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Simulation of passive Q- switching laser pulse Characteristics as a function of output coupler reflectivity

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Abstract

The effect of output coupler reflectivity (R_1) on characteristics (energy and duration) of a Passive Q- switching Laser Pulse has been studied theoretically by numerical analysis (rung- kata method) for mathematical description (rate equations model) for temporal performance of $Cr^{+4}:YSO$ crystal Chromium yttrium which was used as a storable absorber material (passive switch) with $Nd:GdVO_4$ neodymium cadimium vanadium laser. The study shows that the pulse energy is increasing with increase of the output coupler reflectivity, while the pulse duration decreasing with increase of the output coupler reflectivity.

Keywords: Laser , passive Q-switching.

1. **Introduction**

Pulsed solid-state laser widely used in scientific, medical, industrial and military systems, the efficiency and the cost are important factors. For this, the passive Q-switching is sutable for these applications [1,2].The saturable absorber material (S.A.M.) (passive Q- switch) performance depends on its characteristics such as the energy and lifetime of levels, chemical stability, surface tension, absorption cross section, and optical quality [2-4]. Many different Q-switching techniques developed in the past, passive Q-switching was considerable advantages in terms of device simplicity and economy because it is requires less optical element inside the laser cavity and no outside driving circuitry[5,6].

2.**Theory**

The effect of resonance reflectivity effect on passive Q- switching Laser pulse characteristics has been studied by the following rate equations model [7] .

$$\frac{dn}{dt}=(K_gN_g-K_aN_{ag}-\beta K_a(N_{a0}-N_a)-\gamma_c)n \qquad (1)$$

$$\frac{dN_g}{dt}=R_p-\gamma_gN_g-\gamma_pK_gN_gn \qquad (2)$$

$$\frac{dN_a}{dt}=\gamma_a(N_{a0}-N_a)K_aN_{ag}n \qquad (3)$$

Where n is the photon number in the laser cavity. Ng is the population inversion of the laser medium. $K_g = 2\sigma_g/\tau_r A_g$, is a coupling coefficient between photons and the active medium, where σ_g is the laser emission cross section, τ_r is the cavity round-trip transit time, A_g is effective laser beam area on the laser gain medium. N_a is the ground-state population of saturable absorber. $K_a = 2\sigma_{ag}/\tau_r A_a$ is a coupling coefficient between photons and the saturable absorber molecules, where σ_{ag} is the saturable absorber ground –state absorption cross section, A_a is the effective laser beam area on the saturable absorber. $\beta = \sigma_{ae}/\sigma_{ag}$ is the ratio of the excited-state absorption cross section σ_{ae} to the ground-state absorption cross section σ_{ag} of the saturable absorber. $\gamma_c = 1/\tau_R(\log(1/R_2)+\Gamma)$ is the cavity decay rate, where $(\tau_R = 2L_c/c)$ is the round trip transit time, where (L_c) is cavity length, c is the speed of light, l_r is the length of the laser rod, and (R_2) is the reflectivity of output mirrors, (Γ) is the is the remaining round-trip cavity dissipation. R_p is the pumping rate. $\gamma_g = 1/\tau_g$ is the decay rate of the upper laser level, τ_g is the upper laser level lifetime. γ_p is the population reduction factor (bottlenecking parameter), γ_p = 1, 2 for a four –level and three level laser active medium, respectively. $\gamma_a = 1/\tau_a$ is the spontaneous relaxation rate of the saturable absorber, where τ_a is the saturable absorber first excited state lifetime. At the initial time the photon number inside the laser resonator is low, so most population of saturable absorber molecules are in the ground state N_{ag} ,then $N_a \approx N_{a0}$.

Where N_{ao} is the total number of saturabel absorber molecules. At this time the absorption activity of saturabele absorber is very high (i.e. $dn/dt \approx 0.0$) and one can predict the initial value of population inversion for laser medium (N_{g0}) , then from Eq. (1) as [9].

$$N_{g0} = (K_a N_{a0} + \gamma_c)/K_g \tag{4}$$

When the photon number inside the laser resonator is high, most population of saturable absorber molecules are in the excited state (N_{ae}), then

$$N_a \cong 0.0 \tag{5}$$

At this time the absorption activity of saturable absorber is very low, then we can regard $dn/dt \approx 0.0$, also we can predict the threshold population inversion N_{th}

$$N_{th} = \frac{\beta K_a N_{a0+\gamma_c}}{K_g} \tag{6}$$

In general, the build-up time of Q-switched laser pulse is very short compared to pumping rate R_p and the relaxation time of active medium τ_g, then it is possible to neglect pumping rate and spontaneous decay of laser population inversion during pulse generation [5] , then from Eq. (1) and Eq.(2) , we get

$$\frac{dn}{dN_g} = (K_g N_g - K_a N_a - \beta K_a (N_{a0} - N_a) - \gamma_c)/(-\gamma_p K_g N_g)$$

$$\int_{n_i}^{n_p} dn = -\frac{1}{\gamma_p}((\int_{N_{g0}}^{N_{th}} dN_g) - ((K_a N_a + \beta K_a (N_{a0} - N_a) + \gamma_c)/K_g) \int_{N_{g0}}^{N_{th}} \frac{dN_g}{N_g}) \quad (7)$$

