Quantum Electronics **47** (9) 831 – 834 (2017)

LASERS

https://doi.org/10.1070/QEL16458

Efficient operation of a room-temperature Fe^{2+}: ZnSe laser pumped by a passively *Q*-switched Er : YAG laser

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Abstract. **Efficient generation of a train of laser pulses is obtained at room temperature in a Fe^{2+}: ZnSe polycrystal pumped by a passively *Q*-switched Er : YAG laser. The Fe^{2+}: ZnSe laser energy reaches 130 mJ at a slope efficiency with respect to the absorbed pump power of 47 %. The average pulse repetition rate in the train is ~100 kHz.**

Keywords: *Fe^{2+}: ZnSe laser, Er : YAG laser, passive Q-switching, pulse train.*

1. Introduction

Permanent interest in lasers based on A_2B_6 crystals doped with bivalent iron ions is explained by their high efficiency, broad wavelength tuning range and ability to operate at room temperature, which allows one to use these lasers for various practical applications.

Pumping of the active elements of Fe^{2+}: ZnSe lasers by relatively short (several tens of nanoseconds) laser pulses makes it unnecessary to cool them to low temperatures. Lasing in a Fe^{2+}: ZnSe crystal at room temperature was obtained for the first time under pumping by 2.92-μm pulses (second Stokes component of Nd : YAG radiation in deuterium) [1].

In subsequent experiments, pumping was successfully performed by a *Q*-switched Er : YAG laser. In [2], the slope efficiency with respect to the absorbed energy was 13 %, while the maximum output energy reached 0.37 mJ. Energy of 0.58 mJ at room temperature was obtained in [3] at an absorbed pump energy of 5.3 mJ with a slope efficiency reaching 38 %. The output energy was increased to 1.4 mJ in [4] and to 5.8 mJ in [5] with a slope efficiency of 39 %.

The Fe^{2+}: ZnSe laser characteristics at room temperature were further improved by using pump sources based on hydrogen – fluoride lasers [6]. In particular, pumping of a Fe^{2+}: ZnSe single crystal by short single pulses of an electric-discharge HF laser made it possible to achieve an output energy of 1.2 J [7, 8]. Stable repetitively pulsed operation of a Fe^{2+}: ZnSe laser with an average power of 2.4 W and a maximum pulse energy of 14 mJ was achieved under pumping by a 1-s train of 100-ns HF laser pulses with a repetition rate of 200 Hz [9].

However, light sources based on HF lasers are cumbersome, require stabilisation of the working mixture composition and removal of toxic products of chemical reactions upon long-term repetitively pulsed operation, and, in addition, their maximum possible repetition rates are relatively low.

In the present work, we obtained efficient generation of a pulse train of a Fe^{2+}: ZnSe laser at room temperature. As a pump source, we used an Er : YAG laser with passive *Q*-switching by a saturable absorber based on a Fe^{2+}: ZnSe polycrystal.

2. Experimental setup

The experiments were performed on a setup schematically shown in Fig. 1 under normal environmental conditions (T = 19 °C, relative air humidity 19 %).

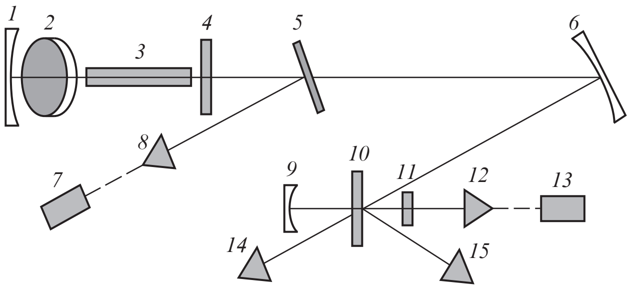

Figure 1. Experimental setup:
(*1*, *4*) mirrors of the Fe^{2+}: ZnSe laser cavity; (*2*) passive *Q*-switch; (*3*) Er : YAG rod; (*5*) CaF_2 plane-parallel plate; (*6*) highly reflecting spherical copper mirror (R = 1000 mm); (*7*, *13*) photodiodes; (*8*, *12*, *14*, *15*) calorimeters; (*9*, *11*) mirrors of the Fe^{2+}: ZnSe laser cavity; (*10*) active element.

