

## **Performance Enhancement of the Solid Saturable Absorber for Laser Passive-Switching at 1.353 $\mu\text{m}$**

**تحسين انجاز الماص القابل للاشباع الصلب لعملياته مفاتيح عامل النوعيه السلبي  
للليزر 1.353 مايكرومتر**

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### **ABSTRACT**

In order to approach the ideal conditions to optimized the performance of the 10mm CaF<sub>2</sub> crystal which is containing(5%) standard mixing of uranium ions as proposal saturable absorber element model for Q-switching laser operation in the spectral wave length around 1.353  $\mu\text{m}$ , the main aspects of this investigation are accomplished by means of the analytical treatments and direct calculations of derived equations as well as several programmed plotted graphs are obtained and applied to evaluated the most important active influences parametric and its effect on this type passively Q-switching laser operation such as, the output pulse peak power, the pulse energy, the depth modulation as well as the absorption cross-section and the nonlinear reflectivity .

The comparing of the interpolated results for this work with the different wave length ranges and by another materials types are strongly agreed with the earlier researchers calculations . Slightly different with some researcher measurements were owing to experiment errors as well as, which were because of the close estimations and the high precise treatments of this work . The errors percentage were only 4-5.8%, which are seem insignificant its influences on the essential goals for this work

The results are very satisfied to applied this proposal model as optimum controlling element for the passively Q-switching laser operation at 1.353  $\mu\text{m}$  •

### **// الخلاصة //**

البحث لايجاد افضل الشروط اللازمه لتحقيق الانجاز الامثل لبلورة فلوريد الكالسيوم المطعم بنسبية قدرها 5% من عنصر اليورانيوم وبطول قدره 10 ملي متر , كماده اساسيه تعمل كمفاتيح عامل النوعيه السلبي للليزر طول موجته 1.353 مايكرومتر .

كانت النتائج المعتمده على المعالجات التحليليه والقيم المحسوبه ووفقا لمعادلات رياضيه اشتقت لافتراضات تطابق الانجاز المثالي لمثل هذه العمليه مع تطبيق الخصائص البصريه واللاخطيه المثاليه للنموذج المقترح واعتمدت كمدخلات لبرامج فرعيه بلغه الفورتران ولاكثر العوامل(البارامترات) المؤثره على انجازها لعمليه مفاتيح عامل النوعيه السلبيه للليزر .

وكانت النتائج مشجعه لتحقيق مثل غايه البحث الرئيسيه كما وانها كانت مطابقه عند معايرتها مع اطوال موجيه لمديات مختلفه و لمواد صلبه متقاربه من خواصها البصريه لنتائج دراسات نظريه لباحثين اخرين واختلاف بسيط لايعتبر مؤثرا في مثل اهداف هذا البحث مع قياسات عمليه سابقه .

## **1. INTRODUCTION**

One of the most useful and the famous way among several ways of achieving high power pulses with short duration is Q-switching technique.

The possibility of Q-switching laser was first proposed by Hellwarth in 1961[1]. In practice, Q-switching can be achieved by deflecting the beam at the high reflecting mirror mechanically (Collins and Kisliuk, 1962)[2] or by acousto-optic (Koechner, 1976) [3] or electro-optic (Hellwarth and McClung, 1962)[4] devices or by using an opaque saturable absorber ( Soffer, 1964 ) [5] , which bleaches and become transparent when the fluorescent light output reaches a given level.

The first three methods of Q-switching are active types, where the switching of the laser light occurs externally, which are difficult to implement, complex for installation, alignment and operation.

Besides of these active methods laser also can be easily **switching passively** as, mentioned in the fourth method. This technique potentially offers an advantage of low cost, reliability and emission of pulses with a relatively narrow line width (Koechner, 1976) [3]. It is also simple in fabrication and operation since it requires no high voltages or fast electro-optic devices[5,6].

