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Optimisation of the pumping parameters of a repetitively pulsed erbium laser

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Abstract. **The lasing parameters of active elements made of a new LGS-KhCh chromium – ytterbium – erbium glass are studied in the free-running mode. The methods for optimising the pump parameters and the laser design are demonstrated. An average output power of 8 W was achieved in a repetitively pulsed regime at the radiation divergence of 12 mrad at the 0.9 level.**

Keywords: *chromium – ytterbium – erbium phosphate glass, erbium laser, repetitively pulsed regime.*

1. Introduction

Erbium glass lasers find increasing applications because they emit at the spectral range (at 1.54 μm), which is safe for vision. Earlier [1], we reported the use of an LGS-KhM chromium – ytterbium – erbium glass in miniature lasers without forced cooling.

In this paper, we study an LGS-KhCh chromium–ytterbium – erbium glass manufactured at IREE, RAS, which is intended for lasers with forced water cooling. In addition, the aim of this paper is to familiarise the developers of erbium glass lasers with the dependences of output characteristics of the lasers on the pump parameters. An appropriate choice of the pump parameters and the elements of the pumping system provides the lasing threshold and efficiency for the erbium glass laser, which are only slightly inferior to the threshold and efficiency of a neodymium glass laser.

2. Spectral characteristics of the laser medium

The repetitively pulsed lasing assumes the possibility of achieving high output power, which is associated with a strong heat release in the active element. This results in a number of negative consequences such as an induced thermal lens and mechanical strains, which limit the maximum pump power due to the destruction of the active element. All this necessitates a search for a reasonable compromise in the choice of the activator concentration, especially, in the case of erbium glasses.

Luminescence of erbium ions is usually sensitised with the help of ytterbium ions. In order to use the radiation from a pump flashlamp more efficiently, chromium ions are doped in glass [2, 3], which have broad absorption bands at 450 and 660 nm (Fig. 1). Although the contribution of these bands to the output energy at the concentration of chromium ions equal to 4×10^{19} cm^{-3} can achieve 100 % and more (relative to the contribution of ytterbium ions) [4], doping with chromium drastically enhances the heat release in the active element. This is caused by a comparatively low (60 %) quantum efficiency of sensitising for a chromium – ytterbium pair and by a large Stokes shift between the energy of pump photons absorbed by chromium ions and the energy of laser photons at 1.54 μm. Even for pumping into the long-wavelength 600-nm absorption band, the pump-photon energy is almost 2.5 times higher than that of the laser photon.

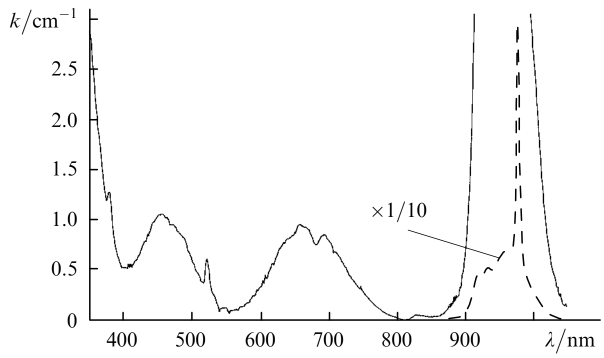

Figure 1. Absorption spectrum of an LGS-KhCh glass.

Taking this into account, the LGS-KhCh chromium – ytterbium – erbium glass with a reduced concentration of chromium ions (7×10^{18} cm^{-3}) was manufactured at IREE, RAS, for the use in repetitively pulsed lasers. The thermo-optic constant W of the glass was minimised to be 1.2×10^{-6} K^{-1}. To compensate for the losses due to the reduced concentration of chromium ions, the concentration of ytterbium ions was increased by a factor of 1.5 compared to that in the LGS-X glass [4]. The absorption spectrum of the new

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glass with the concentration of erbium ions equal to 10^{19} cm^{-3} is shown in Fig. 1.

It is obvious that such a strong change in the activator concentration should result in the redistribution of the contributions from chromium and ytterbium ions to the laser output parameters. This in turn stimulates a search for the pump-pulse parameters that would provide optimal matching between the emission spectrum of flashlamp and the absorption spectrum of a laser material.

We manufactured laser rods of diameter 4 mm and length 80 mm for studying laser characteristics. The rod diameter was made smaller than that in typical neodymium glass lasers (6 – 8 mm) because it was necessary to reduce the lasing threshold and to increase the maximum output power of the laser. To decrease the thickness of the broken layer, the side surface of the rods was polished at the final stage with M10 fine abrasive powder. Just before the tests, the broken layer on the side surface was removed by chemical etching over the depth from 50 to 100 μm. To demonstrate the possibility of obtaining high output power, the rods were etched down to the diameter 3 mm. Mechanical properties of these rods were sufficient to withstand the strains appearing in the rods upon their mounting in the pumping system. The faces of the rods were covered with a two-layer (ZrO_2, SiO_2) anti-reflection coating with the residual reflectivity lower than 0.1 %.

