Optimization of passively ruby laser pulse width Q-switched by Cr:YSO solid state saturable absorber.

التشغيل الامثل لنبضة ليزر الياقوت العامل بالنمط المفتاحي السلبي مع بلورة Cr:YSO الماصة المشبعة.

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ABSTRACT:

The optimization of simulation ruby laser passively Q-switched with Cr:YSO solid state saturable absorber have been investigated numerically, using constrained Rosenbrock optimization technique. The output pulse width is 23.46 ns. The optimum values of some rate equations parameters (γ_c, γ_a and β) were found under the optimization technique. The relation of γ_c parameter with Cr:YSO solid state saturable absorber molecules number and pulse width have been predicted.

Keywords: Q-switching laser, Numerical optimization, Ruby, Cr:YSO.

الخلاصة:

الامثلية لمحاكاة عمل منضومة ليزر الياقوت العامل بالنمط المفتاحي السلبي مع بلورة Cr :YSO الماصة المشبعة قد تم تحقيقها عدديا باستخدام امثلية روزنبروك المقيدة للحصول على امثل شروط تشغيل لهذه المنظومة, اقل قيمة لعرض نبضة ليزر الياقوت تم الحصول عليها بحدود 23.46 نانوثانية . امثل قيم لبعض معلمات معادلات المعدل(γ_c , γ_a و β) تم ايجادها من خلال تطبيق تقنية الامثلية. علاقة المعلم γ_c (معدل اضمحلال الفوتون داخل التجويف الليزري) مع عدد جزيئات المادة الماصة المشبعة وعرض نبضة الليزرقد تم التنبؤ بها.

1. INTRODUCTION

One of important technique in laser is Q-switching. Very short temporal, powerful laser pulses could be obtain using this technique which could be achieved by putting a fast optical shutter inside the resonator to prevent the lasing from occurrence[1], in the same time the pumping energy stay accumulated in the active medium to specific time, finally the shutter suddenly opened (very quickly) to get the giant pulse, a lot off applications which uses Q-switching such as nonlinear studies, surgery, dentistry and any implementation needs powerful and short pulses[2].

There are two types of Q-switching: active with reflecting mirror, electro-optic and acousto-optic devices and passive with saturable absorber, compared with active the passive Q-switching is simpler, compactness, inexpensive and there is no need to outside driving[3].

Although the Ruby laser was the first laser discovered in 1960 by Maiman but it till now used in many applications because it's unique properties [4].

The Cr:YSO (pure tetravalent chromium system) solid state saturable absorber was discovered to work with laser applications in 1991, in 1993 chen et al used Cr:YSO solid state saturable absorber to act effectively with ruby laser at 694.3nm, as illustrate in Fig.1 the broad band absorption spectrum (peaks at 390 nm, 595 nm, 695 nm, and 750 nm) to this crystal extended from the visible to near infrared region and that makes it a good switch for many lasers[5]. According to the passive Q-switching theory with slow relaxing saturable absorber the absorption spectrum to the saturable absorber must be coincide with the emission spectrum of laser, another comment that the emission lifetime to Cr:YSO is 0.7 µs at room temperature which is greater than the pulse duration, also the high damage threshold of Cr:YSO solid state saturable absorber crystal causes to be a durable crystal.

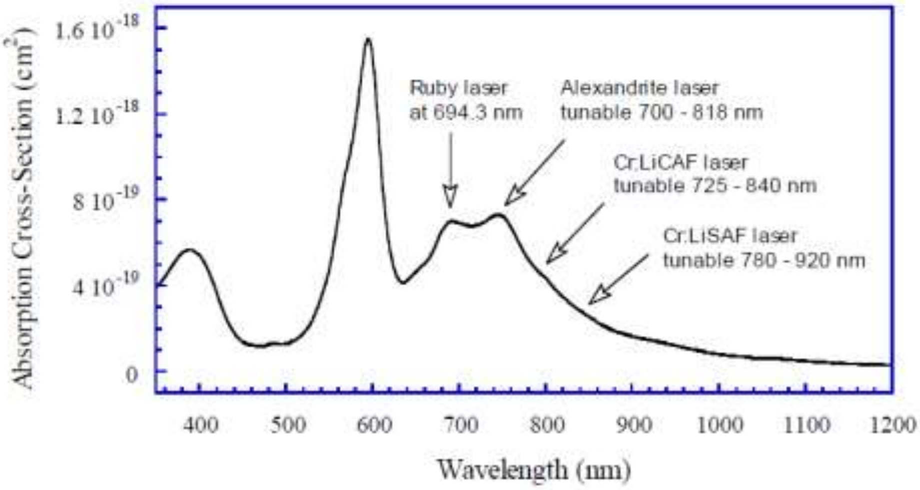


Fig. 1. Absorption cross-section of the Cr:YSO.

