Quantum Electronics **40** (12) 1109 – 1111 (2010)

LASERS AND AMPLIFIERS

PACS numbers: 42.55.Rz; 42.55.Xi; 42.60.Gd; 42.62.Fi
DOI: 10.1070/QE2010v040n12ABEH014428

Lasing of polycrystalline Cr^{2+} : ZnSe pumped by a *Q*-switched Tm : YLF laser

A.A. Andronov, S.S. Balabanov, E.M. Gavrishchuk, O.N. Eremeykin, N.G. Zakharov, A.P. Savikin, N.A. Timofeeva, V.V. Sharkov

***Abstract*. The output characteristics of a laser based on polycrystalline Cr^{2+} : ZnSe obtained by thermal diffusion are studied upon pumping by a cw-diode-pumped *Q*-switched Tm : YLF laser operating at a wavelength of 1.908 μm with a pulse repetition rate of 2 kHz. Efficient pulse-periodic lasing is obtained in the region of 2.32 μm with a total efficiency of ~ 17 %, a pulse duration of ~ 45 ns, and an average power of ~ 1 W.**

Keywords: *Tm : YLF laser, diode pumping, Q-switching, polycrystalline Cr^{2+} : ZnSe laser.*

In recent years, considerable interest is focused on the development of highly efficient lasers emitting in the region of 2 – 5 μm (with the intense absorption lines of most molecules) which extends the applications of laser spectroscopy of molecular gases for solving practical problems in medical diagnostics and environmental monitoring.

Quantum cascade lasers operating directly at mid-IR wavelengths have been extensively studied all over the world for more than 15 years [1, 2]. However, they still cannot compete in energy (in one chip) with solid-state laser systems.

Among the ways of development of solid-state coherent mid-IR sources, one can distinguish two most promising. The first way involves the use of optical parametric oscillators [3]. The drawbacks of parametric oscillation in nonlinear crystals include a high excitation threshold and a low stability of the oscillation frequency and amplitude. These drawbacks are absent in the second-generation lasers based on chalcogenide crystals (ZnS, ZnSe, CdSe, etc.) doped with transition-metal ions (Cr, Co, Ni, Fe). In particular, the tuning bandwidth of lasers based on the Cr^{2+} : ZnSe and Cr^{2+} : ZnS crystals is 2.1 – 3.1 μm [4 – 6].

The absorption band of the Cr^{2+} : ZnSe crystal with the maximum at a wavelength of 1.8 μm and a width of ~ 300 nm determines the choice of pump sources. For pumping, along with diode lasers [7], one uses thulium fibre [8] or crystalline [9, 10] lasers emitting in the wavelength region of 1.8 – 2 μm, which ensures the minimum difference between the pump photon energy and the energy of photons of the laser transition of Cr^{2+} ions, thus decreasing the heat release and increasing the laser efficiency.

The aim of this work is to study the possibility of using an efficient compact *Q*-switched Tm : YLF laser for pumping a polycrystalline Cr^{2+} : ZnSe laser. The pulse-periodic regime with a high pulse power (several tens of kilowatt) and a pulse repetition rate of several kilohertz makes this laser promising for application in analytical spectroscopy with signal recording by the method of synchronous detection.

Chromium-doped ZnSe used in the experiment was synthesised by high-temperature diffusion. For doping, we used samples of polycrystalline ZnSe produced by the CVD method in the form of tablets 20 mm in diameter and 4 mm in thickness, whose both faces were coated with a 1-μm metal chromium film by electron-beam evaporation. The diffusion annealing was performed in quartz ampoules in the argon atmosphere at a temperature of 900 °C for 13 days. A homogeneous distribution of the dopant was achieved by gas-static treatment of the samples for 30 h at a pressure of 190 MPa and a temperature of 980 °C.

The two faces of the Cr^{2+} : ZnSe samples were polished, and the samples were analysed by IR Fourier spectroscopy. All the samples had an absorption band peaked in the region of 1.77 μm; the concentration of Cr^{2+} ions was about 10^{18} at cm^{-3}.

For optical pumping of Cr^{2+} : ZnSe samples, we used a previously designed diode-pumped Tm : YLF laser emitting linearly polarised radiation at a wavelength of 1908 nm [11]. For pulse-periodic operation, we included an acousto-optic modulator in the laser scheme. At a pulse repetition rate of 2 kHz, the pulse duration was ~ 80 ns at an average power of 6 W.