3. Experimental results

3.1 Optimisation of the pump parameters and pumping system elements in the single-pulse regime

Tests were performed in a radiator with a silver-plated monoblock reflector made of alloyed yellow quartz. The resonator of length 130 mm was formed by a highly reflecting concave mirror with a radius of curvature of 3 m and by a flat output mirror with a reflectivity of 86 %, which was close to optimal. The radiator was cooled with distilled water at a flow rate of 10 L min^{-1}. A flashlamp was fed from a power supply (model 730) manufactured at the Physics Instrumentation Centre, GPI, RAS. The power supply allowed the variation of current through the flashlamp between 15 and 150 A and 30 and 300 A, and of the pulse duration within 100 μs – 50 ms. The flashlamp operated in the regime of the attendant arc current.

Fig. 2 presents the results of tests of the laser rods at the fixed current through the flashlamp and a pulse repetition rate of 0.1 Hz. The pulse energy was controlled by varying the pump-pulse duration. One can see that the differential efficiency with an INP-3/75 flashlamp at a current of 20 A achieves a maximum value of 4.15 %. At this current, the optimal relation between the overlap of the emission spectrum of the flashlamp and the absorption spectrum of chromium ions and the losses associated with luminescence of erbium ions is achieved.

Fig. 2 also shows the 'averaged' dependence of the output energy on the pump energy for an INP-5/75 flashlamp. The deviations from this dependence at different currents in the range from 30 to 225 A did not exceed 10 %. Taking into account the dependence of the spectral distribution of the efficiency of tubular xenon flashlamps on the specific power of a discharge [6], we can expect that the optimal current for the INP-5/75 flashlamp does not exceed 30 A. The low efficiency of the INP-5/75 flashlamp is explained first of all by a poor matching between the laser rod diameter and the discharge channel of the flashlamp.

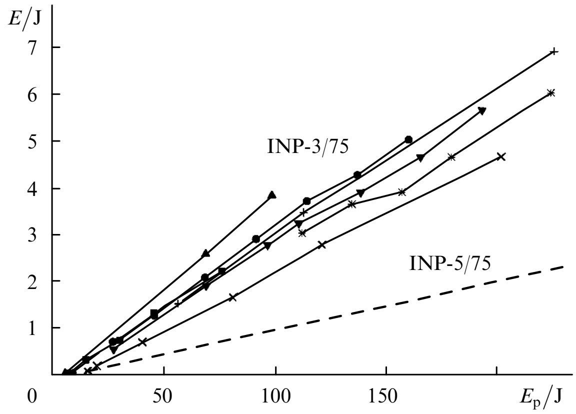

Figure 2. Dependences of the output energy E on the INP-3/75 flashlamp pump energy E_p for the flashlamp currents 17 (■), 20 (▲), 30 (●), 60 (+), 70 (▼), 100 (∗), and 150 A (×) and voltages across the lamp 100 (■), 110 (▲), 170 (●), 210 (+), 220 (▼), 250 (∗), and 300 V (×), as well as the averaged dependence of the output energy on the pump energy for the INP-5/75 flashlamp at currents from 30 to 225 A and voltages between 225 and 290 V (dashed straight line).

Another way of controlling the pump-pulse energy is to change the flashlamp current at the fixed pulse duration. The dependence of the output energy on the pump energy for the constant pump-pulse duration can be calculated from the curves presented in Fig. 2. The results obtained in this case show that the differential efficiency of the INP-3/75 flashlamp increases with increasing pump-pulse duration from 2 % (for 1-ms pulses) to 2.8 % – 3 % (for 10 – 20-ms pulses). The differential efficiency is somewhat stabilised at the pump-pulse duration between 4 and 6 ms. However, by selecting the pump-pulse duration, one should bear in mind that the lasing threshold increases with the pulse duration. These results substantially differ from the results obtained for an LGS-X glass, in which the concentration of chromium ions is four times higher. The optimal pump-pulse duration for this glass was 2 ms [4].

The lasing spectrum consisted of two lines at 1535 and 1545 nm. As the reflectivity of the output mirror was increased to 96 %, these lines shifted to the red and were observed at 1545 and 1560 nm.

Fig. 3 shows the dependences of the output energy on the pump energy obtained for the monoblock reflector described above and for a reflector in the form of a hollow silver-plated quartz tube of diameter 15 mm. The design provided a compact arrangement of a laser rod and a flashlamp inside the reflector: the gap between the lamp surface and the side surface of the rod was 2 mm. The pump-pulse duration was 3 ms.

