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SIMULATION OF EFFECTIVE AREA RATIO EFFECT ON SATURABLE ABSORBER ABSORPTION ACTIVITY IN PASSIVE Q-SWITCHING DOPED FIBER LASER SYSTEM

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Abstract

In this paper the effect of the ratio of active medium effective beam area to the saturable absorber effective beam area *(A/A_s)* on absorption activity of saturable absorber hase been studeid . Fiber doped by thulium used as a active medium , whil Cr^{+4}:YAG used as a saturable absorber .For simulation the system, rate equations model hase been solved numerical using Runge-Kutta-Fehalberge method. The simulation show the absorption activity of each level in SA reaches to converging in value and the optical bleaching state occurs at advanced time with the increase of A/A_s .

Keyword : Passive Q - switching, Tm^{+3} doped fiber laser , Cr^{+4}:YAG , Absorption Activity.

1-Introdution

Thulium (Tm^{+3}) is an element in the periodic table, with an atomic number of 69 in the lanthanide range of rare earth elements. Tm^{+3} absorbs about 793 nm to 1700 nm and emits about 1700 nm to 2100 nm.The emission of 1900 nm makes the Tm^{+3} excellent in the manufacture of special lasers for medical applications, molecular spectroscopy, and remote sensing [1-3]. Related to signefecant propereties of Tm^{+3}, usually used doped the fibers as a active medium(AM) in passive Q-switching technique. The energy levels diagram of Tm^{+3} shown in Fig(1), the lasing prosses occure at the transit

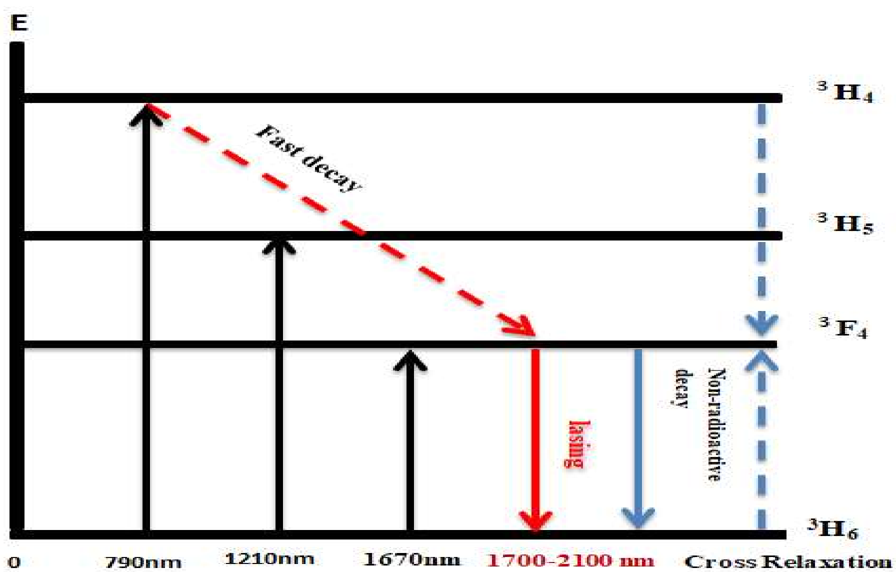

Fig.(1) Energy level diagram of Tm^{+3} [3]

Cr^{+4} - doped yttrium aluminum garnet (Cr^{+4}:YAG) has received great attention and has been rapidly developed due to its higher efficiency, longer life time and better stability comparedwith organic dyes or color center crystals . Asaturable absorption as Cr^{+4}:YAG widely used a passivily element inside the optical cavity of passive Q-switching technique. Cr^{+4}:YAG crystal is very compatable with fiber optic doped by Tm^{+3} as a saturable absorber (SA). At the initial time of Passive Q-switching pulse , most of molecules in the ground state (N_{gs}) (denoted number 1) as shown in Figure (2), this leads to high absorption activity making very low feedback, while at the final time of Passive Q-switching pulse, most of molecules in the excited state (N_{es}) (denoted number 2) as shown in Figure (2), this leads to low absorption activity making very high feedback [4,5].