After passing an optical isolation system (*2*), which consisted of a polarising wedge and a quarter-wave plate, the Tm : YLF laser beam became circularly polarised and was focused by a lens system (*3*) into the Cr^{2+} : ZnSe sample (*4*) (Fig. 1). The pump beam waist diameter was ~ 550 μm. The sample was attached to a copper holder without additional cooling and oriented in the cavity scheme at the Brewster angle. The cavity was formed by mirrors (*5*, *6*, and *7*). The plane mirror (*5*) had a high (no lower than 99.5 %) reflectance at wavelengths in the range of 1.9 – 2.5 μm, which allowed us to increase the absorbed

A.A. Andronov, O.N. Eremeykin, N.G. Zakharov, A.P. Savikin, V.V. Sharkov N.I. Lobachevskii Nizhnii Novgorod State University, prosp. Gagarina 23, 603950 Nizhnii Novgorod, Russia;
e-mail: eon@rambler.ru, savikin@rf.unn.ru;
S.S. Balabanov, E.M. Gavrishchuk, N.A. Timofeeva Institute of Chemistry of High-Purity Substances, Russian Academy of Sciences, ul. Tropinina 49, 603950 Nizhnii Novgorod, Russia

Received 13 September 2010; revision received 10 November 2010
Kvantovaya Elektronika **40** (12) 1109 – 1111 (2010)
Translated by M.N. Basieva

pump power due to the double pass of the pump beam through the active element. The dichroic mirror (*6*) had a high reflectance in the range of 2.1 – 2.5 μm (about 99 % for the vertical polarisation) and a high transmittance at the pump wavelength (about 90 %). As an output mirror, we used the spherical mirror (*7*) with the curvature radius $R = 300$ mm and a transmittance of ~ 80 % at the laser wavelength. Owing to the chosen cavity configuration, the pumped region well coincided with the fundamental mode of the cavity (diameter 500 – 600 μm) in the possible range of the focal lengths (30 – 300 cm) of the thermal lens induced in the active element.

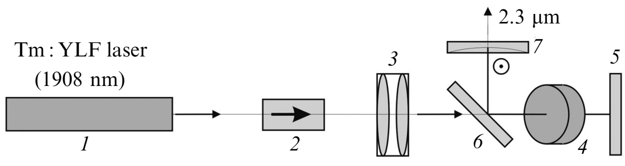

Figure 1. Scheme of the experimental setup: (*1*) Tm : YLF laser; (*2*) optical isolation system; (*3*) lens system; (*4*) Cr^{2+} : ZnSe active element; (*5*) highly reflecting mirror; (*6*) dichroic mirror; (*7*) output mirror.

The laser power was measured with a large-aperture calibrated detector (Gentec) sensitive in the spectral range from 0.5 to 10 μm. The time parameters of lasing were measured by a photodetector based on a HgCdTe structure with a response time of $\sim 5 \times 10^{-9}$ s. The signal from the photodetector was recorded by a LeCroy 62Xi oscilloscope with a transmission band of 600 MHz. The spectral analysis of the output radiation in the range of 1.9 – 2.7 μm was performed using an MDR-41 monochromator.

The luminescence and laser spectra were measured using an FSA-G1 PbS photodetector with the long-wavelength sensitivity edge at ~ 2.7 μm. In the long-wavelength region (2.5 – 2.7 μm) of the Cr^{2+} : ZnSe luminescence spectrum, we observed holes, which can be explained by water vapour absorption [12] (Fig. 2).

The absorption of the linearly polarised pump radiation (p polarisation) in the Cr^{2+} : ZnSe sample oriented at the Brewster angle was preliminarily measured to be 70 %, which corresponded to the absorption coefficient of ~ 2.8 cm^{-1} at the wavelength $\lambda = 1908$ nm.

The lasing threshold was about 0.4 W, and the average laser power $P_{gen} \approx 1$ W was achieved at the pump power $P_p \approx 5.4$ W (taking into account the losses at the dichroic mirror) (Fig. 3). The laser spectrum lay near $\lambda = 2.32$ μm (Fig. 2), which corresponded to the rather wide maximum of the Cr^{2+} : ZnSe luminescence band, which is typical for similar active media [4, 13]. The laser linewidth at half-maximum $\Delta\lambda_{0.5}$ was ~ 55 nm.

