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Pulsed oscillation of a diode-pumped passively *Q*-switched $Nd^{3+}:Ca_3Ga_2Ge_3O_{12}$ laser

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Abstract. **Pulsed oscillation of a diode-pumped passively *Q*-switched $Nd^{3+}:Ca_3Ga_2Ge_3O_{12}$ (Nd : CGGG) solid-state laser is studied. For the absorbed pump power of 0.8 W, the pulse energy was 3.5 μJ and the pulse rise time, duration and decay time were 6, 11 and 13 ns, respectively. The pulse repetition rate varied from 3 to 13 kHz when the absorbed pump power was changed from 0.45 to 1 W. It is shown that all the temporal parameters of the generated pulse decrease with increasing the absorbed pump power. The sensitivities of these parameters and the pulse repetition rate to changes in the absorbed pump power and the laser resonator length are measured. The results of the research are compared with the corresponding results for the pulsed Nd : YAG laser operating under the same conditions.**

Keywords: *solid-state lasers, diode pumping, passive Q-switching.*

1. Introduction

Neodymium-doped calcium–gallium–germanium garnet crystals, $Nd^{3+}:Ca_3Ga_2Ge_3O_{12}$ (Nd : CGGG), are a promising material for developing compact diode-pumped solid-state lasers, because they allow doping with large concentrations of Nd^{3+} ions, have almost the same heat conduction as YAG crystals (significantly exceeding the heat conduction of laser glasses) and successfully combine attractive luminescent, physical and technological properties [1, 2].

In addition, the inhomogeneous absorption spectrum of Nd^{3+} ions in Nd : CGGG crystals is matched with the emission spectra of pump laser diodes, while a comparatively broad emission band of Nd:CGGG crystals makes them promising for generating short laser pulses [3, 4].

In paper [5], pulsed oscillation of a diode-pumped *Q*-switched Nd : CGGG laser was obtained and the dependences of the average laser power and the pulse energy and duration τ_i on the absorbed pump power P were studied. The dependence of the pulse duration of a diode-pumped passively *Q*-switched Nd : YVO_4 laser on its resonator length L was studied in [6]. Because the pulse rise (τ_r) and decay (τ_f) times in these lasers are comparable with the time τ_i [7], the influence of changes in the power P and length L on all the temporal parameters of the laser pulse is of special interest.

The aim of this paper is to study the dependences of τ_r, τ_i, τ_f and the pulse repetition rate f of a diode-pumped passively *Q*-switched Nd:CGGG laser on the pump power and the resonator length and to measure the sensitivities of the parameters τ_r, τ_i, τ_f, and f to changes in P and L.

2. Experimental

The scheme of the experimental setup for studying pulsed oscillation of the diode-pumped passively *Q*-switched Nd : CGGG laser is presented in Fig. 1. Pumping was performed by 805-nm laser diode (*1*) with fibre output (*2*) (NA = 0.22, $d_c = 100$ μm). The diode laser linewidth (FWHM) was ~2 nm. Microlens (*3*) focused radiation from the output end-face of fibre (*2*) into a spot of diameter of 90 μm on laser element (LE) (*4*). The LE was fixed on a copper heatsink with a thermal paste. The front face (blackened in Fig. 1) – the LE input mirror with spherical mirror (*6*) with the transmission coefficient $T = 0.01$ and the radius $R = 5$ cm, form the laser resonator, whose length L could be varied. Cr^{4+} : YAG saturable absorber (*5*), which had an AR coating at 1.06 μm and the transmission coefficient $T = 0.9$ at low radiation intensities

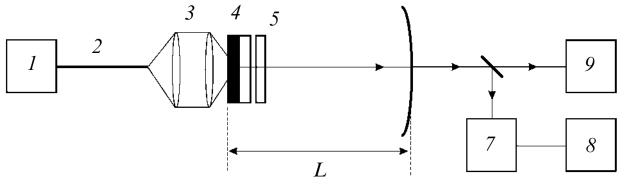

Figure 1. Scheme of the experimental setup for studying the pulsed oscillation of the diode-pumped passively *Q*-switched Nd:CGGG laser: (*1*) laser diode; (*2*) optical fibre; (*3*) microlens; (*4*) laser element; (*5*) saturable absorber; (*6*) output spherical mirror; (*7*) photodetector; (*8*) oscilloscope; (*9*) power meter.

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incident on it, was placed in the laser resonator. The thickness of absorber (*5*) was 1 mm and the LE thickness was 1.5 mm. The concentration of Nd^{3+} ions in the Nd : CGGG crystal was 2.0×10^{20} cm^{-3}.