Crystal of calcium fluoride  $\text{CaF}_2$  containing uranium ions have been used to passively Q-switch at  $1.54 \mu\text{m}$  (Er:Yb):glass laser [ 7-9], a recent studies reported appreciable excited state absorption (ESA) at  $1.573 \mu\text{m}$  assuming divalent uranium( $\text{U}^{+2}$ ) as the absorber and details of the complex absorption spectra depend on the methods and materials used to dope and grow these crystal materials were chemical activity studied[10-12 ].

Interpretation the optical spectra has been problematic ever since Conway [13], published an analyses of the absorption spectrum in 1959.

Hargreaves [14,15] characterized  $\text{CaF}_2:\text{U}$  crystals by their wavelength of green, red and yellow and proposed that the numerous absorption lines and bands were due to transitions between crystal-field split state of divalent, trivalent, and tetravalent uranium ions in the green, red and yellow crystals, respectively, located in different charge-compensated site. That the green  $\text{CaF}_2$  crystal would be the only known sample of  $\text{U}^{+2}$  occurring in the solid state made the verisimilitude of this particular assignment doubtful.

Subsequently, based on chemical analyses and spectroscopic arguments, McLaughlin et al. [16], proposed instead that the green  $\text{CaF}_2:\text{U}$  crystals contained mostly  $\text{U}^{+4}$  ; their conclusions that the red crystals contained a mixture of  $\text{U}^{+3}$  and  $\text{U}^{+4}$  and the yellow crystals contained the uranyl complex  $\text{UO}_2^{+2}$  in different charge-compensated site, are substantially consistent with the investigation of Hargreaves [14, 15].

To elucidate the details of the spectra, Hargreaves provided Gruber and his colleagues [17, 18] with samples of green and red  $\text{CaF}_2:\text{U}$  crystals for site-selective spectroscopy measurements. A comparative study between the transmittance and the site-selective laser excitation and fluorescence spectra of both crystals led these investigators to the identification of different charge-compensated site for  $\text{U}^{+4}$  in the green crystal and different site for both  $\text{U}^{+4}$  and  $\text{U}^{+3}$  in the red crystal. Depending on whether Hargreaves had used  $\text{UO}_2$  or  $\text{UF}_4$  as the doping in growing crystals, Gruber et al. [17] found differences in the spectra that were traced to uranium ions in different sites. Two sites of  $\text{U}^{+4}$  that were identified in the green crystals. These two sites was also identified from electron spin resonance studies on  $\text{CaF}_2:\text{U}^{+4}$  reported earlier [19].

Recent interest in improving the optical properties of the green crystals for use as a saturable absorber in laser transmitters has led to re-examination of the methods used for growing crystals and the absorption spectrum from high purity different crystal types have reported [12].

In this work fluoride calcium ,  $\text{CaF}_2$  crystal is very suitable chosen element for this passively switching laser operation around  $1.353 \mu\text{m}$  owing to its higher transparency, lower refractive index limiting the nonlinear effect and lower photon-energy to reducing the no radiative

relaxation between the energy level caused by the lower photon frequency as well as high withstand thermal .

The aim of this work is accomplished to approach the ideal conditions to optimize the performance of this CaF<sub>2</sub> model, which is assumed to be has thickness equal to 10 mm and containing standard 5% uranium as the application element of the passively Q-switching at the sharply 1.353 $\mu$ m wave length laser●

## **2. Principle of the Passively Q-switching operation**

Passive Q-switching received its name from the action of generated radiation itself as mentioned earlier by Smith and Soroken in 1964 and 1966 [6,23]. Passive Q-switches can be used with pulse pumped systems only in the range of infra and far infrared wavelengths because a CW pumped laser never produces sufficient fluorescence to bleach either the dye (Kuhn, 1998)[20], or the solid saturable absorber such as, crystal of calcium fluoride which is the basic substance for our model construction in this investigation.