Figure (

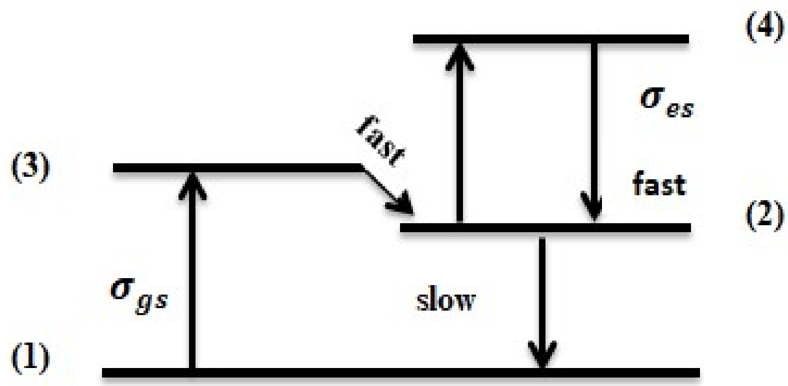

Fig. (3) shows the effective beam area *(A)* in Am and the effective beam area in SA (A_s) [6].The effect of A/A_s on the SA absorption activity has been studied in this study.

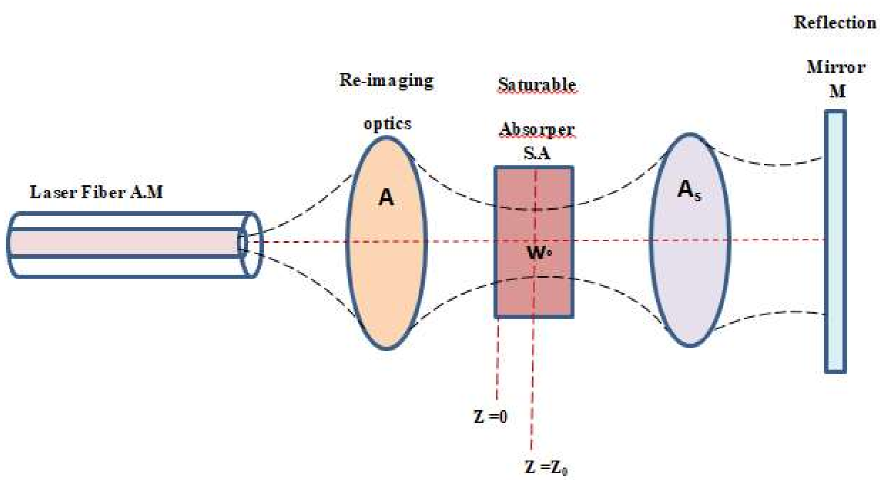

Fig. (3) An external cavity diagram in the Q-switch fiber laser passivly[6]

2- Theory

Coupled rate equations model [7] has been modified to study the effect of the ratio of Am effective area to the SA effective area absorption activity of saturable absorper of passively Q-switching doped fiber laser system as the followi equations:

$$\frac{d\phi(t)}{dt}=\frac{\phi(t)}{\tau_r}[2\sigma_{am}l_{am}N(t)-2\sigma_{gs}l_{sa}N_{gs}(t)-2\sigma_{es}l_{sa}N_{es}(t)-(\ln(\frac{1}{R})+L_{loss})] \quad (1)$$

$$\frac{dN(t)}{dt}=R_p-\gamma c\sigma_{am}\phi(t)N(t)-\frac{N(t)}{\tau_{am}} \quad (2)$$

$$\frac{dn_{gs}(t)}{dt}=\frac{n_{es}(t)}{\tau_{sa}}-(2\sigma_{gs}l_{sa}\phi(t)n_{gs}(t)/\tau_r)(A/A_s) \quad (3)$$

$$\frac{dn_{es}(t)}{dt}=-\frac{n_{es}(t)}{\tau_{sa}}+(2\sigma_{gs}l_{sa}\phi(t)n_{gs}(t)/\tau_r)(A/A_s) \quad (4)$$

Where: ϕ (cm^{-3}) is the photons number density, $\tau_r=2l_{am}/c$ (s) is the transit time for one round –trip, , l_r (cm) is the length of optical cavity, σ_{am} (cm^2) is the active medium emission cross section, c (ms^{-1}) is the light speed, σ_{gs} (cm^{-2}) is the absorption cross section of SA ground-state, l_{am} (cm) is the length of AM, l_{sa} (cm) is the length of SA, n_{gs} (cm^{-3}) is the SA ground state population, N (cm^{-3}) is the active medium population inversion density, n_{es} (cm^{-3}) is the SA exited state population, $R=(R_1R_2)^{1/2}$ is the geometric mean of the cavity, R_1R_2 is the reflectivity of mirrors, l_{loss} is the dissipative optical losses for round - trip. N (cm^{-3}) is the population inversion density, σ_{es} (cm^2) is the absorption cross section of SA excited-state, γ is the population reduction factor equal 1, 2 for 4 levels and 3 level of active medium system respectively, R_p is the optical pumping rate, τ_{sa} (s) is the lifetime of the excited level of SA, τ_{am} (s) is the fluorescence lifetime of the upper laser level. A is the effective aria of AM, A_s is the effective aria of SA.

