser was passively *Q*-switched by means of a Fe^{2+} : ZnSe single crystal plate [6]. The FWHM of the output pulses of this laser was 60 ns and their energy was up to 10 mJ. The pump laser emitted single pulses with a period of no less than 1 min.

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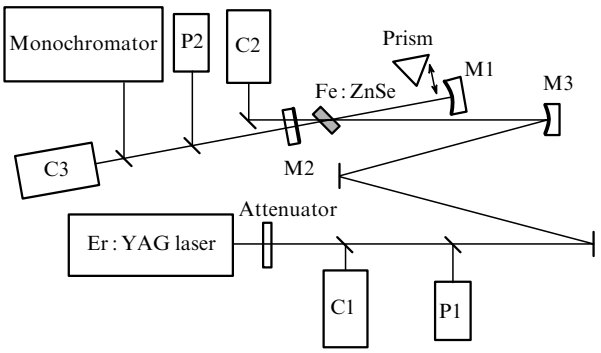

Figure 1. Scheme of the experimental setup: (M1) rear spherical mirror; (M2) plane output mirror; (M3) focusing mirror; (C1 – C3) calorimeters; (P1 and P2) photodetectors.

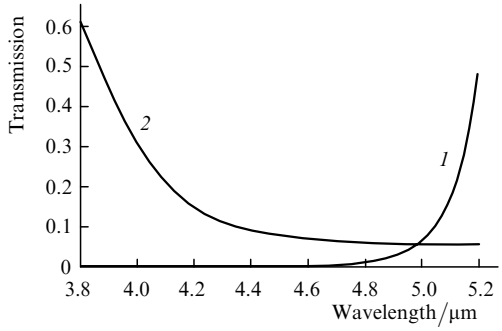

Figure 2. Transmission of the rear (*1*) and output (*2*) resonator mirrors.

The pump radiation was linearly polarised, with the electric filed vector lying in the plane of incidence of the pump beam on the laser crystal (horizontal plane), which reduced Fresnel reflection losses to the minimum. The pump beam was directed at a small angle ($\sim 2^\circ$) to the resonator optical axis. The beam was focused by spherical mirror M3 with a focal length of 50 cm so that its spot in front of the crystal surface was a circle of diameter 1.4 mm. The pump energy was varied with the help of a set of calibrated light filters.

The pump energy incident on the crystal and transmitted through it was measured with C1 (VChD-2) and C2 (IMO-2H power meter) calorimeters. The output energy of the Fe^{2+} : ZnSe laser was measured with a C3 (VChD-2) calorimeter.

The time profiles of pump and output laser pulses were recorded with P1 and P2 FSG-22-3A2 photoresistors, respectively, whose output signals were fed to a TDS-1012 Tektronix oscilloscope. The time resolution of the detection system allowed the recording of pulse fronts with the 10-ns rise time. The output wavelength of the Fe^{2+} : ZnSe laser was measured with a diffraction monochromator equipped with a VChD-2 calorimeter.

The tuning of the Fe^{2+} : ZnSe laser was studied by placing a 70° CaF_2 prism in front of the rear mirror of the resonator. The emission spectrum was tuned by rotating the rear mirror of the resonator around the vertical axis. Because the transmission of the rear mirror with the interference coating sharply increased in the long-wavelength emission region of the laser (Fig. 2), we used a mirror with an aluminium coating in the dispersion resonator instead of this mirror.

3. Results and discussion

We studied in this paper the energy and spectral characteristics of the Fe^{2+} : ZnSe laser. All experiments were performed at the active element temperature of 295 K.

Figure 3 shows the dependence of the output energy of the laser on the absorbed pump energy obtained in the absence of a prism in the resonator. The maximum output energy was in this case 0.37 mJ. A straight line approximating the experimental points by the method of least squares gives the slope efficiency of the laser with respect to the absorbed pump energy equal to 13 % and the threshold pump energy of 1.4 mJ. The width and central wavelength of the laser spectrum were 0.1 μm and 4.4 μm, respectively.

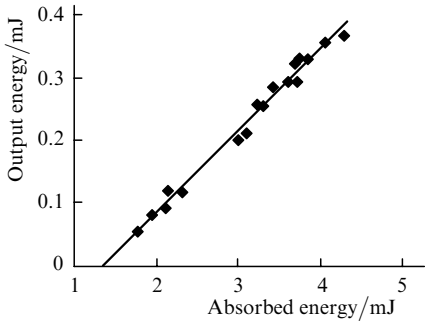

Figure 3. Dependence of the output energy of the Fe^{2+} : ZnSe laser on the absorbed pump energy.

Figure 4 presents the oscillograms of pump and output pulses for pump energies equal to 8.3 and 4.2 mJ. For high pump energies, the leading edge of the laser pulse was delayed with respect to the pump pulse maximum by 20 – 30 ns and its duration did not exceed 40 ns. As the pump energy was decreased, the laser pulse duration increased and was 60 ns near the lasing threshold, while the time delay increased up to 200 ns.