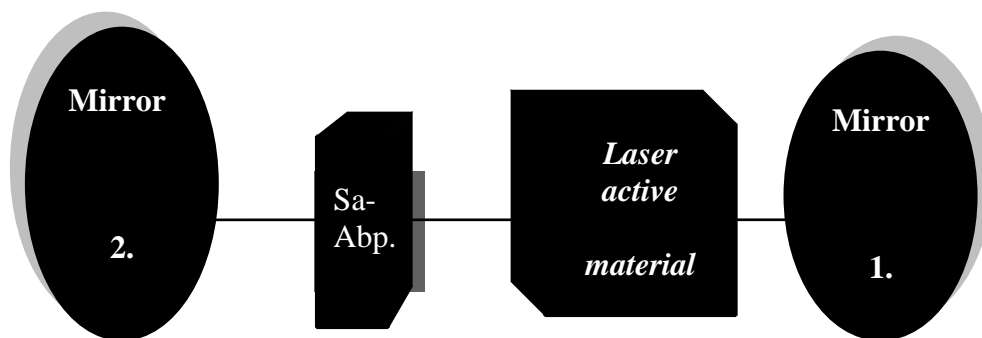
In this type Q-switching operation, the absorbing molecules of the material are transferred to excited state, and the material become transparent and the switching is opened. The essential of this passively Q-switching method is the bleaching process inside the material either dye or solid, therefore in the following section this processing is deeply described.

The saturable absorbers which are using as element for passive Q switching or mode locking of lasers depend on the physical idea that the relationship of the light absorbers with a degree of absorption which is decreases at high optical intensities.

The saturable absorber is an optical component with a certain optical loss, which is reduced at high optical intensities. This can occur, in a medium with absorbing doping ions, when a strong optical intensity leads to depletion of the ground state of these ions. Similar effects can occur in semiconductors, where excitation of electrons from the valence band into the conduction band reduces the absorption for photon energies just above the band gap energy.

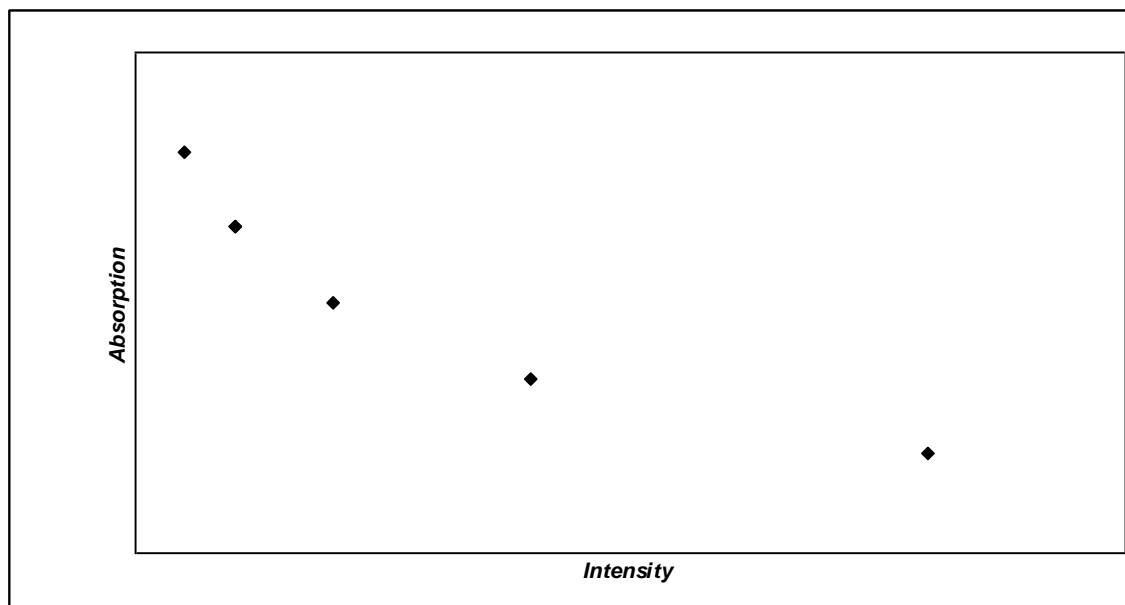
### **2.1 Bleaching processing mechanism**

Passive Q-switching consists of a saturable absorber placed inside the optical cavity, between the active material of the laser and the high reflection mirror as shown in figure 1.