From Eq. (6), the photon number reaches a peck value n_p when population inversion N_g is equivalent to N_{th} , also N_a approaches zero $(N_a \approx 0.0)$, then

$$\int_{n_i}^{n_p} dn = -\frac{1}{\gamma_p}(\int_{N_{g0}}^{N_{th}} dN_g - N_{th} \int_{N_{g0}}^{N_{th}} \frac{dN_g}{N_g})$$

but $n_p >> n_i$, then

$$n_p = -\frac{1}{\gamma_p}(N_{g0} - N_{th} - N_{th} \ln(\frac{N_{th}}{N_{g0}})) \quad (8)$$

After the release of the Q-switched laser pulse, the population inversion is reduced to the final value N_f , this value can be utilized to calculate the output energy of Q-switched pulse using the following equation

$$E_{out} = (\frac{N_{g0} - N_f}{\gamma_p})(\frac{N_{g0} - N_f}{Ngo})h\upsilon \quad (9)$$

Where $h\upsilon$ is the laser radiation energy. The peak power of the Q-switched laser output can approximately be calculated by using Eq.(10) as

$$P_P \cong \frac{n_p h\upsilon}{\tau_c}(\frac{N_{g0} - N_f}{N_{g0}}) \approx -\frac{h\upsilon}{\gamma\tau_c}(N_{th} - N_{g0} - N_{th} \ln(\frac{N_{go} - N_{th}}{N_{go}}) \quad (10)$$

The pulse width of the Q-switched laser pulse can be calculated approximately by the following formula

$$\tau_{pulse} \approx \frac{E_{out}}{P_P} \quad (11)$$

3 . Results, and discussion

The numerical analysis by Rung-Kuta method has been used in this study. The published parameters values of saturable absorber $Cr^{+4}:YSO$ and of active medium $Nd:GdVO_4$ are used in study as the following table.

Table (1) : The input data

Parameter	Value	Reference	Parameter	Value	Reference
β	0.33	[7]	τ	$90\mu s$	[8]
K_a	$3.15\times10^{-8}\ \sec^{-1}$	[7]	γ_g	$0.11\times10^{5}\ \sec^{-1}$	[8]
γ_a	$1.43\times10^{6}\ Sec^{-1}$	[7]	K_g	$1.5\times10^{-9}\ \sec^{-1}$	[8]
λ	1064 nm	[8]	Γ	0.2	[8]
L_c	60 mm	[8]	γ_p	1	[8].
N_{a0}	1×10^{16}	[7]	Rp	1×10^{20}	[7]

Figures (1) and(2) shows the decreasing in pulse duration and increasing in pulse energy respectively, that is related to the low photon loss occur with the increasing of output coupler reflectivity that is lead to increasing in photons feedback to the active medium and release the stored energy in it throw the increasing of laser photon number caused increasing in pulse energy ,also shortly rising and falling time of pulse lead to shortly pulse duration .

Fig. (3) shows the increasing of power with the increasing of output coupler reflectivity, that is related to increasing of laser photon number and decreasing in pulse duration. Fig.(4) shows the profile of passive Q-switching pulses , that is appear the deference in energy and duration of pulse as a function of output coupler reflectivity.

.4. Conclusions

The pulse energy is increasing with increase of the output coupler reflectivity, while the pulse duration decreasing with increase of the output coupler reflective

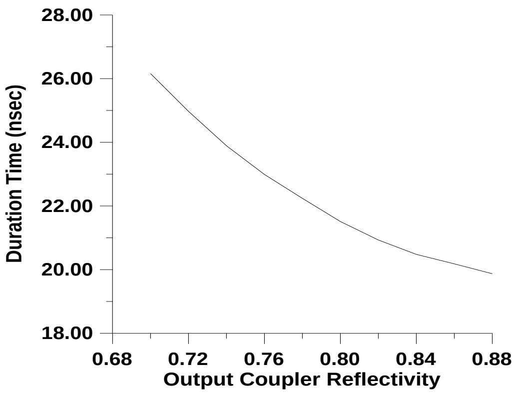

Fig.(1) : The pulse duration as
a function of output coupler reflectivity

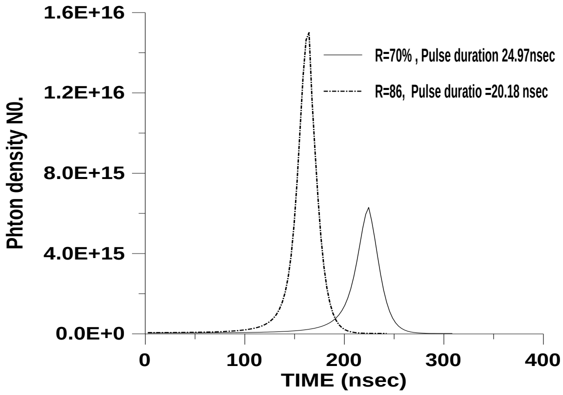

Fig.(4): The profile of pulse as a function
of output coupler mirror reflectevity

