Passively Q-switched Nd:YAG laser with direct bleaching of a saturable absorber

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One of the most significant deficiencies of passively Q-switched lasers comparing with the lasers with active Q-switching is the output pulse timing jitter. The method of bleaching a passive shutter with an external light source can be used to relate the generation pulse to time and reduce jitter, as considered earlier in [1,2]. However, the authors discussed an actively Q-switched laser as a source of a bleaching light, which reduces the prospects of using this method to zero. Recently, inexpensive high-power laser diodes (tens of watts) for solid-state lasers pumping have become available. We propose to use them as sources of bleaching light. In this case, the lasing wavelength and the wavelength of the bleaching pulse may not coincide. However, bleaching of a passive shutter will occur, because the population of the lower level will fall regardless of the absorption wavelength. Such an approach makes the prospects of using this method quite real.

The laser model considered in this work is presented in Fig. 1.

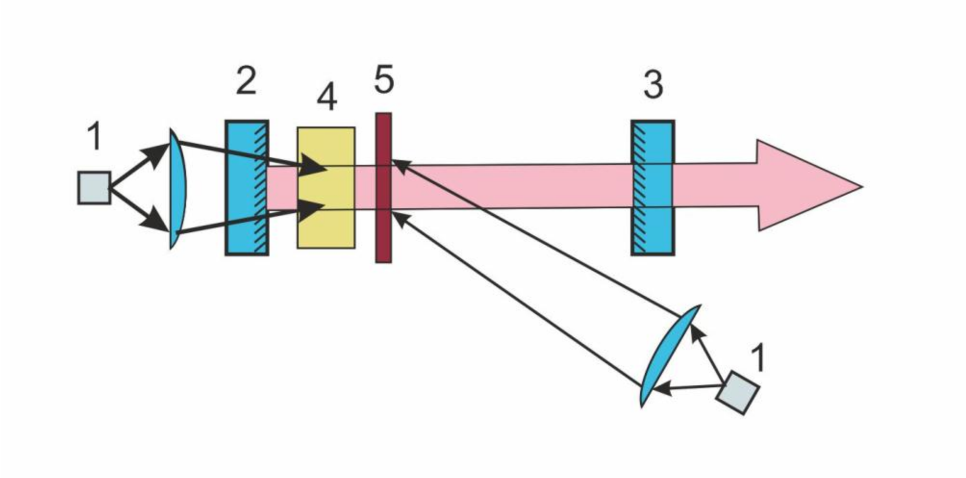

Fig.1. Laser scheme: 1 – laser diode, 2,3 – cavity mirrors,
4 – laser crystal (*Nd:YAG*), 5 – passive shutter (Cr^{4+}*:YAG*)

Modeling of laser generation in the passive Q-switching mode with passive shutter bleaching was carried out using the rate equations (1) written in the approximation of the point model of the active medium [3,4]. Here S is the photon flux density in the cavity, P_{pump} and P_b are the pump power and the power of the bleaching pulse, respectively, n_i are the population densities at the levels of the active medium, and n_{q2} is the population density at the upper level of the saturable absorber.

The threshold pump power for these system parameters (at zero power of the bleaching pulse) is 2.73 W.

$$\begin{aligned}
&\frac{dS}{dt}=\frac{l}{L_{opt}}c\sigma_e S(n_2-n_1)+K_s l\frac{n_2}{t_2}-S\frac{c(\gamma l-\ln(\rho)/2)}{L_{opt}}-\frac{l_q}{L_{opt}}c\sigma_{qa}S(N_{qs}-n_{q2})\\
&\frac{dn_3}{dt}=\frac{P_{pump}}{s_{pump}hc/\lambda_a}\sigma_a(N_s-n_1-n_2-n_3)-\frac{n_3}{\tau_3}\\
&\frac{dn_2}{dt}=-\sigma_e S(n_2-n_1)-\frac{n_2}{\tau_2}+\frac{n_3}{\tau_3}\\
&\frac{dn_1}{dt}=\sigma_e S(n_2-n_1)-\frac{n_1}{\tau_1}+\frac{n_2}{\tau_2}\\
&\frac{dn_{q2}}{dt}=\sigma_{qa}(N_{qs}-n_{q2})\left(S+\frac{P_b}{s_b\,hc/\lambda_e}\right)-\frac{n_{q2}}{\tau_2}
\end{aligned}\qquad(1)$$

The laser parameters are as follows: pump wavelength λ_a = 808.6 nm, generation wavelength (and wavelength of the bleaching light) λ_e = 1064 nm, absorption cross section $\sigma_a = 7.7\cdot10^{-20}$ cm^2, emission cross section $\sigma_e = 28\cdot10^{-20}$ cm^2, lifetime at $^4F_{3/2}$ level τ_2 = 230 μs, lifetime at $^4F_{5/2}$ level τ_3 = 30 ns, lifetime at $^4I_{11/2}$ level τ_1 = 10 ns, concentration of Nd^{3+} ions (1%) $N_s = 1.38\cdot10^{20}$ cm^{-3}, refractive index of the active medium n = 1.82, crystal length l = 0.3 cm, pump area s_{pump} = 0.007854 cm^2 (pump radius 500 μm), cavity length L = 20 cm, coefficient of inactive losses in the cavity γ = 0.002 cm^{-1}, the output mirror reflectivity ρ = 0.97.