*Figure 1, The saturable Absorber configuration for passively Q-switching*

The saturable absorber either dye or solid material, whose absorption is decreasing with increasing light intensity as shown in figure 2.



*Figure 2, The absorption as a function of incident light intensity [21]*

The solid material absorber are strongly absorb the light of the active material frequency, and this absorption prevents net amplification until a much large proportion of satiable absorber molecules have been pumped the excited state. The pumping energy input increases until amplification in the active material overcomes the loss due to absorption in the cell, and the laser begins to emit coherent light weekly. A very small amount of this weak laser light bleaches the saturable absorber either the solution or black of the solid, which then becomes almost perfectly transparent to the active material light. At this instant, there is suddenly a large net amplification and a narrow pulse that containing at the stored energy in the lasing medium, develops rapidly.

Usually, this Q-switching pulse energy is lower compared to the normal operation laser, owing to the losses and the absorption of the photon along the instant of the Q-switching process. However, the peak of this Q-switched laser pulse power is much higher short duration (less than nanoseconds range) . So, the output peak power Q-Switching laser pulse is computed in this work according to the Zehang relationship[3]:

$$\text{Peak Power} = \text{Pulse Energy} / \text{Pulse Duration} \dots\dots\dots(1)$$

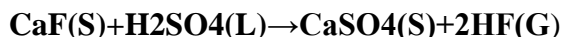
In passive Q-switching, this saturable absorber is used to introduce a variable loss in order build up the light in the cavity until bleaches, in this case the cavity opening suddenly to emitted very short pulse so called Q-switching pulse. After emitted this giant laser pulse, the molecules returning quickly to its absorbing and beginning build up of the next narrow pulse and so on [3].

Passive Q-switching are used the organic dyes as saturable absorber, but this dyes cell is highly absorption and low intensity, as well as this dye Q-switches suffer from poor chemical stability and inadequate thermal properties. To overcome this problem a few semiconductors such as, fused silica and CaF<sub>2</sub> crystals have chosen for this type Q- switching operation. However, the other benefits of saturable absorber are only one optical component and no complex electronics.

**2.2 Material description and its properties**

Calcium fluoride which is indicated as, CaF<sub>2</sub> and an insoluble ionic compound of calcium and fluorine, it occurs naturally as the mineral fluorite (fluorspar) and it the source of the most fluorine. This insoluble solid adopts a cubic structure where in calcium is coordinated to eight fluoride anions and each F<sup>-</sup> ions is sounded by four Ca<sup>+2</sup> ions[21]. Although the pure material is colorless, the mineral is often deeply colored due to the presence of F-centers.

Naturally occurring CaF<sub>2</sub> is the principle source of the hydrogen fluoride, commodity chemical used to produce a wide range of material. Fluoride is liberated from the mineral sulfuric acid:



The resulting HF is converted into fluorine, fluorocarbons and divers fluoride materials.

Calcium fluoride is appearance white crystalline solid as single crystals and virtually insoluble water. The most physical and chemical properties are listed below in table 1.

*Table 1, Specification and properties of 10mm thickness CaF<sub>2</sub> for optical crystals [22]*

Transparence range $\mu\text{m}$	Crystal structure	Lattice constant	Density g/cm <sup>3</sup>	Mohs hardness	Refractive indexes	Solubility in g/100g water at 18 C	Clear aperture	Diameter tolerance mm	Thickness Tolerance mm	Flatness 0.633 $\mu\text{m}$	Optical loss at 4 $\mu\text{m}$
0.15-9.00	cubic	5.462	3.18	4	1.6921-1.3161	0.0016	90 % of Demeter	$\pm 0.1$	$\pm 2$	$\lambda/4$	5.6%