Optimization of realized passive Q-switching has much interest in final years [6], the manner of this operated take two ways: the first one be based on rate equations that describe the passive Q-switching laser which result in the transcendental analytical relation between the chosen input parameters and maximal output pulse energy and minimal pulse width, the second manner based on creation of a group of graphical curves reflecting the laser output characteristics versus such input parameters as the output coupler and saturable absorber transmissions [7]. In this work we first solve the coupled rate equations that describe the simulation of ruby laser Q-switched by Cr:YSO slow relaxing solid state saturable absorber by using Runge-Kutta-Fehlberg method. The optimization of simulation passively Q-switched has been utilized to obtain minimize pulse width by deals with rate equations numerically with three keys parameters.

The Models of Cr:YSO & Rate equations

The mechanisms of absorption in solid state saturable absorber can be explain according to the four –levels model, as shown in Fig.2. Most of the molecules located in the ground state level, molecules absorbed the stimulated photons and excited to level (3), the molecules relax fast to temporal equilibrium level (2) of excited state (τ_{32} very short), molecules in level (2) absorbed the incident photons and excited to level (4) and relax to level (2), within stay the molecules in the first excited state (relaxation time τ_1 relatively long) they may be excited to level (4)(relaxation time τ_3 very short) molecules back to level (2).That make all the molecules in the first excited state advert in the absorption activity to this level, the absorption will increase with increasing the incident photons in the saturable absorber. So the absorption will not stop unless transfer the majority of molecules to the excited state. This model gives a better understanding about the nature of absorption and more reality than the two or three levels model.

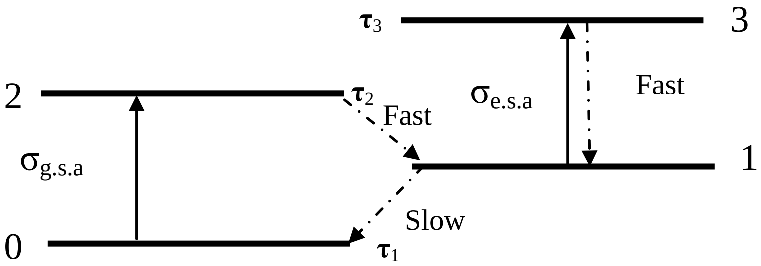


Fig.(2) Energy levels for a solid state saturable absorber with excited state absorption

The rate equations presented are four non-linear first order differential equations describing the performance of passive Q-switching according to four energy levels system where the absorption of first excited state is taken in to account. Given by:

$$\frac{dn}{dt} = [K_g \ N_g - K_a N_a - \beta K_a N_{au} - \gamma_c]n \qquad (1)$$

$$\frac{dN_g}{dt} = R_p - \gamma_g N_g - 2 * K_g N_g n \qquad (2)$$

$$\frac{dN_a}{dt} = \gamma_a N_{au} - K_a N_a n \qquad (3)$$

$$\frac{dN_{au}}{dt} = K_a N_a n - \gamma_a N_{au} \qquad (4)$$

Where:

n is the photon number inside the laser resonator .
N_g is the population inversion of active medium.
N_a is the ground state population of the saturable absorber.
N_{au} is the initial value of N_a.
γ_g $= 1/\tau_g$ is the effective decay rate of the upper laser level(sec^{-1}) .
τ_g is the laser emission lifetime (sec) .
γ_a is the saturable absorber decay rate(sec^{-1}).
R_p is the pumping rate (sec^{-1}).
K_g is the coupling coefficient between the stimulated photons and the active medium element. Thus K_g appears in the term which represents the stimulated emission. Also, it refers to the probability of the stimulated emission per unit time.
K_a is coupling coefficient between the stimulated photons and the saturable absorber molecules. Thus K_a appears in the term which represents absorbance of the stimulated photons .Also, it refers to the probability of absorption of the stimulated photons per unit time.
The cavity decay is given by:

$$\gamma_c = \frac{1}{\tau_c}$$

τ_c is the photon life time inside the cavity.
$\beta = \sigma_{e.s.a} / \sigma_{g.s.a}$ is the ratio of the excited state absorption cross-section to the ground state absorption cross-section of the saturable absorber molecules [8].
The first equation represent the cavity photon number; the second represent gain medium rate with population inversion, the third and fourth describe the differential population rate in saturable absorber at ground and first excited state respectively. A FORTRAN 90 programs have been written to simulate the model and optimize the system.

