DEVELOPMENT OF ORIGINAL APPROACH FOR INCREASING OF THE MAXIMUM PEAK POWER IN Q-SWITCHED QUANTUM ELECTRONIC GENERATORS: APPLICATION IN RUBY LASER

Margarita Angelova Deneva [1], Dimitar Aleksandrov Dimitrov[1], Marin Nenchev Nenchev [1,2]

[1] Dept. Optoelectronics and Lasers, Technical University – Sofia, Branch Plovdiv, 61 blvd. St.Peterburg, 4000 Plovdiv, e-mail: mdeneva@yahoo.com
[2] Institute of Electronics – Bulgarian Academy of Sciences, 72 blvd. Tzarigradsko Chausse, 1784 Sofia, Bulgaria

We describe and investigate the application of our original approach for introducing in very appropriate manner a single Q- switching element in Ruby quantum electronic generator (Ruby laser). The approach permits to modulate the two outputs of the active medium using a single Q- switching element and thus to prevent the appearance of the parasitic free lasing and the strong double-pass amplification of the amplified spontaneous emission. This leads to essential increasing of the maximal inversion population and respectively of the maximum gain that is the condition for obtaining a "giant pulse" with essentially increased peak power. We present a new solution and develop the theoretical model on the base of rate differential equations for the Ruby laser action. On the base of the numerical investigation, we have shown the attractiveness of the application of our technique in the Ruby laser. The last is very convenient for Q-switch operation related with its very long upper laser level lifetime (~ 3 ms). The combination of our system and the properties of the Ruby active medium offer the possibility to obtain essentially increasing inversion population in comparison with the traditional approaches, especially in the cases of high level pumping.

Keywords: Q-switched quantum electronic generator (Q-witched lasers), increased peak power, Q-switching approaches

1. INTRODUCTION

As it is well known, the Q-switched solid-state lasers are very important tools of Quantum Electronics with wide application in the practice and sciences [1, 2]. This is a result of their property to produce a nanosecond duration laser pulses with a Megawatt powers. Nevertheless that the Q-switching is one of the first developed mode of laser operation (in the start of the 70-th years), due to their practical importance, every progress in this technology is of constant interest and actual.

The Ruby lasers (Cr^{4+}:Al_2O_3) [1] is very attractive quantum electronic generator in point of view of Q-switching operation due to its very long lifetime of the upper laser level of ~3 ms - more than an order of magnitude higher that this one of the most widely used Nd:YAG lasers. This long lifetime level permits easily to accumulate a high inversion population and respectively to obtain an effective Q-switching operation. Nevertheless that the Ruby laser is the first laser made in action, it is and actually in continuous use in many practical situations (holography, metrology, scientific works, industry) due to very useful operating wavelength in the visible range of 0.6943 μm, high output power and high repetition rate and perfect and stable optical, mechanical and thermal active medium properties. The Ruby lasers permits an extraction of hundred and more Joules energy and hundreds Megawatts power in Q-switched operation. Note also that in the last year there is an essential progress in the quality of the fabricated Ruby crystals.

Here we report and investigate a development of original our solution [3] for high power Q-switched Ruby laser. Our method permits to increase essentially the maximum accumulated inversion population in the Ruby active medium and thus to obtain very high power pulses by this laser – with a few times high power than in the traditional arrangements.