The commonly application of Calcium fluoride is used as optical crystal and window material for both infrared and ultraviolet, owing to it is low loss optical windows, prisms, lenses, achromatic lenses and parallel planes can be fabricated from theses materials as well as its good transparent from 0.15  $\mu\text{m}$  to 9 $\mu\text{m}$  and extremely exhibit weak birefringence[3]. Furthermore these materials are fairly inert chemically so that these windows are not attacked. Nevertheless, at wavelengths as low as 0.157  $\mu\text{m}$ , which are interesting to semiconductor manufacturers, the birefringence of the calcium fluoride (CaF<sub>2</sub>) exceeds tolerable limits[21]. This problem with birefringence can be mitigated through optimized growth process. It is practically important as, an ultraviolet materials for integrated circuit lithography. Calcium fluoride are used in some components in some application laser lenses to reduce the dispersion of the light in wide wavelength range, its from the ultraviolet to far infra red region, these types crystals are widely applied to the entire optical wavelength range form ultraviolet (0.11  $\mu\text{m}$ ) to far infrared(40 $\mu\text{m}$ ).

Uranium-doped calcium fluoride was the second type of the solid state laser invented by Peter Sorokin, and later achieved at 2.5  $\mu\text{m}$  shortly after Miamian's ruby laser [23].

The most important parameters of this type satiable absorber, which are studied in this work are listed in the following:

- **The modulation depth**, i.e. the maximum possible change of optical loss
- **The insatiable loss**, i.e. the part of the loss which can be not saturated.
- **The recovery time**, i.e., the decay time of the excitation after an exciting pulse, its energy per unit area by  $1/e \approx 37\%$  .
- **The saturation energy**, i.e. the saturation influence times the mode area.
- **The saturation intensity**, i.e. the optical intensity ( power per unit area ) it take in a steady state to reduce the absorption to one half its unbleached value.
- **The saturation power**, i.e. the saturation intensity times the area mode.

**3. Analytical treatments on influents the parameters of the passively Q-switching operation**

This study is supplemented by the following analytically treatments on the bleachable absorber operation and its influences on the output of this passively Q-Switching.

In order to understanding this non-linear optical effect by means of the general and basic interaction transients between, the light and material, we can consider bleachable absorber to represent able by a simple two-level with population densities  $N_2$  and  $N_1$  for energy level  $E_2$  and  $E_1$ . When a beam of light interacts with a material, three fundamental phenomena will occur, namely, the process of spontaneous and stimulated emission as well as the process of absorption as description earlier by Smith and Sorokin [6].

For the level  $E_1$ , the population density changing due to the absorption is given by:

$$(\frac{d N_1}{d t}) = - \sigma_{12} F \dots\dots\dots (2)$$

$$W_{12} N_1 = \sigma_{12} F \dots\dots\dots(3)$$

Where,  $F$  ,  $\sigma_{12}$  ,  $W_{12}$  are, the photon flux of the incident light, the absorption cross-section and the absorption probability respectively.

The absorption process populates level 2 can be here expressed by:

$$(\frac{d N_2}{d t}) = - W_{21} N_2 \dots\dots\dots (4)$$

The processes of the spontaneous and stimulated emissions are depopulated level 2 by the following rate equations:

$$(\frac{d N_2}{d t}) = - A_{21} N_2 \dots\dots\dots (5)$$

$$(\frac{d N_2}{d t}) = - \sigma_{21} F \dots\dots\dots (6)$$

Also,

$$\sigma F = W N_2 \dots\dots\dots (7)$$

Here,  $\sigma_{21}$  is represented the stimulated emission cross section .

With the relation case of this our aim work model, the stationary case became where is:

$$d N_2 = 0 \dots\dots\dots (8)$$

Then the suitable solution for this condition is become as the following expression:

$$N_2 / N_1 = ( W_{12} / W_{12} + A_{21} ) \dots\dots\dots (9)$$

If we assuming the laser is pumped with high values pumping rate as, it is one of the assuming parametric conditions which have been applied on this our investigation model, in this case the absorption probability became extremely higher then the spontaneous emission:

$$W_{12} \gg A_{21} \dots\dots\dots (10)$$

Therefore, the equation 9 became as:

$$N_2 / N_1 \approx 1 \dots\dots\dots (11)$$

The physical meaning of this equation (11), is that the number of the absorbed photon becomes the same as the emitted ones. According to this condition the material is transparent and the pulse of the

laser can be suddenly emitted with the output energy can be given by the following general expression for passive Q-switched [20,5].