The parameters of the Cr^{4+}YAG absorber: emission cross section (at 1064 nm) $\sigma_{qe} = 87\cdot10^{-20}$ cm^2, lifetime at the upper level τ_{q2} = 4 μs, concentration of chromium ions $N_{qs} = 0.0185\cdot10^{20}$ cm^{-3}, refractive index n_q = 1.82, absorber length l_q = 0.17 cm, the area radiated by the bleaching pulse s_b = 0.007854 cm^2 (radius 500 μm).

In this work, we studied the dependence of time between the appearance of a giant pulse and the onset of the bleaching laser action on its power. Besides, the dependence of this time on the pump power at a fixed power of the bleaching pulse was investigated. The bleaching pulse was considered rectangular with constant power and duration of 10 μs.

Figure 2a shows the dependence of time between the bleaching pulse onset and the maximum of generation pulse on the bleaching laser power. The bleaching laser is switched on since 500 μs from the start of pumping, pump power is 3 W. The minimum time value (for infinite power of bleaching light) is 0.11 μs, the powers of the order 50-200 W correspond to times of about 2-3 μs.

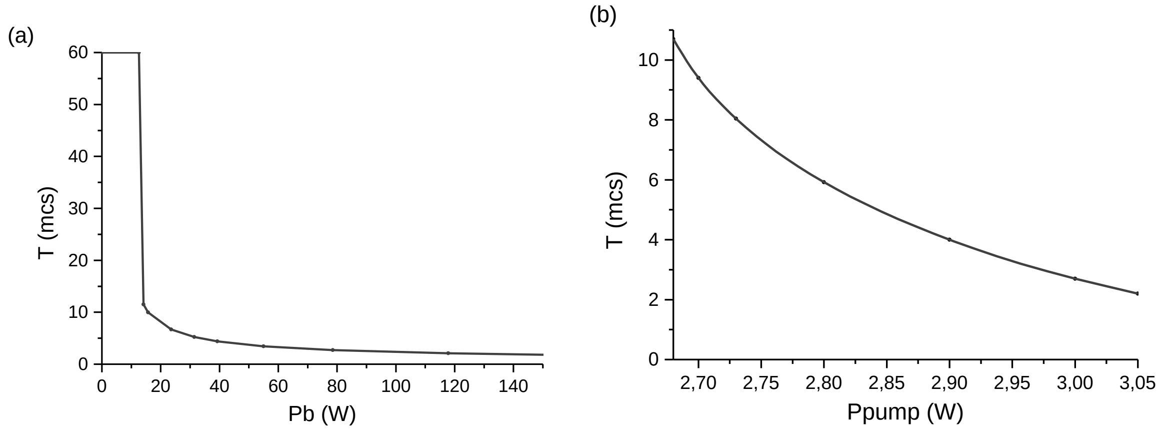

Fig. 2. Delay of the *Nd:YAG* laser pulse relative to the bleaching pulse as a function of power of the bleaching laser (a) and pump power (b)

Figure 2b shows the dependence of the laser pulse delay relative to the bleaching pulse on the pump power. The power of the bleaching laser diode is 78.5 W (corresponds to the intensity of 0.01 MW/cm^2). In this case, the threshold pump power is 2.68 W; with a pump power of more than 3.05 W, the generation starts earlier than 500 μs.

Thus, it was shown that a sufficiently high bleaching power is required to start the generation using an external light pulse, but modern laser diodes can provide such powers. The start time of the giant pulse generation is shifted relative to the beginning of the bleaching pulse and substantially depends on the pump power. The jitter of the generation pulse can be quite small, which makes the method promising for real application.

1. *Baichao Zhang, Ying Chen, Pengyuan Wang et al.* // Applied Optics. 2018. Vol. 57, No 16. P. 4595-4600.
2. *B. Cole, L. Goldberg, C. W. Trussell, et al.* // Opt. Express. 2009. Vol. 17. P. 1766–1771.
3. *R. I. Navitskaya and I. V. Stashkevitch* // Nonlinear Phenomena in Complex Systems. 2019. Vol. 22, No 2. P. 177-189.
4. *J. Swiderski, M. Skórczakowski, A. Zajac* // Opto-Electron. Rev. 2005. Vol. 13, No 1. P. 43-50.