2. Description of the Proposed Q-switched Ruby Laser. The Problem of the Conventional Arrangement and the Solution

2.1. The problem for the conventional Q-switched Ruby laser arrangement

Physical base of the Q-switching operation is the creation of conditions to accumulate in the laser active medium a high energy as inversion population and to provide its liberation in condition of very high initial gain that leads to very short time for the laser pulse formation. Thus, the creation of the high inversion population that provides the proportionally high gain is important moment for the Q-switched lasers. However, concerning high power Q-switched lasers, including the Ruby laser case, there are two basic processes that limit the maximum accumulated inversion population. The first process, that strongly limits the accumulation, is the natural parasitic resonator that forms the constantly opened output mirror M_{out} (being obligatory perpendicular to the resonator axis) and the parasitic reflection from the ends of the active medium, also the partially remains after anti-reflection treating. There is an axial reflection also from the certain non-homogeneities in the Ruby crystal, from the elements of the Electro-optical Q-switching device, and from its remaining transmission in the closed state. In sum, the noted reflection can be considered as second constantly opened equivalent mirror M_{eq} (with reflectivity R_e) at the opposite end the Ruby crystal by respect of M_{out}. This formation of the equivalent parasitic resonator leads at some inversion population to appearance of the parasitic free-generation (pre-lasing) before the Q-switch opening. We have considered this first mechanism as a main limiting problem and here we will discuss theoretically its influence. The second problem – the amplification in the double-pass of the Amplified Spontaneous Emission (ASE) by the non-modulated retro-reflection from the output mirror is also of importance and increases additionally the noted problem for the conventional scheme applications. Our proposal eliminates or strongly reduces simultaneously the limitation imposed by the two mechanism discussed. In the work, we considered the problem and the solution on the example of most widely realized in practice case of electro-optical Q-switching. In Fig.1 is presented schematically the discussed problem with the equivalent parasitic resonator. The standard commercially available Pockel’s Cell (PC), using λ/4 voltage electro-optical crystal in combination with a Glan Prism and with switching time given by the controlled electronics of order of ten nanoseconds is used as Electro-optical Q-switched device. Its action is synchronized with the flash lamp pumping by electronic synchronizer. The flat mirrors M_{out} and M_{end} form the laser resonator with the Ruby laser crystal. In the figure schematically is shown the equivalent parasitic resonator, thus illustrating the problem.

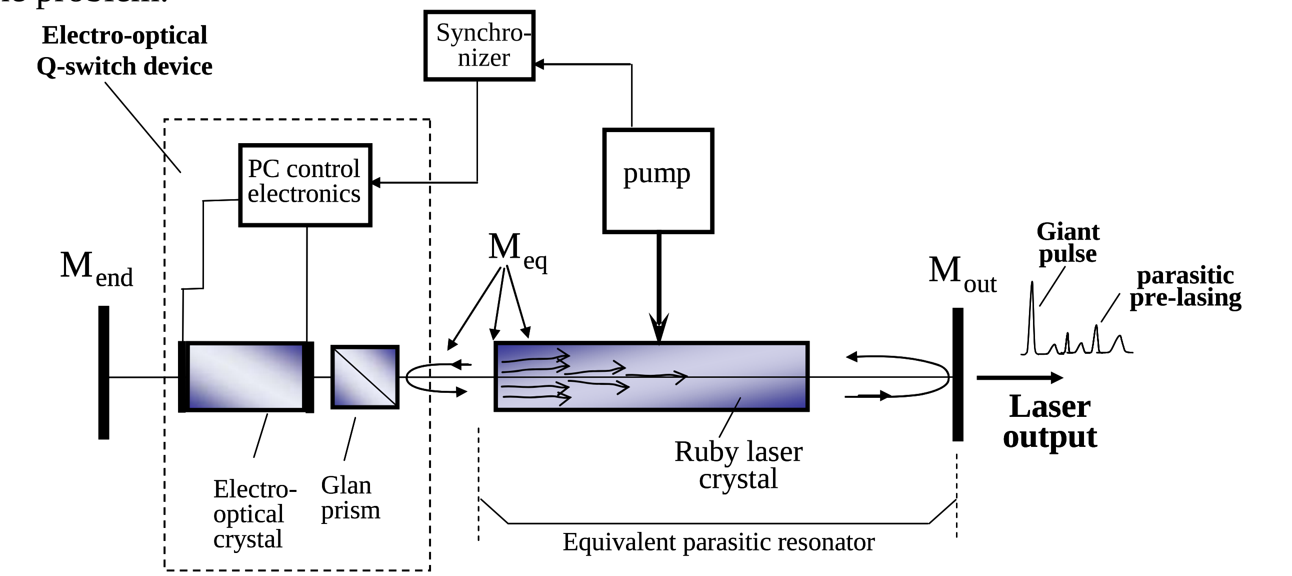

Fig. 1. Traditional Q-switched Ruby laser set-up and illustration of the problem.