$$E = (h\nu A / 2\gamma\sigma)\rho \ln(1/R) \dots\dots\dots (12)$$

Where,  $h\nu$ ,  $A$ ,  $\sigma$ ,  $\gamma$ , and  $R$  are the laser photon energy, the effective laser beam area, the spectroscopic cross section of the laser transition, the inversion reduction factor and the reflectivity of output mirror respectively and the parameter  $\rho$  can be expressed by the following equation:

$$\rho = \ln(n_i / n_f) \dots\dots\dots (13)$$

Where,  $n_i$  and  $n_f$  are the population inversion density at the onset of the Q-switching operation and the final population inversion density after the passage of the Q-switched pulse. Also the parameter  $\rho$  can be related to others parameters as shown in the following expression:

$$[1 - 1/\rho \{1 - \exp(-\rho)\}] = \phi [1 - (1/\alpha)\{1 - \exp(-\rho\alpha)\}] \dots\dots\dots (14)$$

Where,

$$\phi = (1 - \delta)[\ln(1/T_0) / \ln G_0] \dots\dots\dots (15)$$

and  $\alpha$ ,  $\delta$ ,  $T_0$  and  $G_0$  are the ration of saturation energy, the inverse of the optical modulation depth, transmission and the gain respectively.

If the transmission of this  $\text{CaF}_2$  for only one way passing i.e only one half tripe and by assuming the effective beam area in the gain laser equal to the effective area of the satiable absorber, therefore the ratio of the laser saturation energy to the absorber saturation energy can be calculated by:

$$\alpha = \sigma_{gs} / \gamma\sigma_{es} \dots\dots\dots (16)$$

Where,  $\sigma_{gs}$  and  $\sigma_{es}$  are the absorption cross-section of the ground and excited state, respectively.

The peak power ( $P$ ) of the general passively Q-switched laser can be calculated by means of the following equation:

$$P = (h\nu A \ln G_0 / \gamma\sigma\tau_r \rho) \ln(1/R) [(1 - 1/\alpha)] \dots\dots\dots (17)$$

In order to approach the rough approximation for 1.353  $\mu\text{m}$  range modulation with this  $\text{CaF}_2$  type, the values of  $G_0 \approx 2$ , and by dividing the equation (19) in to equation (14), the laser pulse width ( $\tau_p$ ) is yielding by the following expression:

$$\tau_p \approx (13.328 \tau_r \rho) / (1 - 1/\alpha) \dots\dots\dots (18)$$

But for more precise estimated with the fully saturated absorber condition can evaluate by the following equation:

$$(\tau_p)_{\text{ful}} = 1.56 L / \Delta\Theta \dots\dots\dots (19)$$

Where,  $L$ ,  $\Delta\Theta$  are optical length and the maximum modulation depth respectively.

#### **4. The model construction and its influences on the characteristics of the operation of the passively Q-switching**

According to these above analytically treatments, the optimization values of the absorption cross section of this type material, the output pulse energy, the peak power and the pulse width of the laser were programmed by Fortran-V.90, computed as shown in table 2 and also by the programmed plotting, as shown in figures 3-4.

The input data of the theoretical computations were constructed by means of applying the above derivation equations(12,17,18) and using the following assumptions:

- The roundtrip losses was assumed to be equal zero( i.e negligibly) , owing to be very small compared to the high roundtrip gain
- The laser beam area was assumed to be constant and equal to  $\approx 1.5\omega\omega$  where  $\omega \approx 60-120 \mu\text{m}$  with the pumped power in the range 3-15 Watt.
- Satiabie absorber cross-section for the ground and for excited states were used the values of Burshtien measuring[10], which are equal to  $7 \times 10^{-18}$ - and  $2 \times 10^{-18} \text{ cm}^2$
- The cross-section and the inversion reduction factor of according to this our model conditions and by well compared to reference[11] were assumed to be approximately equal to  $6 \times 10^{-19} \text{ cm}^2$  and 0.45 respectively.