The parameters of the water-cooled tubular reflector are second to those of the water-cooled monoblock reflector. However, when the tubular reflector is cooled by heavy water, its output parameters become higher than those of the monoblock reflector. This is explained by the fact that the gap filled by cooling water is larger in the tubular reflector than in the monoblock reflector. It is known that common water has the absorption band at 976 nm (absorption is approximately 30 % in a 1-cm thick layer) which overlaps with the absorption band of ytterbium ions. One can see from the results obtained that in some cases (for

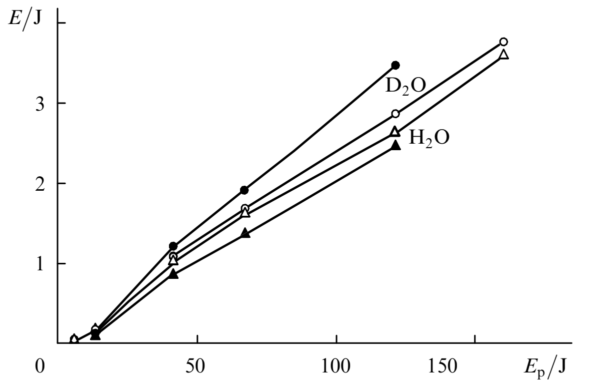

Figure 3. Dependences of the output energy E on the pump energy E_p for the monoblock reflector (open circles and triangles) and the tubular reflector (dark circles and triangles) upon cooling with H_2O (triangles) and D_2O (circles).

example, in the single-pulse regime or at low pulse repetition rates), simple and low-cost tubular reflectors can be used instead of monoblock reflectors.

3.2 Repetitively pulsed regime

The INP-3/75 flashlamp was tested in the repetitively pulsed regime using the same power supply and cooling system as above and 4-ms pump pulses. The results of these tests are presented in Figs 4 and 5, where the dependences of the average output power and the radiation divergence of the pump power are presented. For the laser rod of diameter 4 mm, the critical pump power at which some rods were destroyed was 260 W; some rods withstood the power up to 300 W. Such a scatter is related to the quality of the side-surface polishing and also can be explained by the damage of the side surface during the radiator assembling.

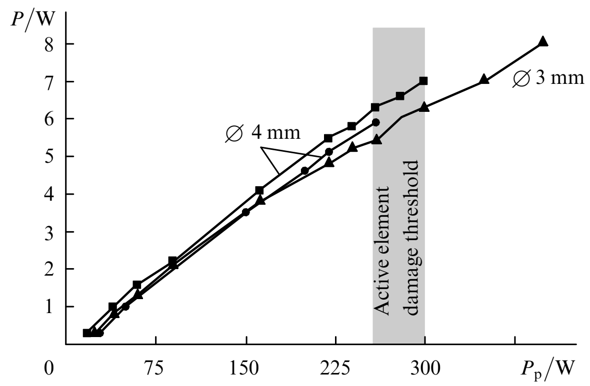

Figure 4. Dependences of the average output power P on the pump power P_p for laser rods of diameters 3 and 4 mm for a pulse repetition rate of 1 (■) and 2 Hz (▲, ●).

The radiation divergence was quite acceptable and did not exceed 12 mrad at the 0.9 level for the maximum pump power. The laser rod etched to a diameter of 3 mm, withstood the pump power up to 400 W, the lasing efficiency being only slightly decreased. This rod produced the average output power up to 8 W at a pulse repetition rate of 2 Hz. Note for comparison that a maximum output power achieved with a neodymium glass rod of close dimensions (of diameter 4.3 – 4.6 mm and length 80 mm) was 15 W (a KNFS glass) and the maximum pump power was 600 W (LGS-T and KNFS glasses) [5].

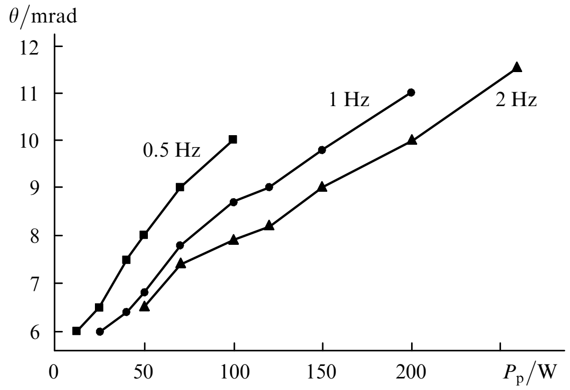

Figure 5. Dependences of the divergence θ on the pump power P_p for different pulse repetition rates.

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