One simplest solution to reduce the noted problem is to use two symmetrically disposed by respect of the Ruby crystal Electro-optical Q-switch devices, each of them that modulate the corresponding active medium output, as it is shown in Fig. 2.

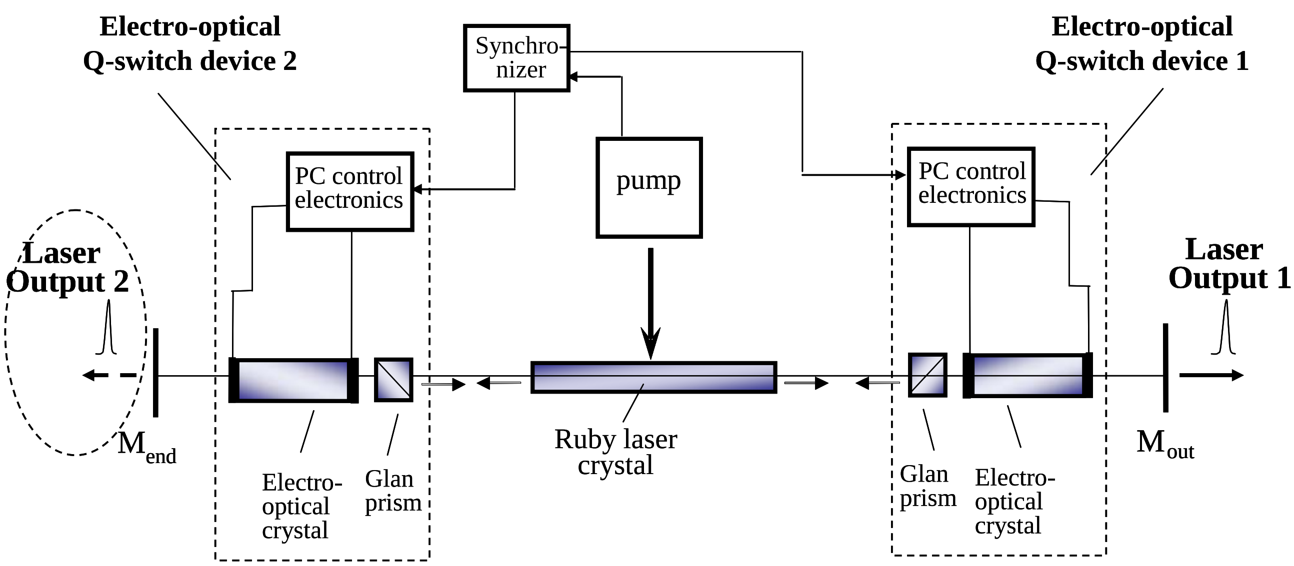

Fig. 2. Q-switched Ruby laser arrangement used two separate electro-optical Q-switched devices.

However, this in first point of view simple solution [e.g. 4], suffers from the essential disadvantages. It needs in the nanosecond time range (one or few ns) complicated synchronization of high voltage electronic schemes. The price of such devices is high; also, the laser construction becomes very complicated.

2.2. PROPOSED SOLUTION

Our solution is schematically shown in Fig.3. It uses only a single Electro-optical Q-switch device and the need of the noted above synchronizing electronics drop out.