The Er : YAG laser cavity 200 mm long was formed by a spherical (R = 2000 mm) gold-coated mirror (*1*) and a plane output mirror (*4*) with a reflection coefficient of 64 % at the wavelength λ = 2.94 μm. A passive *Q*-switch (*2*) was a plane-parallel plate with a diameter of 25 mm and a thickness of 4 mm made of polycrystalline ZnSe doped with Fe^{2+} ions

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Received 26 June 2017
Kvantovaya Elektronika **47** (9) 831 – 834 (2017)
Translated by M.N. Basieva

directly in the process of chemical vapour deposition (CVD). For this purpose, iron chloride vapours were introduced into the CVD reactor simultaneously with zinc and hydrogen selenide vapours in an argon flow. Thermally activated iron atoms formed as a result of a chemical reaction were incorporated into the zinc selenide crystal lattice with the formation of Fe^{2+}: ZnSe. To improve the optical homogeneity of CVD-synthesised Fe^{2+}: ZnSe samples, we subjected them to additional after-growth HIP treatment in an argon atmosphere at a pressure of 1000 atm and a temperature of 1150 °C for 34 h.

Figure 2 shows the transmission spectrum of a plate (*Q*-switch) made of CVD Fe^{2+}: ZnSe. The effective concentration of Fe^{2+} ions calculated from the transmission spectrum taking into account the sample thickness is 2.2×10^{17} cm^{-3}. The *Q*-switch was placed into the cavity at a Brewster angle (67.7°, refractive index $n = 2.44$). An Er:YAG rod (*3*) was pumped by an INP2-5/90A pulsed xenon lamp.

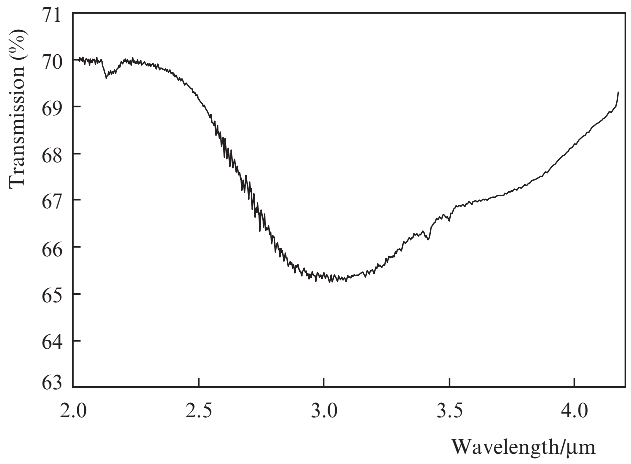

Figure 2. *Q*-switch transmission spectrum.

The Fe^{2+}: ZnSe laser cavity 80 mm long was formed by a gold-coated spherical (R = 1000 mm) mirror (*9*) and a plane mirror (*11*) with a reflection coefficient of 60% for λ = 4.1–4.5 µm. An active element (*10*) in the form of a disk 60 mm in diameter and 3.6 mm thick was made of polycrystalline CVD ZnSe by diffusion doping with Fe^{2+} ions in the process of barothermal treatment at a temperature of 1000 °C for 126 h. The doping method is described in detail in [10]. The concentration of iron ions was 6×10^{18} cm^{-3}. The radiation of the Er:YAG pump laser was focused by mirror *6* on the front face of the Fe^{2+}: ZnSe crystal, the angle of incidence on the crystal being 15°.

The pump energy incident, reflected and passed through the crystal, as well as the lasing energy, was measured by OPHIR PE 50BB and OPHIR 30A-BB-18 calorimeters; in addition, we measured energy using an OPHIR Laserstar power meter. The laser pulses were recorded using VIGO-SYSTEM PD-3 and PVM-10 photodiodes with time constants no larger than 1.5 ns; the parameters of electric signals were measured by a digital oscilloscope with a transmission band of 1 GHz. The intensity distribution was recorded by a Pyrocam IIIHR pyroelectric camera. The transmission of all samples was measured with a Varian 660-IR Fourier transform IR spectrometer.

3. Results and discussion

The Er:YAG laser in the *Q*-switching regime emitted a train of giant laser pulses with a total energy of 0.5 J. This operation regime was previously achieved in [11], but the train there consisted of only three pulses and its total energy did not exceed 23 mJ. In the present work, a 160-µs train contained about 15 giant pulses with a repetition rate of 100 ± 20 kHz. The maximum energy of an individual giant pulse reached 40 mJ at a FWHM duration of 90 ns. Typical pulse profiles of the pump lamp and the Er:YAG laser are given in Fig. 3. The delay of the laser pulse train with respect to the pump pulse was 140 µs.