Compared to the fluorescence life of the upper laser level, SA's lifetime in (microsecond) [8] with the Q-switched laser pulses normally have a very short build-up time, then can be neglect the spontaneous decay in AM and SA, also the pumping rate during pulse generation very longer capering Q-switched laser pulses build-up time [9] , then Eq.(2), Eq.(3), and Eq.(4) can be reformulation as the below respectively:

$$\frac{dN(t)}{dt} = -\gamma c\sigma_{am}\phi(t)N(t) \quad (5)$$

$$\frac{dn_{gs}(t)}{dt} = (-2\sigma_{gs}l_{sa}\phi(t)n_{gs}(t)/\tau_r)(A/A_s) \quad (6)$$

$$\frac{dn_{es}(t)}{dt} = (2\sigma_{gs}l_{sa}\phi(t)n_{gs}(t)/\tau_r)(A/A_s) \quad (7)$$

The density number of photons inside the optical cavity is minimum at the initial time, also most of SA molecules are in the ground state (n_{gs}), then can be regards $n_{gs} \approx n_{so}$, $n_{es} \approx 0$,where ($n_{so} = n_{gs} + n_{es}$) is the total number of SA molecules. The SA absorption activity is also very high at initial time, from Eq.(1) can be consider ($d\phi \ /dt \approx 0$) while cannot consider $\phi(t) = 0$. Then;

$$2\sigma_{am}l_{am}N_o - 2\sigma_{gs}l_{sa}n_{so} - (\ln(\frac{1}{R}) + L_{loss}) = 0 \quad (8)$$

From eq.(1) , at initial time of pulse can be regards $N(t) \approx Loss(t)$,and $\frac{d\phi}{dt} \approx 0$, then can be write:

$$Loss(t) = [2\sigma_{gs}\ell_s N_{gs}(t) + 2\sigma_{es}\ell_{sa}N_{es}(t) + (Ln(\frac{1}{R}) + Loss)]/(2\sigma_{am}\ell_{am}) \quad (9)$$

The first term of Eq.(9) represent photons loss due to the ground state absorption activity(Gact), while the second term represent photons loss due to the excited state absorption activity(Eact).

$$Gact(t) = 2\sigma_{gs}\ell_s N_{gs}(t)/(2\sigma_{am}\ell_{am}) \quad (10)$$

$$Eact(t) = 2\sigma_{es}\ell_{sa}N_{es}(t)/(2\sigma_{am}\ell_{am}) \quad (11)$$

$$Tot_{abs} = \frac{(2\sigma_{gs}l_{sa}n_{gs}(t) + 2\sigma_{es}l_{sa}n_{es}(t))}{2\sigma_{am}l_{am}} \quad (12)$$

At maximum of ϕ , also from Eq.(1) can be regards ($\frac{d\phi}{dt} \approx 0$), $n_{es} \approx n_{so}$, that mean n_{gs} can be neglected, then can be estimates the threshold population inversion density as the expression:

$$N_{th} = \frac{2\sigma_{es}n_{so}l_{sa} + \ln(\frac{1}{R}) + L_{loss}}{2\sigma_{am}l_{am}} \quad (13)$$

Can approximate the pulse energy as the following [10].

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Volume 54, Issue 02, October, 2022

$$E_{out} = (\frac{N_{o-}N_f}{\gamma})hv(\frac{N_o - N_f}{N_o}) \tag{14}$$

Where N_f represents the final value of population inversion density it is taken from computation, h is Blank's constant ,v (s^{-1}) is the laser frequency .To calculate the maximum photon number density (at the pulse peak) ϕ_{max}., can be dividing Eq.(1) onto Eq.(5), and can be regards $n_{gs} \approx 0.0, n_{es} \approx n_{so}$ at the pulse peak.