A 4.1-mm-thick Nd : YAG crystal doped with Nd^{3+} ions at the concentration 0.8×10^{20} cm^{-3}, was used as a reference LE to compare the pulsed oscillation parameters. The absorption of pump radiation in the reference LE was approximately equal to that in the Nd : CGGG crystal.

The shape and temporal parameters of laser pulses were measured with low-noise broadband photodetector (*7*) and Tektronix TDS 5104 oscilloscope (*8*). The power was measured with Coherent FieldMaster FM power meter equipped with a LM10 measuring head.

3. Results and discussion

The typical pulse of the Nd : CGGG laser is shown in Fig. 2. The pulse rise time (the leading edge duration) τ_r was defined as the time during which the signal increased from 0.1 to 0.9 of its maximum value. The pulse duration τ_i was defined as the pulse FWHM, and the decay time (the trailing edge duration) τ_f – as the time during which the signal decreased from 0.9 to 0.1 of its maximal value. Typical values of the parameters τ_r, τ_i, and τ_f of the Nd : CGGG-laser pulse were 6, 11 and 13 ns, respectively, and for the Nd : YAG laser they were 9, 15 and 18 ns.

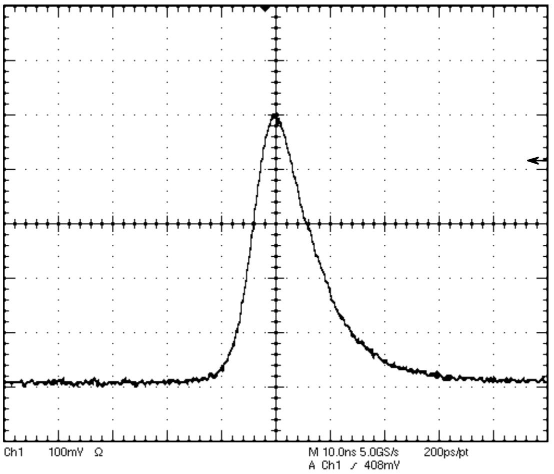

Figure 2. Shape of a single laser pulse for $\tau_r = 6$ ns, $\tau_i = 11$ ns and $\tau_f = 13$ ns; the time scale is $M = 10$ ns div^{-1}.

3.1 Dependence of the laser energy and pulse repetition rate on the absorbed pump power

Figure 3 shows the dependences of the energy E and pulse repetition rate f of the Nd : CGGG and Nd : YAG lasers on the absorbed pump power P. One can see that in the Nd : CGGG laser the pulse repetition rate varies from 3 to 13 kHz when the absorbed power is changed from 0.46 to 1 W. The obtained dependence of f on P for the Nd : CGGG laser can be approximated by the linear function with the proportionality coefficient $K_{f\mathrm{C}} \approx$ 17 kHz W^{-1}, which is equal to the sensitivity coefficient of the pulse repetition rate to changes in the absorbed pump power.

The change in P in the range from 0.35 to 1 W for the Nd : YAG laser leads to changes in f in the range from 4 to 35 kHz, and the corresponding sensitivity coefficient $K_{f\mathrm{Y}}$ is equal to 49 kHz W^{-1}.

The difference in the sensitivity coefficients $K_{f\mathrm{C}}$ and $K_{f\mathrm{Y}}$ is related to the difference in the effective cross sections of induced transitions σ in Nd^{3+} ions in these crystals: for the Nd : CGGG laser $\sigma_\mathrm{C} = 1.4 \times 10^{-19}$ cm^2, for the Nd : YAG laser $\sigma_\mathrm{Y} = 3.2 \times 10^{-19}$ cm^2 [3] and the frequency f is proportional to σ [8].

The pulse energy generated by the Nd : CGGG laser, as follows from Fig. 3, is 3.5 μJ for the absorbed pump power 0.7 – 1.1 W and the pulse energy of the Nd : YAG laser is ~2.1 μJ, when the absorbed pump power is changed in the range from 0.6 to 1 W. The peak pulse power E/τ_i of the Nd : CGGG laser was 0.32 kW and that of the Nd : YAG laser was 0.14 kW, i.e. the pulse energy and peak power of the Nd : CGGG laser exceeds the pulse energy and peak power of the Nd:YAG laser by 1.7 and 2.3 times, respectively.

The greater pulse energy of the Nd : CGGG laser compared to the pulse energy of the Nd : YAG laser is also mainly due to the difference in the effective cross sections σ for these lasers ($\sigma_\mathrm{C} < \sigma_\mathrm{Y}$), because the energy E is inversely proportional to the effective cross section σ [6].