Optimization

The optimization is a technique for finding the optimum value (maximum or minimum) of a function $F(x_1, x_2, x_3, \ldots x_n)$ of n variables[9], the values of the variable may be constrained or unconstrained. The method presented here is constrained Rosenbrock which is classified as a numerical multivariable search nonlinear method and this technique deals with constrained variables [10].
The optimization is utilized to minimize the first equation from four coupled rate equations; equation (1) (which describes the differential photon rate in the laser cavity) collected the other three equations as parts of it (equation 2, 3 and 4), equation (1) dealt as objective function, (γ_a, γ_c and β) dealt as decision variables.

Results & Discussion

The optimization of simulation passively Q-switched ruby laser with Cr:YSO solid state saturable absorber has been achieved, a pulse duration of 23.46 ns was obtained (compared with experimentally pulse width 22.2nsec [5]) when the solid state saturable absorber molecules number (ni) was($1*10^{16}$), Fig.3(A&B) show the numerical optimization solution of rate equations.

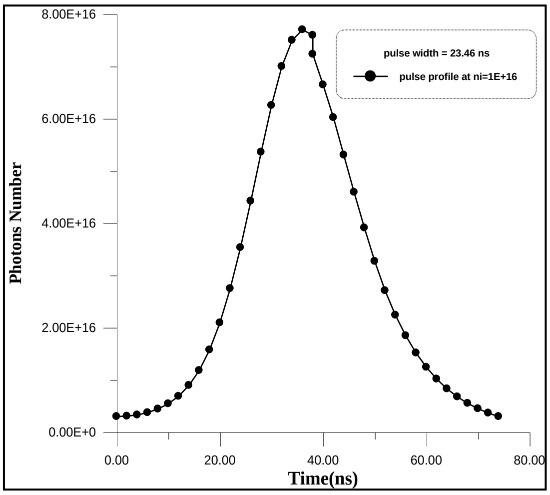


Fig.3A-Temporal profile of giant laser pulse of width 23.46ns

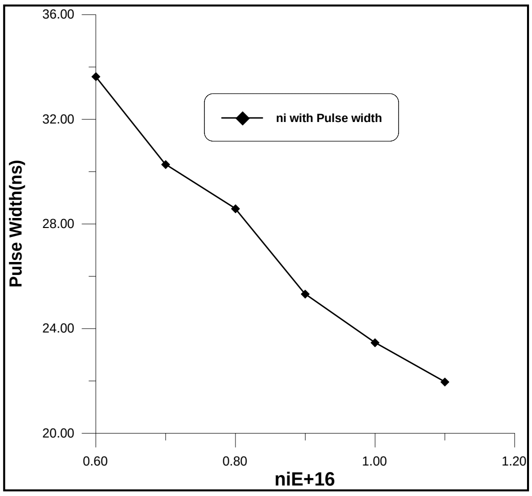


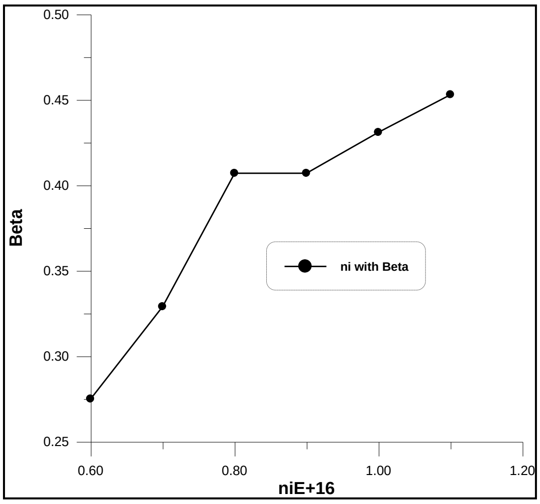
Fig.3B-The profile of pulse width as a function of Cr:YSO molecules number

The solid state saturable absorber molecules number (ni) of Cr:YSO has been increased from ($0.6*10^{16}$) to ($1.1*10^{16}$) molecules. The results for prediction three decision variables (γ_a, γ_c and β) are listed in table (1) , these result obtained while utilizing the minimization option to equation (1) from coupled rate equations as objective function which is the differential photon rate in laser cavity, the parts of this equation represents: the first part (K_gN_g) represent the second equation, the second part (K_aN_a) represent the third equation, the third part (βK_aN_{au}) represent the fourth equation and the fourth part (γ_c) represent the cavity decay rate, so minimize this equation (equation (1)) will minimize the pulse duration which mean optimum operation to the ruby laser passively Q-switched Cr:YSO solid state saturable absorber and that give a physical meaning to the optimization process, through that we determine the optimum values of decision variables.

ni(mole.*10^{16})	**β**	**γ_C(sec^{-1})**	**γ_a(sec^{-1})**	Pulse duration (ns)
0.6	0.274	49835745	1454525	33.63
0.7	0.403	49895330	1427790	30.27
0.8	0.407	49854267	1516534	28.58
0.9	0.407	49949116	1516834	25.32
1	0.431	49998994	1428893	23.46
1.1	0.453	50000011	1427003	21.96

Table (1) optimum values of γ_a, γ_c and β at different molecules number (ni) to Cr:YSO.