Parameter	Refer	Parameter	Refer	Parameter	Refer
$l_{am} = 25cm$	[11]	$R1 = 90\%$	[12]	$t_{sa} = 4.0 \times 10^{-6} s$	[13]
$\sigma_{am} = 0.46 \times 10^{-20} cm^2$		$R2 = 95\%$		$\sigma_{es} = 2.25 \times 10^{-19} cm^2$	[14]
$\tau_{am} = 2.38 \times 10^{-3} s$		$l_r = 300cm$		$\sigma_{gs} = 8.75 \times 10^{-19} cm^2$	
$\lambda = 1875nm$				$\sigma_{gs} = 8.75 \times 10^{-19} cm^2$	

$$\frac{d\phi(t)}{dN(t)} = \frac{\frac{1}{\tau_r}[2\sigma_{am} l_{am} N(t) - 2\sigma_{es} l_{sa} n_{so} + \ln(\frac{1}{R}) + l_{ioss}]}{-\frac{2l_{am}}{\tau_r}\gamma\sigma_{am}N(t)} \tag{15}$$

Substitution Eq.(13) in to Eq.(15) to get:

$$\phi_{max} - \phi_{init} = \frac{-1}{\gamma}((N_{th} - N_o) - N_{th}\ln(\frac{N_{th}}{N_o})) \text{, but } \phi_{max} >> \phi_{inil}$$

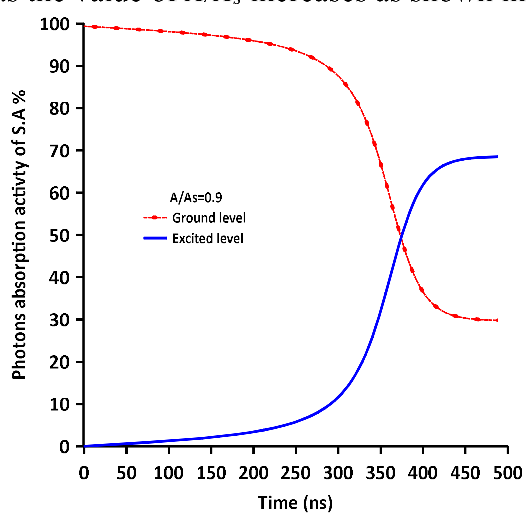
$$\phi_{max} = \frac{1}{\gamma}(N_o - N_{th} - N_{th}\ln(\frac{N_o}{N_{th}})) \tag{16}$$

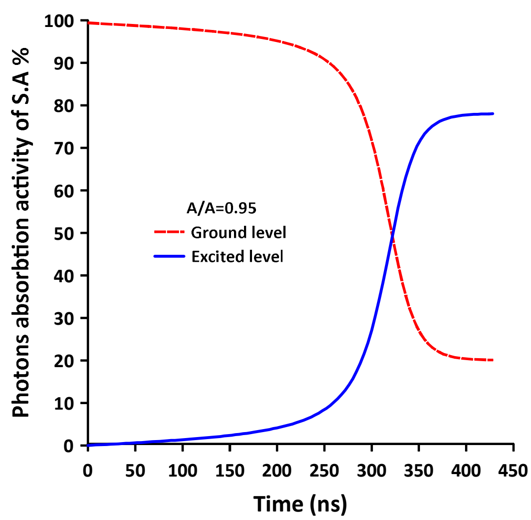
3- Results and discussion

Software program prepared in this study for solve the rate equations (1,5,6,7) numerically using Rung- Kutta– Fehlberge method. The input data used as shown in table (1):