3.2 Dependence of the temporal parameters of the laser pulse on the resonator length and absorbed pump power

Figure 4 shows the experimental dependences of the rise time τ_r, duration τ_i and decay time τ_f of Nd : CGGG- and Nd : YAG-laser pulses on the absorbed pump power P and the length L of laser resonators. One can see that when P increases for these lasers, the laser pulse parameters tend to decrease. The sensitivity coefficient of each of these parameters to the change in the power P was determined as the slope of the straight line approximating experimental points of the corresponding dependence. These coefficients for each laser were approximately the same: $K_{\tau\mathrm{C}}^{(P)} \approx -2$ ns W^{-1} and $K_{\tau\mathrm{Y}}^{(P)} \approx -3$ ns W^{-1}.

The decrease in the laser pulse with increasing the absorbed pump power can be explained by changes in the saturable absorber properties (YAG : Cr^{4+} crystal) [9] and by changes in the pump-beam profile and the amplification working volume [10]. In particular, the focusing effects [3, 11] in the LE can lead to significant changes in the working volume of the LE generation [10]. Because the laser element of the Nd : YAG laser is thicker than that of the Nd : CGGG laser, one can expect that the focusing effects in the Nd:YAG laser [3, 11] are more pronounces due to which $|K_{\tau\mathrm{Y}}^{(P)}| > |K_{\tau\mathrm{C}}^{(P)}|$.

The increase in the laser resonator length L leads, as follows from Fig. 4, to the increase in τ_r, τ_i, and τ_f of the laser pulse. The result is quite expected because the laser pulse duration is proportional to the round-trip transit time of light in the resonator [6]. The sensitivities of the parameters τ_r, τ_i, and τ_f to changes in L for each of the lasers are approximately the same and are 2 ns cm^{-1} (the Nd : CGGG laser) and 3 ns cm^{-1} (the Nd : YAG laser). The higher sensitivity $K_{\tau\mathrm{Y}}^{(L)}$ is caused by the greater thickness of the laser element of the Nd : YAG laser.

The error in the measured sensitivity coefficients is 30 %, which is explained by the scatter in the experimental points, one of the reasons being the inhomogeneity of the saturable absorber appearing in such measurements [6].

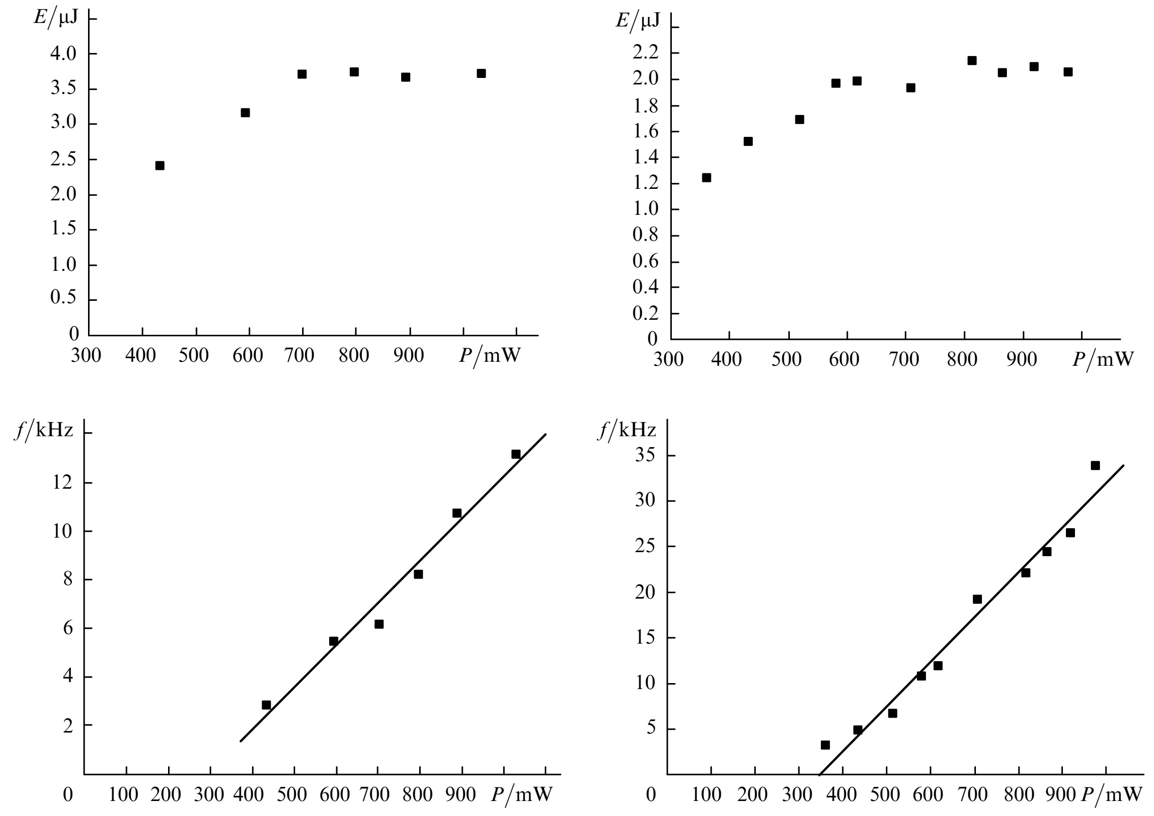

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Figure 3. Dependences of the energy E and pulse repetition rate f of Nd : CGGG- (a) and Nd : YAG-crystal (b) lasers on the absorbed pump power P.