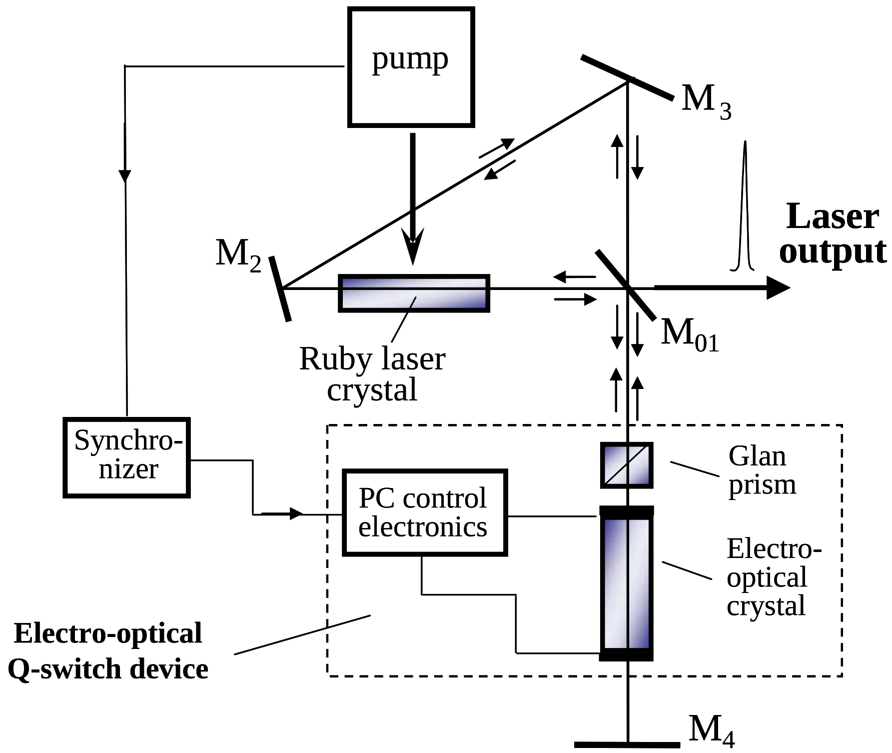

Fig. 3. The proposed arrangement for two active medium outputs modulation by a single electro-optical Q-switched device.

The laser construction is simple and chipper. We apply at the place of the Fabry-Perot resonator type a Sagnac–type resonator in the external arms of which is placed the Electro-optical Q-switch device. The mirror M_{01} is semi-transmission; M_2, M_3 and M_4 are flat deaf mirrors. Following our notation in the Fig. 3 by the arrows, it can be seen that in our arrangement a single Electro-optical Q-switch device modulates simultaneously both outputs of the active medium, thus eliminating the discussed retro-reflection by the output laser reflector. Very convenient situation is that the two pair beams composed each by the transmitted and reflected portion of light by the mirror M_{01}, superimpose and form single output beam and single beam, directed to the Q-switching element.

3. THEORETICAL MODELING AND COMPUTER ANALYSIS OF THE LASER ACTION. COMPARISON WITH THE CONVENTIONAL ARRANGEMENT

We have performed a computer simulation of the generation of the lasers described in the previous section by adapting a conventional set of differential rate equations [1, 5, 6]. The action of our system can be considered as an equivalent in the action of a linear resonator with modulated by the proper Q-switch devices a reflectivity of each resonator mirrors (M_{out} and M_{end}). Thus, the theoretical consideration is similar to the treatment of the system, shown in Fig. 2 with appropriately chosen values of the resonator parameters. We considered the high power Ruby laser with active rod with length of 30 cm and diameter of 1 cm. The Cr^{4+} concentration N_t is the typical of $1.8x10^{19}$ cm^{-3} [1]. We accept that the pumping is sufficiently high to assure at all cases needed pumping parameters for obtaining the maximum inversion population, limited by the discussed above processes. We will treat theoretically the influence of the parasitic resonator and will consider the values attainable of the inversion population given of this process as a maximal. The re-injection of the ASE will be considered only as process that decreases additionally this maximum obtainable inversion population and underlines the usefulness of our system. The precise treatment of the combined action of both processes will be given in the next our works. Thus, first we will compared the maximum inversion population obtainable in the traditional scheme, given in Fig.1 and in the proposed by us (Fig. 3), but modeling the last with this one, given in Fig. 2 with equal reflectivity of the end resonator mirrors of 0.25, which follows from the comparison of the scheme in Fig. 2 and Fig. 3. In Fig. 2, the laser has two outputs, which are superimposed as one output in Fig.3. Following Ref. 1 we will calculate firstly the obtainable maximum population of the upper laser level N_2^m, limited by the achievement of the threshold in the parasitic resonator. Note that for the three lavel Ruby laser scheme the inversion population ΔN is given by N_2^m and the constant value N_t of the total Cr^{4+} active ions ($\Delta N = 2N_2^m - N_t$). From Ref. 1, the formula for N_2^m can be definite as:

$$N_2^m = \frac{1}{2} N_t + \frac{\ln(R_{out}) + \ln R_e + 2 \cdot \ln(1 - T_i)}{4 \cdot \sigma \cdot l} \qquad (1)$$

