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Efficient IR Fe : ZnSe laser continuously tunable in the spectral range from 3.77 to 4.40 μm

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***Abstract*. The lasing characteristics of a Fe : ZnSe single crystal grown from the vapour phase by the free-growth technique using the chemical transport in hydrogen are studied. A Fe^{2+} : ZnSe laser cooled to liquid nitrogen temperature and pumped by 2.9364-μm radiation from an Er : YAG laser produces the 130-mJ output energy with a slope efficiency of 40 % in terms of the absorbed energy, which corresponds to a quantum efficiency of 55 %. The lasing spectrum in a dispersive resonator can be continuously tuned between 3.77 and 4.40 μm.**

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

1. Introduction

Lasers tunable in the spectral range of 2–5 μm are of great interest for solving numerous scientific and applied problems. Medicine, remote sensing of atmosphere, and the environment monitoring are only some fields of their application. The development of such lasers is especially important for elaborating highly sensitive techniques of spectral analysis, because strong vibrational absorption lines of many molecules lie within this wavelength range.

Chalcogenide crystals (ZnS, ZnSe, etc.) doped with transition-metal ions (Cr, Ni, Fe, etc.) [1], are of special interest as laser media for this spectral range. Among them a ZnSe : Fe crystal exhibits the most long wavelength, emitting in the wavelength range of 3.98–4.54 μm [2]. By using a crystal grown by the Bridgman method, the authors of [2] obtained a maximum output energy of 12 μJ and a slope efficiency with respect to the absorbed energy of 8.2 %. The Fe^{2+} : ZnSe laser oscillation was observed at temperatures from 15 to 180 K. The best laser parameters were obtained at temperatures 130–150 K.

It is well known that a more perfect structure and a higher optical homogeneity are achieved in crystals grown from a vapour phase. Therefore, laser crystals grown by this technique have low internal losses [3, 4]. In our previous work [5], the first laser on a ZnSe : Fe crystal grown from a vapour phase was built and preliminary studies of its characteristics were performed. As a result, a slope laser efficiency of 18 % was obtained at an output energy of 25 mJ. However, the resonator used in Ref. [5] had rather high parasitic losses caused by the low optical quality of the ZnSe : Fe crystal and the Fresnel reflection from the windows of the cryostat in which the crystal was placed.

The aim of this work was to study the lasing characteristics of a ZnSe : Fe crystal placed in a laser resonator with minimum parasitic losses.

2. Experimental setup

A ZnSe : Fe single crystal was grown from a vapour phase by the free-growth technique on a single-crystal seed using a chemical transport in hydrogen. This growth technique is close to that developed for growing single crystals of solid solutions of A_2B_6 compounds [6]. The crystal was grown from separate sources containing ZnSe and FeSe polycrystalline compounds. The concentration of Fe^{2+} ions determined from the absorption spectrum with allowance for the absorption cross section, which was taken from [2], was 10^{18} cm^{-3}. An active element (AE) with a cross section of 17 × 10 mm and a length of 10 mm was cut from the grown sample.

An optical scheme of the setup is shown in Fig. 1. The AE was mounted at the Brewster angle on a copper heat sink inside the cryostat with plane–parallel CaF_2 plates

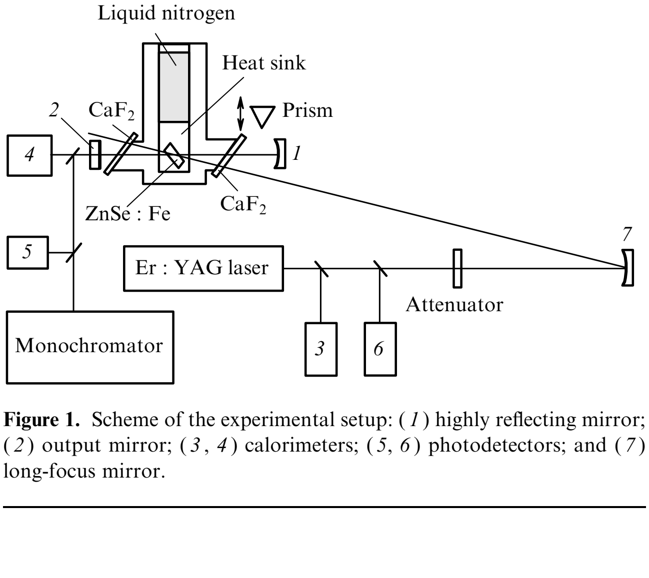

Figure 1. Scheme of the experimental setup: (*1*) highly reflecting mirror; (*2*) output mirror; (*3*, *4*) calorimeters; (*5*, *6*) photodetectors; and (*7*) long-focus mirror.

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serving as the windows and also oriented at the Brewster angle. All experiments were performed with the ZnSe : Fe crystal cooled to liquid nitrogen temperature. The resonator of the Fe^{2+} : ZnSe laser was formed by highly reflecting rear mirror (*1*) with a 50-cm radius of curvature and flat output mirror (*2*) deposited on a CaF_2 substrate and having a reflectivity of 70 % at a wavelength of 4 μm. The resonator was 30-cm long.

The Fe^{2+} : ZnSe laser was pumped by a 2.9364-μm, 0.6-J free-running Er : YAG laser emitting 300-μs pulses. The pump radiation was linearly polarised, thus minimising the losses due to the Fresnel reflection from the AE and cryostat-window surfaces. The ZnSe : Fe crystal was pumped at a small angle with respect to the resonator optical axis. The pump beam was focused by long-focus mirror (*7*) so that its cross section in front of the entrance to the crystal was shaped as an ellipse with axes of 3.5 and 2.5 mm. The crystal absorbed 54 % of the incident pump energy. When studying the laser output energy as a function of the pump energy, the latter was reduced using a set of calibrated light filters serving as attenuators.