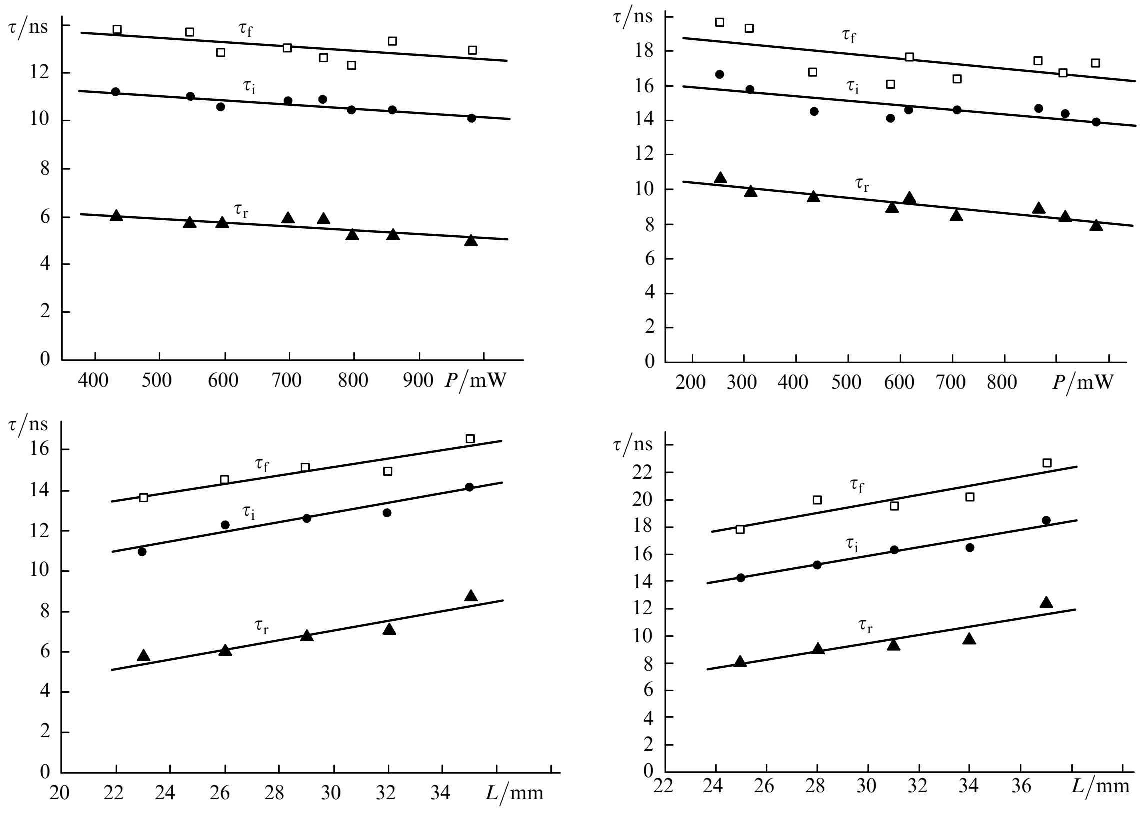

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Figure 4. Dependences of the pulse rise time τ_r, duration τ_i and decay time τ_f of Nd : CGGG- (a) and Nd : YAG-crystal (b) lasers on the absorbed pump power P and the resonator length L.

4. Conclusions

We have studied the pulsed oscillation of the diode-pumped passively *Q*-switched Nd : CGGG laser and compared the results with the corresponding results for the pulsed Nd : YAG laser operating under the same conditions. The YAG : Cr^{4+}-crystal saturabale absorber was used as a modulator. The pulse repetition rate varied from 3 to 13 kHz when the absorbed pump power was changed from 0.45 to 1 W. The laser pulse energy was 3.5 μJ and its rise time, duration and decay time were 6, 11 and 13 ns, respectively. The pulse peak power and energy of the Nd : CGGG laser were approximately twice those of the Nd : YAG laser. It has been shown that when the absorbed pump power increased, all temporal parameters of the generated pulse decrease. The sensitivities of these parameters and the pulse repetition rates to changes in the absorbed pump power and the laser resonator length are measured.

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