Table (1) : The input data

Fig.(4) shows the percentage of absorption activity of SA as a function of time, the two levels of the SA being active in absorbing of oscillating laser photons during the time of pulse generation of the passive Q-switching pulse when adopting the value of A/A_s = 0.9. The absorption activity of the ground level of the SA at initial time of the pulse construction represents most of the absorption activity of SA, then the percentage of the absorption activity of the level is gradually reduced and a significant decrease occurs over a very short period of time approach to saturation state. While the excited level shows different behaviour from that of the ground level. It is noted that there are moments of time of variation in the behavior of the two levels, with approximately 302 ns, the absorption activity of the excited level begins with the dramatic increase in order to offset the contraction by the absorption activity of the ground level due to the increased of excited level population and the decrease in the ground level. While in time approximately 368 ns its observed as close to the percentage of absorption activity for both levels due to the equilibrium between the ratio effect of the absorption cross sections and their ions population. In time, approximately 462 ns of saturation is observed in the absorption activity of the two levels. The study explains this to the fact that the population of both levels remains almost constant. When increasing the active area ratio as shown in figs. (5,6), the same behavior is observed for the absorption activity of SA but is different in its earlier in time. Can be observe at A/A_s = 0.95 as in the Fig. (5) at time approximately 318 ns, the percentage of absorption activity of each one of two levels converges. In time, approximately 416 ns the saturation state is observed of the two levels. As can be notes at the value of A/A_s = 1 as in Fig. (6), the absorption activity of the excited level begins with the effective increase to offset the decreasing in the absorption activity of the ground level at advanced time comparing with the state in the two Figs. (4,5), where it occurs at approximately 240 ns. While in time approximately 288 ns the percentage of absorption activity for both levels converges. The study explains this to the high interaction between oscillating photons and SA ions due to the increased density number of photons as the value of A/A_s increases as shown in Fig.(7).





ISSN: 2096-3246
Volume 54, Issue 02, October, 2022

Fig.(4) Absorption activity of ground and exited level as a function of time, A/As=0.9

Fig.(5) Absorption activity of ground and exited level as a function of time, A/As=0.95

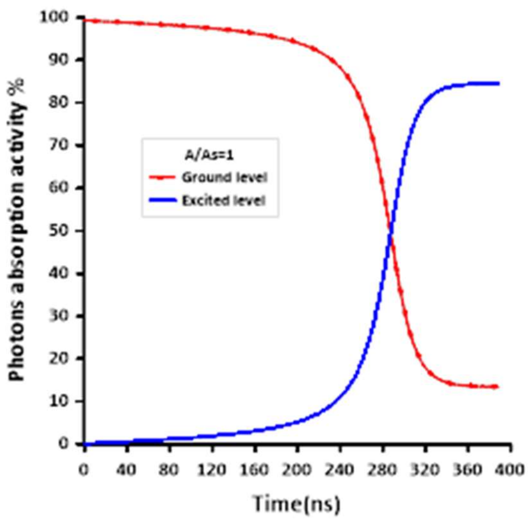


Fig.(6) Absorption activity of ground and exited level as a function of

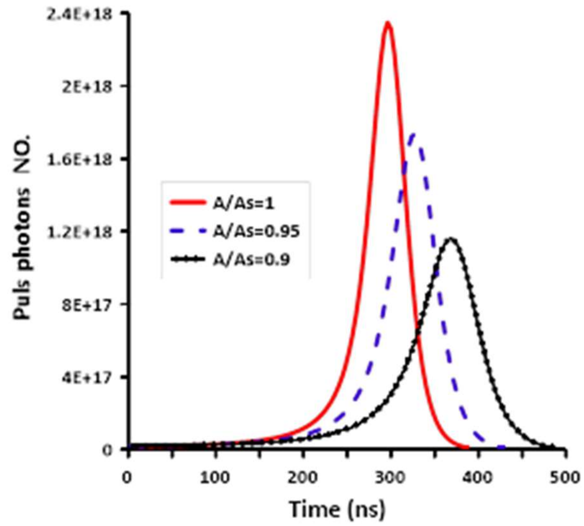


Fig.(7):Pulse profile as a function of A/A_s

It is noted from the forms (7,8,9) that the difference between absorption saturation values (optical bleaching) increases with the increase of A/A_s and to enhance the illustration, the figures (8- a, b, c) represents the time variation of the absorption activity of both the ground level and the excited in the SA and its total activity in terms of the effective area ratio respectively. It can be noted that the increase in the A/A_s ratio leads to two important outcomes: first, the optical bleaching occur at earlier time which reinforces the discussion, and second, continued absorption activity and absorption saturation at lower rates of activity, which positively reverses on passive Q-switching system performance, resulting in rapid discharge to low values of population inversion density in AM as shown in the Fig.(9), thereby increasing the energy of pulse generated as shown in fig. (10).

