Parameters affecting the existence of high amplitude regime in passively Q-switched laser

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The present paper highlights few parameters that optimize the high amplitude regime of the passively Q-switched laser. Numerical results done by other authors showed that this regime can be obtained by the increase the ratio of the effective cross section of the saturable absorber (SA) over that of the gain medium, or the SA concentration. In the present work, we showed that the laser regime optimization depends upon both situation, i.e., the cross section ration and the SA concentration. This work helps provide answers on the other results reported in the literature.

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1. Introduction

High power Q-switched pulsed lasers are widely used in different fields such as materials processing, medical treatment, laser location, and others [1]. The Q-switching laser is either actively triggered by means of electro-optic modulators, acousto-optic modulators, or passively triggered by saturable absorber (SA). The advantage of the active switching resides in the ease of controlling the switching frequency as well as the Q-switching time period (duration for which the laser cavity is sustained with minimum losses). This allows to optimize the laser functioning and to extract the total energy stored in the gain medium by the laser pulse. Hence, the actively Q-switched lasers seem more efficient compared to the passively Q-switched ones. In contrast, for the case of passively Q-switching, the loss modulation is done automatically and there is no control on the modulation duration. Luo and Chu [2] showed that there is a possibility of optimizing the operation of passively Q-switched laser. In this study concerning a fully fibered laser doped Er:Sm, two operating regimes (low and high amplitude) have been observed and for the case of high amplitude regime the laser is optimized for C_{AL} parameter value greater than 21.9, where $C_{AL} = \frac{\sigma_S}{\sigma_L}$ denotes the ratio of the cross section of Sm absorption to that of Er emission cross section.

In another work done by Lecourt.*et al* [3], these authors reported that despite the use of C_{AL} = 30 in their simulation the regime of high amplitude was not observed. Thus, they conclude that the numerical simulations carried out in the work [3] had a problem with stiff equations, however they said that the increase of SA ions concentration play an important role in optimizing passively Q-switched laser.

From these remarks raised above, clarifications in relation to these two works are provided in this study. Using the model kinetic equations, we have tried to discuss the relevance of the critical value of C_{AL} parameter described in the work of Luo *et al.* [2]. In addition, we affirm the existence of high amplitude regime in contrast with the work of Lecourt *et al* [3].

2. Simulation model

Starting from the well-known kinetic equations governing the operation of passively Q-switched laser which may be expressed in the following forms:

$$\frac{dF_a}{dt} = \frac{F_a}{t_r}\{\alpha_a n_a - \alpha_s n_s + L\} \tag{1}$$

$$\frac{dn_a}{dt} = -(\beta_a F_a + \beta_p + A_l)n_a + (\beta_p - f_N A_l)N \tag{2}$$

$$\frac{dn_s}{dt} = -\beta_s F_a n_s + (N_s - n_s)A_s \tag{3}$$

F_a, n_a, n_s denote the instantaneous values of the photon density, the population inversion and SA ions density, respectively. N, N_s, $A_l = \frac{1}{\tau_l}$, $A_s = \frac{1}{\tau_s}$, t_r ,L characterize the initial density of the gain medium, the initial SA ions density, the lifetime of the gain medium, the SA lifetime, the round trip time cavity and the total loss of the laser cavity, respectively. Putting $\alpha_a = 2\,\sigma_l \Gamma_a l_a$, where σ_l is the cross section for stimulated emission, Γ_a is recovery factor in the medium gain and l_a depicts the medium gain length. Similarly, one writes $\alpha_s = 2\,\sigma_s \Gamma_s l_s$, where σ_s, Γ_s and l_s characterize the SA absorption cross section, recovery factor for SA medium and SA medium length, respectively. $\beta_a = \gamma \frac{c}{\eta_a} \sigma_l \Gamma_a$, $\gamma =$ 1 or 2 and f_N = 0 or 1 for a gain medium of four or three energy levels, respectively. c is the light velocity, η_a is the refractive index of the gain medium. $\beta_s = \rho \frac{c}{\eta_s}\sigma_s\Gamma_s$, $\rho = \frac{S_a}{S_s}$ is the area ratio of the gain medium to that of the SA and η_s corresponds to the refractive index of the SA medium. $\beta_p = \frac{k\sigma_p P_p}{h\nu_p A_p}$. Here k, σ_p , P_p, $h\nu_p$, ν_p and A_p describe the pumping efficiency, the absorption cross section of the pump in the gain medium, the pump power, the photon energy and the pump beam area in the gain medium, respectively.

Let us quote that the model kinetic equations are widely used in the design of solid-state lasers [4,5] and even fiber lasers [6] and this model is similar to the equations used by Luo et *al.* and Lecourt et *al.* [2,3]. In addition, simulation parameters used in this section are similar to those employed in the recent work [7].

3. Results and discussion

As our objective in this work is based on the impact caused by some parameters (C_{AL} or SA concentration) on obtaining high amplitude regime, it seems useful to present the case of small amplitude regime by varying one of these parameters, the regime of high amplitude is then observed. Consequently, Fig. 1 illustrates in the first step the low amplitude regime scheme obtained with a pump power value of 45 W, a SA concentration value of 1.8×10^{24} ions/m^3 and C_{AL} value around 6.03. As illustrated in Fig. 1 for this regime, the laser is not optimized and the gain oscillates with small amplitude and therefore the energy stored is not all extracted by the laser pulse.