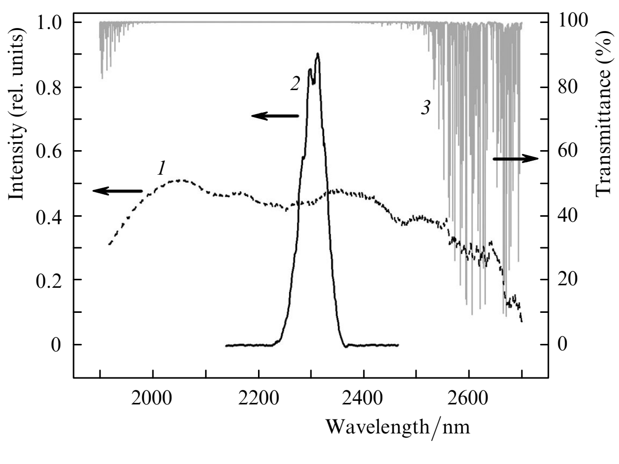

Figure 2. Cr^{2+} : ZnSe luminescence spectrum measured with a spectral resolution of ~ 1 nm (*1*), output spectrum of the Cr^{2+} : ZnSe laser (*2*), and atmospheric transmission spectrum [12] (path length 0.1 m) (*3*).

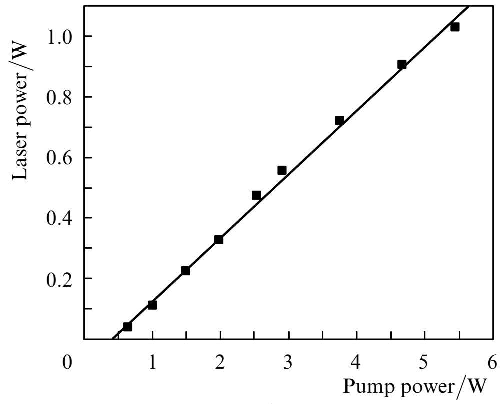

Figure 3. Dependence of the Cr^{2+} : ZnSe laser average power on the power of the Tm : YLF pump laser.

In addition to the losses at the dichroic mirror, a considerable part of the pump energy (~ 25 %) was lost at the reflection of the circularly polarised radiation from the front face of the active element. The total laser efficiency η in the case of the output mirror transmittance of 20 % was 17 %, which corresponded to the slope efficiency with respect to the absorbed power $\eta_{abs} \sim 38$ %. The laser radiation was linearly polarised due to both the active element orientation and the selective properties of the dichroic mirror introducing the minimum losses for the vertical polarisation.

At the pump pulse duration $\Delta t_p \approx 80$ ns (pulse repetition rate 2 kHz, $P_p = 6$ W), the pulse duration of the Cr^{2+} : ZnSe laser was $\Delta t_{gen} \approx 45$ ns at the average power $P_{gen} \approx 1$ W (Fig. 4). These parameters correspond to the laser pulse power $P_{puls} \approx 10$ kW with the pulse energy of

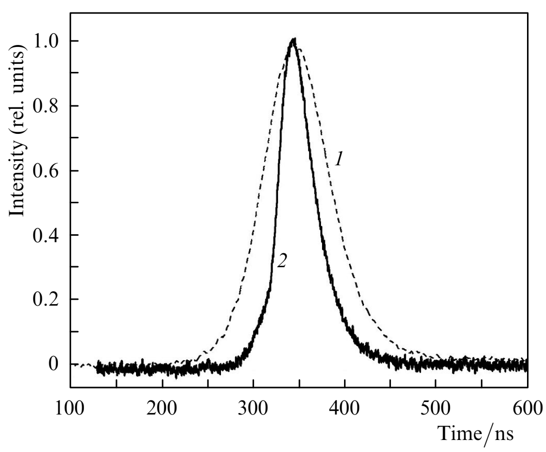

Figure 4. Oscillograms of the pump (*1*) and Cr^{2+} : ZnSe (*2*) laser pulses.

0.45 mJ. It should be noted that the pulse shape of the Cr^{2+} : ZnSe laser in our scheme was smooth, without oscillations at the leading front that were observed in [9].

Thus, in this work we studied the output characteristics of the laser based on polycrystalline Cr^{2+} : ZnSe obtained by diffusion annealing. It is shown that this laser can be efficiently (with the total efficiency of 17 %) pumped by a cw-diode-pumped Tm : YLF laser operating at a wavelength of 1.908 nm in the pulse-periodic regime (pulse repetition rate 2 kHz). We obtained laser radiation at a wavelength of 2.32 μm with an average power of about 1 W.

Acknowledgements. This work was supported by the Analytical Departmental Targeted Program 'Development of the Scientific Potential of the Higher School' (Project No. 2.1.1/3603) and by the Federal Targeted Program 'Scientific and Scientific-Pedagogical Personnel of Innovative Russia' (Contract No. 02.740.11.0563).

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