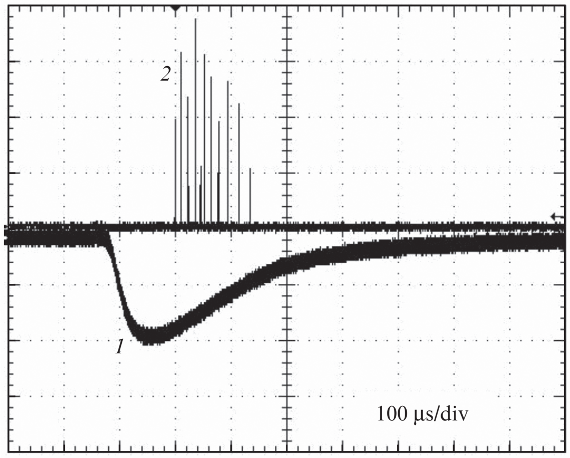

Figure 3. Profiles of (*1*) a pump lamp light pulse and (*2*) a train of giant pulses of the Er:YAG laser.

Figures 4a–4c show different distributions of the Er:YAG laser intensity on the Fe^{2+}: ZnSe crystal surface in the first giant pulse of the train. An increase in the exposure time of

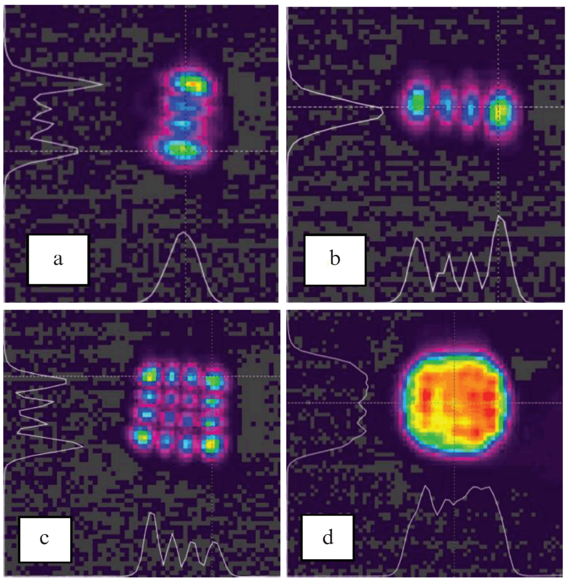

Figure 4. Intensity distribution of the Er:YAG laser radiation in (a–c) individual giant pulses and (d) the entire train.

the pyroelectric camera led to summation of radiation pulses (Fig. 4d).

Typical profiles of the pump and Fe^{2+}: ZnSe laser pulse trains are presented in Fig. 5. The energy instability of the giant pulses is caused by the unstable intensity distribution of the Er : YAG laser in the multimode regime (see Figs 4a–4c). The energy densities on the Q-switch and the active element of the Fe^{2+}: ZnSe laser did not exceed 0.55 and 1.25 J cm^{-2}, respectively, which is lower than the Fe^{2+}: ZnSe crystal breakdown threshold (1.5–2.0 J cm^{-2} at a pulse duration of 100 ns).

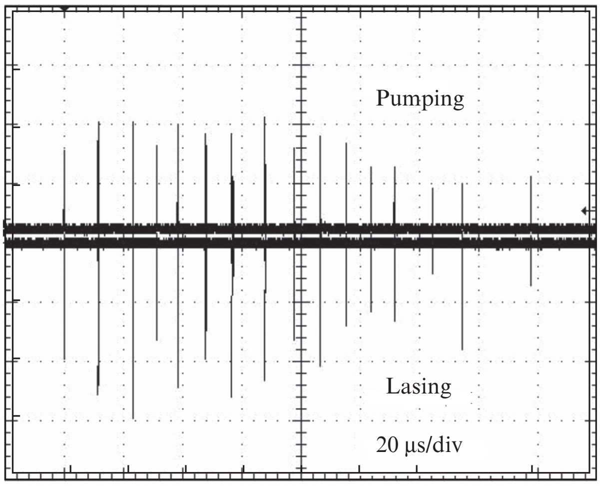

Figure 5. Pulses of the Er : YAG pump laser and the Fe^{2+}: ZnSe laser.

Variations in the duration and shape of the Fe^{2+}: ZnSe laser pulses with absorbed pump energy are shown in Fig. 6. A decrease in the absorbed pump energy led to an increase in the delay of the laser pulse and to a decrease in its duration. Near the lasing threshold, the laser generated short spikes.

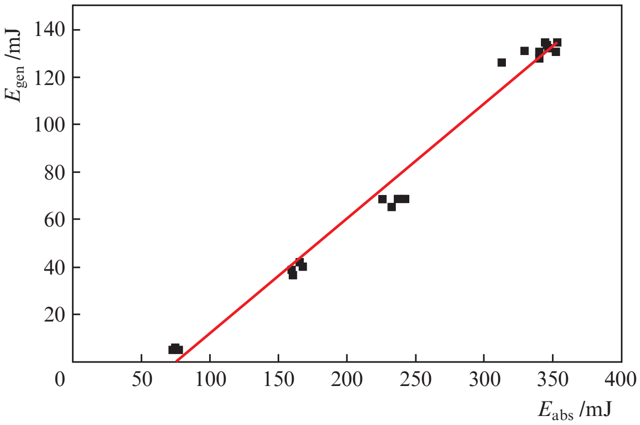

Figure 7. Dependence of the Fe^{2+}: ZnSe laser output energy on the absorbed energy of the Er : YAG laser.