From observation of the results in table (1), one can notice that the increasing in the molecules number of saturable absorber (ni) cause to increase of β values and that indicate the increasing of absorption in the first excited state level through the increase of absorption cross section of saturable absorber until certain value after that the increasing in (ni) will be increased by non-significant amount of β value because of the saturation, Fig.(4a,4b) shows the relations of β with saturable absorber molecules number (ni) and pulse width respectively.



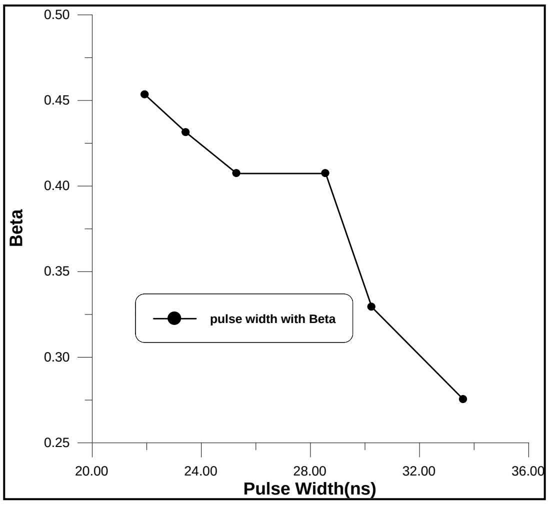
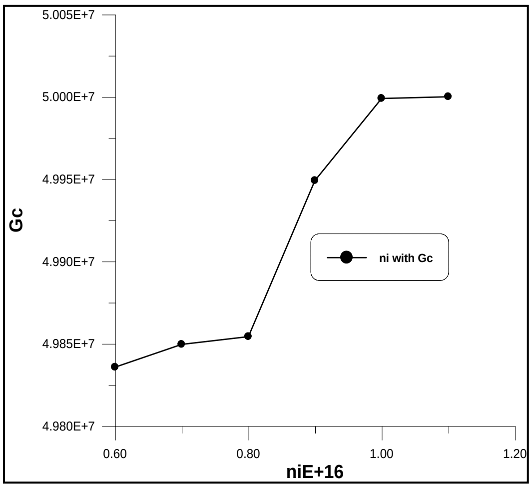


Fig.4A-The profile of β as a function of Cr:YSO molecules number

Fig.4B-The profile of β as a function of pulse width

γ_c parameter represent the photons losses inside the laser cavity, this losses result from: absorption, scattering, diffraction. it is obvious that when the molecules number of saturable absorber (ni) increase the γ_c values increase too, because increasing the molecules number of saturable absorber led to increasing of the absorption activity to the saturable absorber, so the absorption cross section also increase in both the ground state absorption cross section and first excited state absorption cross section (and that increase the photons losses)until specific value after it the increasing in molecules number will not increase the value of γ_c clearly as illustrate in Fig.5(A&B) which shows the relation between the γ_c values with saturable absorber molecules number (ni) and pulse width respectively.



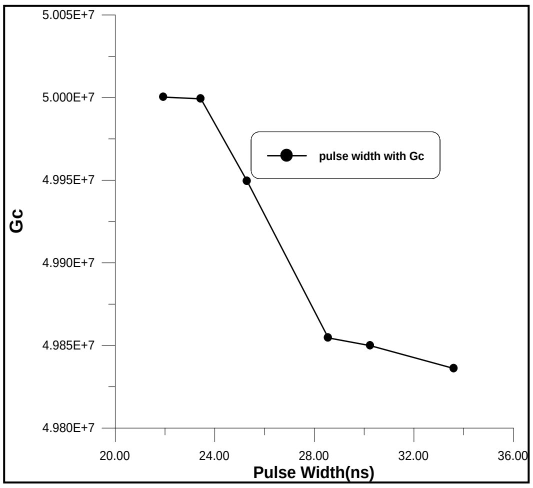


Fig.5A-The profile of γ_c as a function of Cr:YSO molecules number

Fig.5B-The profile of γ_c as a function of pulse width

Conclusions

The optimization of simulation passively Q-switched ruby laser with Cr:YSO solid state saturable absorber has been investigated numerically by applying constrained Rosenbrock optimization technique and under the optimum solution to rate equations the optimum values of some rate equations parameters (γ_a, γ_c and β) was founded.

When solid sate saturable absorber molecules number increase the β value increase and the value of γ_c increase too until certain value after it the increasing of saturable absorber number will increase by non-effecting value.

The increasing of β and γ_c values will decrease the pulse width.

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