Here, T_i is the fractional internal losses per pass, σ is the emission cross-section with value of $1.8x10^{19}$ cm^{-3} for the Ruby active medium and l is the length of the Ruby crystal. The calculations for the different realistic values of the sum parasitic retro-reflection in the direction of the laser axis, presented as an effective mirror M_e with a reflectivity R_e and for the priory estimated optimal reflectivity R_{out}= 0.3 of the output mirror M_{out}, is plotted in Fig.4 (the noted curve with R_e = 0.3) . In the same figure are presented the cases for our scheme (obtained from the equivalent scheme in Fig. 2) for use of Q-switching device to close also the output mirror. In this case, the values of R_{out} are estimated to vary between 0.01 and 0.04 in the similar manner as for the R_e. The essential increasing of the values for N_2^m when our arrangement is used, is evident from the last figure. Using the obtainable maximum values for the inversion population we can calculate the parameters of the generated "giant pulse" in the conventional arrangement an in the proposed by us. This calculation is made by adapting the traditional rate equation system [1] for description of Q-switched operation:

$$\begin{cases} \dfrac{dN_2}{dt} = -B \cdot q \cdot (2N_2 - N_t) \\ \dfrac{dq}{dt} = Va \cdot B \cdot q \cdot (2N_2 - N_t) - \dfrac{q}{\tau_c} \end{cases} \quad (2)$$

with $P_{out}(t) = (\gamma_1 \cdot c/2L') \cdot h\nu \cdot q(t)$ (3)

Here $B=\sigma.l.c/Va.L'$ [s^{-1}]; $c=3\text{x}10^{10}$ cm/s is the light velocity; $L'=$ *65 cm* and *100 cm* for the conventional resonator case and for our resonator, respectively, is the optical length of the resonator; $h\nu = 2.86\text{x}10^{-18}$ J is the energy of the generated photons. The dumping time of a photon in the resonator is $\tau_c= L'/c.\gamma$, where γ describes the loss in the resonator [1]. The crystal length is 30 cm with a diameter of 1 cm. For the solutions we take, as the initial conditions, the maximum obtainable inversion population, calculated for the two cases – for the traditional arrangement from Fig.1 with output mirror reflectivity of R_{out}= 0.3 and R_e = 0.04 and for the proposed scheme with the same value of R_e and R_{out} = 0.02. The calculated "giant pulses" for the cases considered are plotted in Fig.5 top and bottom, respectively. The increasing of the maximum obtainable laser power in the "giant pulse" when our method is applied increased three times to be ~ 3 GW against ~ 1 GW for the conventional system. The rate equation system is solved numerically by Runge-Kuta-4 method.