The pump and output energies of the Fe^{2+} : ZnSe laser were measured with calorimeters (*3*) and (*4*), respectively (IMO-2N power meters). The laser was tuned using an intracavity CaF_2 prism. The lasing wavelength was measured with a grating monochromator. The profiles of pump and laser pulses were recorded with photodetectors (*5*) and (*6*) (FSG-22 photoresistors) whose output signals were fed to a storage oscilloscope.

3. Experimental results

Typical shapes of pump and laser pulses are shown in Fig. 2. The pump pulse had an irregular structure with spikes. The laser pulse also consisted of spikes that followed the pump spikes with a delay of 0.2 – 0.5 μs (depending on the excess of the pump power over its threshold level). Figure 3 shows the Fe^{2+} : ZnSe-laser output energy as a function of the absorbed pump energy measured without a prism in the resonator. In this case, the lasing spectrum was centred at 4.04 μm and had a width of 0.03 μm. A straight line approximating the experimental points gave the threshold value of the absorbed pump energy (5 mJ) and the slope laser efficiency in terms of the absorbed energy (40 %), which corresponds to a quantum efficiency of 55 %. The maximum output energy in our experiments was 130 mJ.

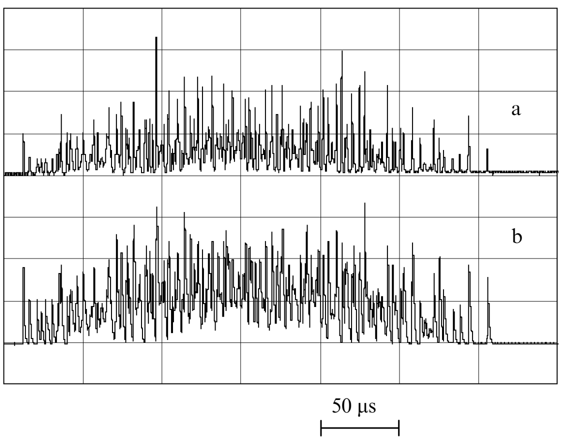

Figure 2. Oscillograms of (a) a pump pulse and (b) a Fe^{2+} : ZnSe laser pulse.

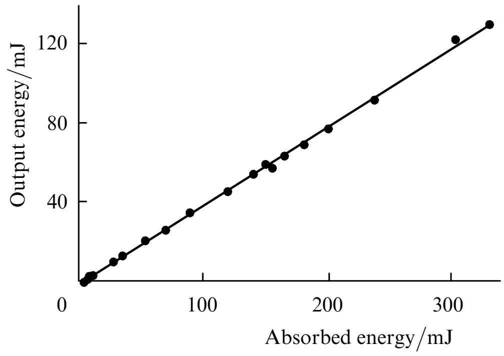

Figure 3. Output energy of the Fe^{2+} : ZnSe laser as a function of the absorbed pump energy.

The Fe^{2+} : ZnSe lasing spectrum was continuously tuned from 3.77 to 4.40 μm with the help of CaF_2 lens. The tuning curve obtained for an absorbed pump energy of 265 mJ at liquid nitrogen temperature is shown in Fig. 4a. Because the transmission of the output mirror increased with the wavelength (see Fig. 4b), this could in principle limit the long-wavelength boundary of the tuning curve in our experiments. It seems that the use of a mirror with a wavelength-independent transmission spectrum can extend the tuning region to longer wavelengths.

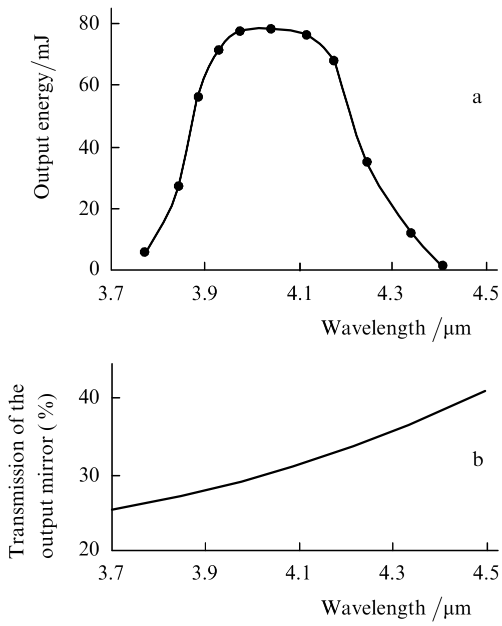

Figure 4. (a) Fe^{2+} : ZnSe laser spectrum and (b) the transmission of the output mirror as a function of the wavelength.

4. Conclusions

We have shown that a Fe : ZnSe laser cooled to liquid nitrogen temperature and pumped by a 2.9364-μm Er : YAG laser ensures a slope efficiency of 40 % with respect to the absorbed energy, which corresponds to a quantum efficiency of 55 %. The lasing spectrum in a dispersive resonator containing a prism can be smoothly tuned within the range of 3.77 – 4.40 μm. The maximum output energy (130 mJ) and the differential efficiency (40 %) of the Fe^{2+} : ZnSe laser obtained experimentally are, respectively, four orders of magnitude and five times higher than those achieved in Ref. [2].

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