Figure 7 presents the dependence of the Fe^{2+}: ZnSe laser energy on the pump energy absorbed in the crystal. The radiation incident on the crystal was attenuated by calibration filters. The threshold pump energy was 54 mJ, the total energy of the Fe^{2+}: ZnSe laser train exceeded 130 mJ. The laser efficiency with respect to the absorbed pump energy reached 39 %. The slope efficiency with respect to the absorbed energy was estimated by the least squares method from the slope of a straight line drawn through experimental points and turned out to be 47 %.

Thus, we have demonstrated operation of a Fe^{2+}: ZnSe laser pumped by a train of giant laser pulses at room tempera-

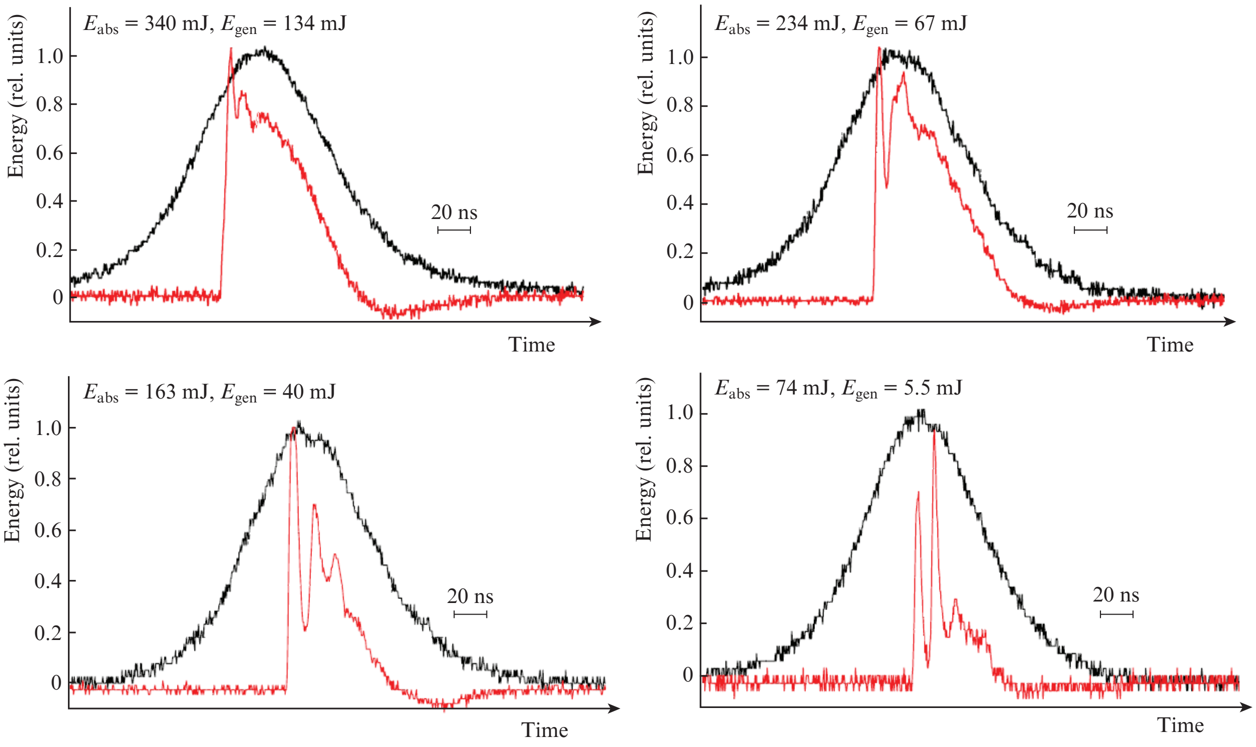

Figure 6. Profiles and durations of the pump and laser pulses. E_{abs} and E_{gen} correspond to the total energy of pulses in the train.

ture. The laser energy exceeded 130 mJ, and the slope efficiency with respect to the absorbed energy was 47% at a pulse repetition rate in the train of 100 ± 20 kHz.

Q-switching of the Er:YAG pump laser allows the Fe^{2+}:ZnSe laser to operate with a high (tens of kilohertz) repetition rate of short pulses.

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