Figure 5 shows the tuning curve of the Fe^{2+} : ZnSe laser with a dispersion prism in the resonator. The tuning range was 3.95 – 5.05 μm, being restricted in the short-wavelength

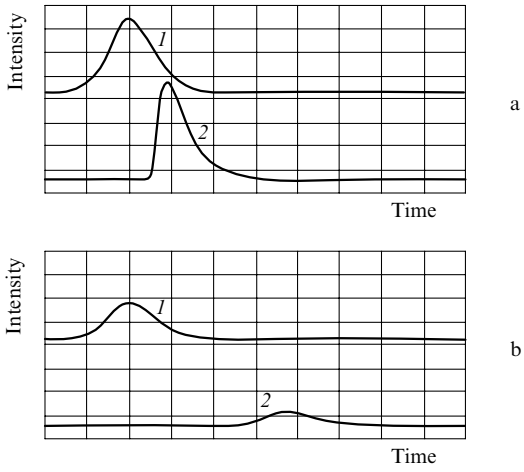

Figure 4. Oscillograms of pump (*1*) and output (*2*) pulses of the Fe^{2+} : ZnSe laser for the pump energy 8.3 (a) and 4.2 mJ (b). The time scale is 50 ns div^{-1}.

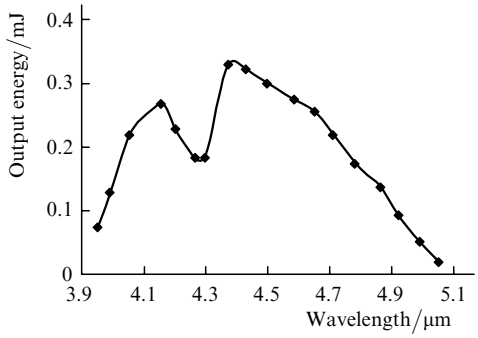

Figure 5. Tuning curve of the Fe^{2+} : ZnSe laser with a dispersion resonator.

region probably by the output mirror whose transmission drastically increased at wavelengths shorter than 4.2 μm (Fig. 2). The dip in the tuning curve observed in the 4.2–4.3-μm region is caused by atmospheric carbon dioxide absorption [7]. The width of the output spectrum of the laser with the dispersion resonator was 0.05 μm.

As mentioned above, the necessity of using short pulses to obtain lasing in a Fe^{2+} : ZnSe crystal at room temperature is caused by the high rate of nonradiative relaxation from the upper laser level. Because the experimental data on the lifetime of the $^5T_2$ level of the Fe^{2+} ion in a ZnSe matrix at room temperature are not available in the literature, we measured the decay of luminescence from this level in this paper.

The crystal luminescence was excited by 2.9364-μm, 60-ns, 7–8-mJ laser pulses. The Fe^{2+} : ZnSe crystal was mounted outside the laser resonator. Luminescence was detected in the direction perpendicular to the excitation beam with a photodetector P2 placed near the crystal and recorded with TDS-1012 Tektronix oscilloscope. The scattered excitation beam was attenuated by four orders of magnitude with an optical filter formed by two mirrors with the reflection coefficient above 99% in the 3-μm spectral region and the transmission coefficient above 50 % in the crystal luminescence region.

Figure 6 shows the typical oscillograms of the excitation pulse and luminescence signal. The processing of these data shows that at room temperature the crystal luminescence decay reveals the exponential decay with the lifetime of 355 ± 15 ns.

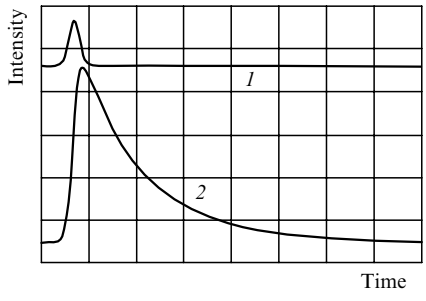

Figure 6. Oscillograms of the excitation pulse (*1*) and luminescence signal (*2*) of the Fe^{2+} : ZnSe crystal. The time scale is 250 ns div^{-1}.

4. Conclusions

We have demonstrated efficient lasing in a Fe^{2+} : ZnSe crystal at room temperature. The slope efficiency of the laser with respect to the absorbed pump energy is 13 %, corresponding to the quantum efficiency 20 %. The laser can be continuously tuned in the spectral range from 3.95 to 5.05 μm. Thus, the entire continuous tuning range of the Fe^{2+} : ZnSe laser, taking into account the results obtained upon crystal cooling [5], covers the spectral region from 3.77 to 5.05 μm. The decay time of luminescence from the upper laser level at room temperature has been measured to be 355 ± 15 ns.

Note that the lasing efficiency achieved in our experiments is not ultimate and apparently can be increased by providing the better matching between the pumped and lasing volumes in the laser element and optimising the output resonator mirror.

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