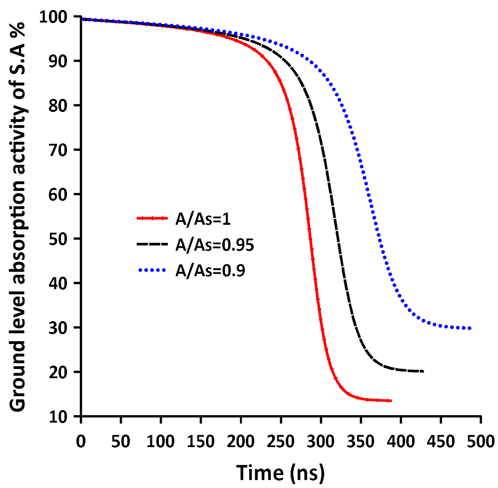


Fig.(8-a) Ground level absorption activity as a function of time

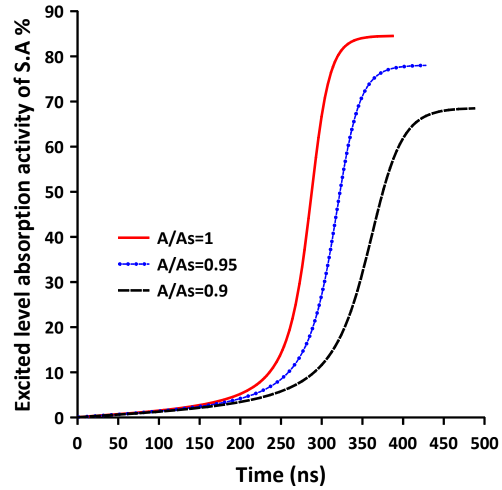


Fig.(8-b) Excited level absorption activity as a function of time

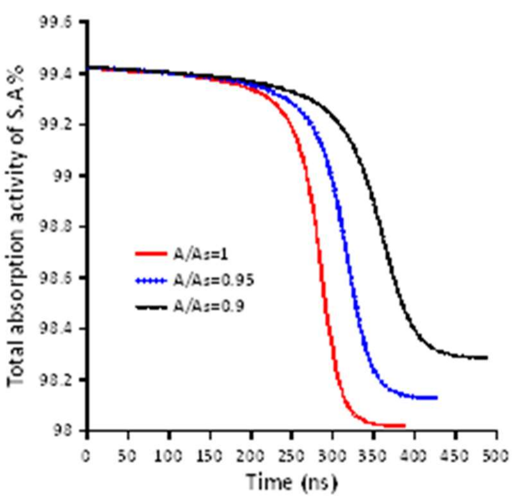


Fig.(8-c) Total absorption activity as a function of time

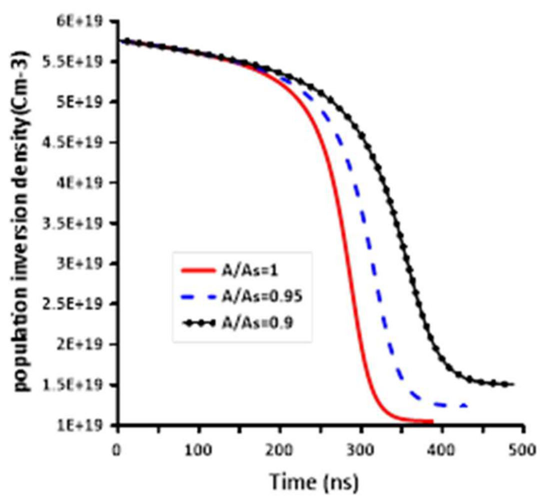


Fig.(9): The time variation of population inversion density as a function of A/A_s

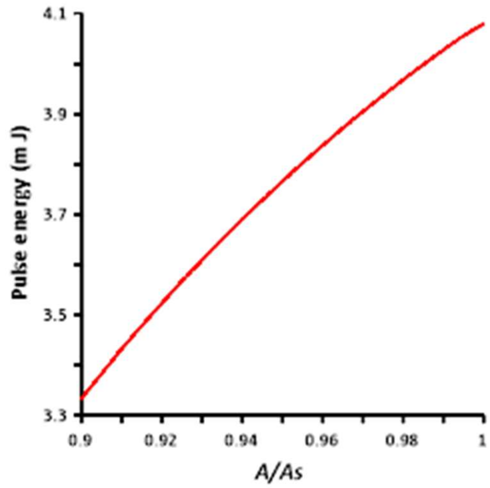


Fig.(10):Pulse energy as a function of

Conclusions

The study reached the following conclusions:

1- The absorption activity of each level in SA reaches to converging value at advanced time when the A/A_s increases.

2- The optical bleaching state of SA occurs at advanced time with the increase of A/A_s .

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