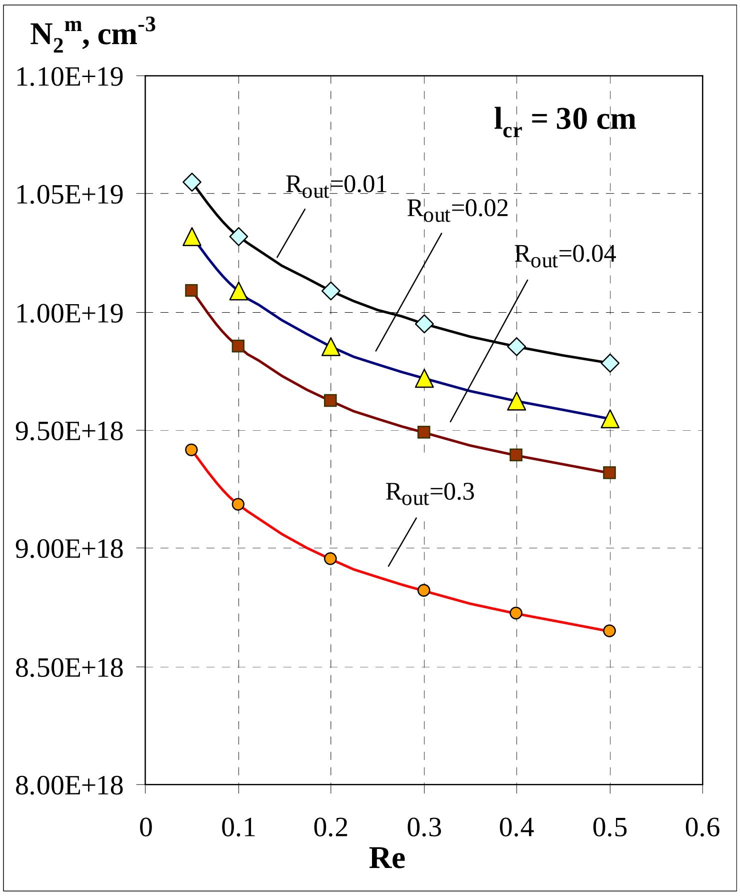

Fig. 4. Dependence of maximal obtainable population of the upper laser level N_2^m versus equivalent mirror reflectivity R_e

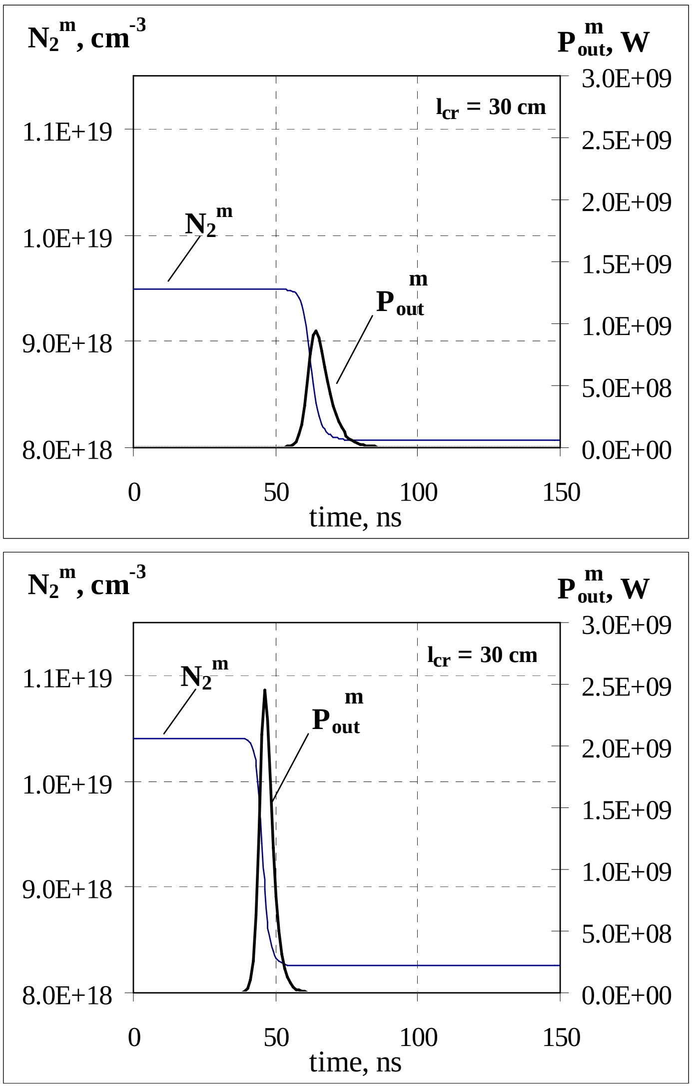

Fig.5. The calculated maximal obtainable power "giant pulses" for the traditional Q-switch arrangement (top) and for the arrangement proposed (bottom).

4. Conclusion

In conclusion, we have described and investigated the application of our original approach for introducing in very appropriate manner a single Q- switching element in Ruby quantum electronic generator (Ruby laser). The modulation of the two outputs of the Ruby active medium by a single Electro-optical Q- switch device leads to the elimination (or strong reduction) the creation of the parasitic resonator and the re-injection of ASE that improves essentially the laser action for high level pumping. From the theoretical modeling and numerically investigation, we have shown quantitatively the expected improvement. The maximal obtainable output power in the "giant pulse" can be increased a minimum few times in Gigawatts power range for a single laser Ruby laser construction with the same crystal.

5. Acknowledgement

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6. References

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