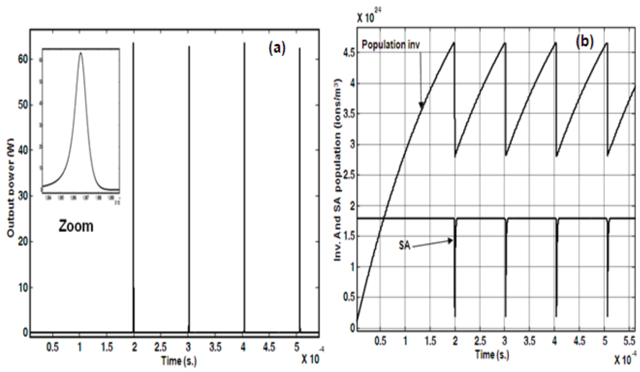

Fig. 1. Self-pulsed regime amplitude versus time obtained with a low SA ions concentration (1.8×10^{24} ions/m^3), gain ions concentration (1.4×10^{25}ions/m^3) and C_{AL}=6.08. a)Power laser output. b)Density of active ions.

The obtained Figs. 2 and 3 illustrating high amplitude regime are obtained using power pump value of 45 W. Noting that Fig. 2 is obtained using same parameters as in Fig. 1 except that the SA ions concentration value is around 5.2×10^{24} ions/m^3. This result is in agreement with those evidenced by Lecourt et *al*. [3] who argue that the increasing SA ions concentration optimizes the passively Q-switched laser. Fig. 3 is also obtained with the same parameters used as in Fig. 1 except that the parameter C_{AL} = 18.01. Two important points are raised; Firstly, our simulation results are consistent with those obtained by Luo *et al.* [2] who argue that the high amplitude regime can be obtained by increasing C_{AL} parameter. Second, disagreement is noted because our results show the possibility that high amplitude regime can be observed for C_{AL} value less than the critical value described in this reference (C_{AL}>21.9) (see Figs. 2 et 3 for which the high amplitude regime is obtained for C_{AL}= 6.03 and 18.01, respectively). Moreover, in combination with our simulation parameters, the value C_{AL}=18.01 is a critical threshold above which the laser stops functioning. Note that the high amplitude regime exists only in the vicinity of this value. Similarly, the threshold of non operating laser is observed for a saturable absorber concentration value as reported in a recent work [7]. From these observations, we can conclude that the condition as reported in reference [2] for the occurrence of high amplitude regime in passively Q-switched lasers seems not satisfied.

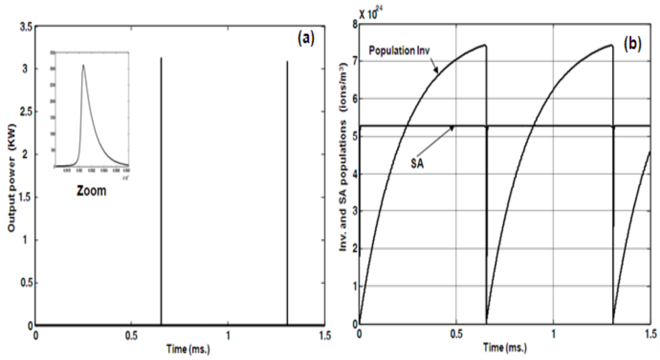

Fig. 2. High amplitude regime versus time obtained for SA ions concentration (5.2 10^{24} ions/m^3) and C_{AL}=6.03.
a) Output power of the laser. b) Active ions density.

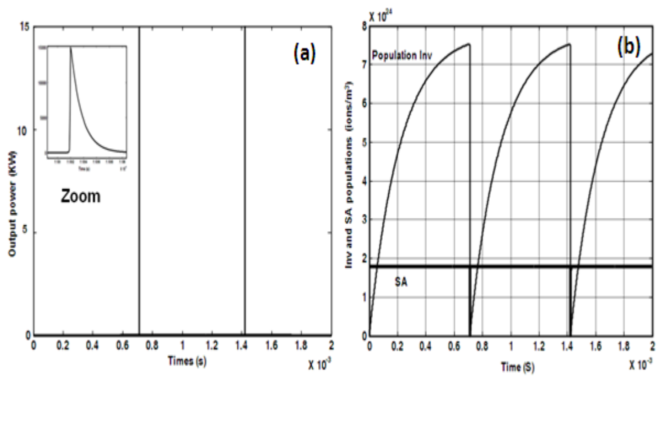

Fig. 3. High amplitude regime versus time obtained for C_{AL}=18.01 and SA ions concentration (1.8×10^{24} ions/m^3). a) Output power of the laser. b) Active ions density.

In high amplitude regime, it can be remarked that the inversion population varies with strong amplitudes and then each laser pulse extracts a totality of stored energy. Hence, the laser is optimized and high peak powers are obtained. In two recent published setup laser [8,9], high peak powers are obtained, Thus, we believe that these lasers are operating in high amplitude regime because their pulse width and peak power do not vary with the pump power. This result is in qualitative agreement with our previous simulation results [7].

4. Conclusion

This work illustrates the impact of certain parameters especially the concentration of saturable absorber and the ratio of cross section on the occurrence of high amplitude regime in passively Q-switched lasers. Our results show that the regime of high amplitude can be obtained with C_{AL} value lower than the critical value described in Ref [2]. Indeed, in our study, it was found that adequate choice of SA concentration values as well as the ratio of cross sections values allows the existence of high amplitude regime. Hence it appears that an increase in SA concentration leads to occurrence of high amplitude regime. Therefore, trough this contribution we show that the value of C_{AL} factor for obtaining a high amplitude regime depends on the concentration of saturable absorber. We believe that this contribution may provide lightening that leads to the achievement of the high-amplitude regime in passively Q-switched lasers.

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