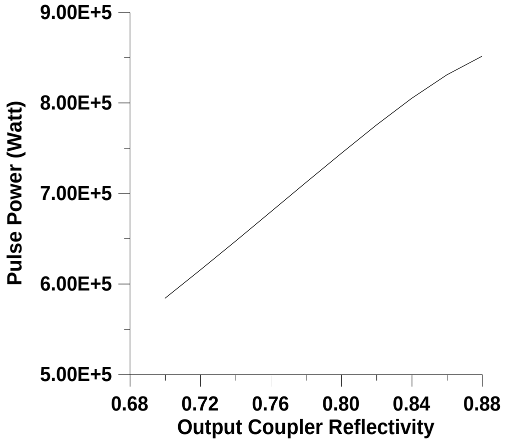

Fig.(3): The pulse power as function
of output coupler reflectivity

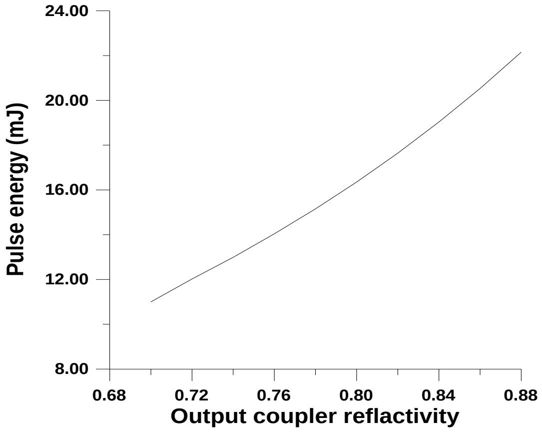

Fig.(2): Pulse energy as a function
of output coupler reflectivity

References

[1]- Yen-Kuang, Kuo and Yi-An Chang,” Numerical study of passive Q- switching of a Tm: YAG laser with a Ho:YLF solid-state saturable absorber “, Applied Optics,42, (9), (2003),1685-1691.

[2]- S. Sebastien, F. Druon, F. Balembois et al., "Passively Q-switched diode -pumped $Cr^{3+}:YAG/GdVO_4$ monolithic microchip laser", Optics communications, 259, (2005) 816-819.

[3]- Abdul-Munim K. Al-Kamil, Abdul-Kareem M. Salih, "Solvent surface tension effect on passive liquid Q- switch pulse duration " J. of The-Qar Science, 1, (1), (2008) 73

[4]- Fanting Kong, Liping Liu, Charlotte Sanders, and Y.C. Chen," Phase locking of nanosecond pulse in a passively Q- switched two –element fiber laser array", Appl. Phys. Lett.,90, (2007), 151110

[5]-.Sigman A.E " Lasers ", University Science,Milivalleg, California, 1007, 1025, (1 986).

[6] Yasi Jiang, Ruikun Wu, Daniel L.Rhonehouse, Michael J. Myers, John D. Myers and Scott J. Hamlin, "Bleaching and Q-switching of $U^{2+}:CaF_2$ at 1535 nm ",Solid state lasers and nonlinear crystals, 2379, 1-6 (1995).

[7] – Yen-Kuang Kuo Horng –MinChen Jih-YuanChang , " Numerical study of the Cr:YSO Q-switched ruby laser",Opt.Eng.,40,(9),(2011),2031-2035.

[8]- Iftitan M. Azzouz and Adel El-Nozahy," Numerical study of $Cr^{3+}:YAG$ passively Q-switching $Nd:GdVO_4$ laser ", Egept J. Solids, V(29), No. (1), P(215), (2005).

[9]-A.E Siegman, Lasers, University Science Books, Mill Valley, California (1986).

محاكاة خصائص نبضة التحويل السلبي لعامل النوعية بدلالة مرآة خرج الليزر

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الخلاصة

درس تأثير قيمة انعكاسية مرآة خرج الليزر على خصائص نبضة التحويل السلبي لعامل النوعية(الطاقة والامد) نظريا باستخدام الحل العددي باستخدام طريقة (رونج –كوتا) لأنموذج معادلات المعدل التي تصف التصرف الزمني اللحظي لبلورة $Cr^{+4}:YSO$ كمادة ماصة قابلة للتشبع مع ليزر $Nd:GdVO_4$. واظهرت الدراسة نقصان قيمة امد النبضة وزيادة طاقتها مع زيادة قيمة انعكاسية مراة خرج الليزر.