**Table 2, Evaluated parameters of an operation Q-switching with the satiable absorber of 10mm-5% U+4 CaF2 crystal at 1.353  $\mu\text{m}$  with repetition rate of 350 Hz**

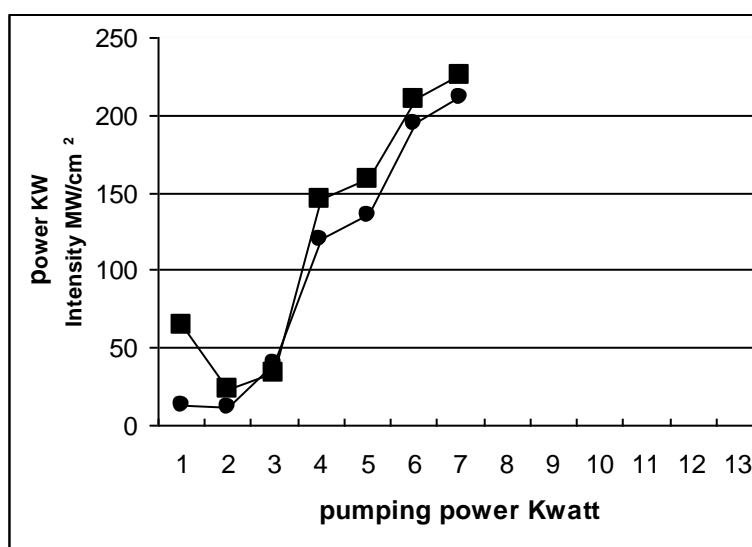
<i>Pumping power Watt</i>	<i>Pulse Energy <math>\mu\text{J}</math></i>	<i>Pulse Width nsec</i>	<i>Peak Power KW</i>	<i>Peak Intensity <math>\text{mW}/\text{cm}^2</math></i>
1	12.1	800	12.5	64
3	15.4	1400	11.2	22.6
5	19	2500	39.7	34
7	22.5	1600	120	145
9	26.7	410	135.5	159
13	30.4	1200	195	210
15	31.5	1550	210.8	225

The sensitivity of the both of these parametric, the peak power and the peak intensity of this passively model Q-switching are proportional with the pumping powers and seem to be goes with the same ratio as shown very clear in Figure 3.

The point of the optimal performance of this model also, shown in figure 4, where the minimum width of the producing pulse is coincident with maximum pulse energy;

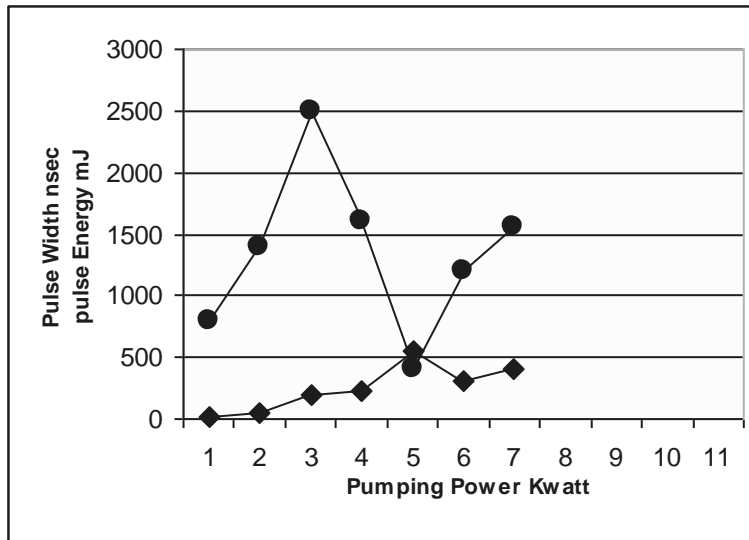
Both of these above two results are indicated that our treatments and evaluations were agreement with the basic principals and optimal performance conditions of the general Q-switching laser operation.

Therefore, the following parts of this investigation is worthy to further extend to construct and apply the optimization conditions for the passively Q-switching at 1,353 wavelength by means of this proposed type CaF<sub>2</sub>.



**Figure 4, Dependences of the peak power and peak intensity of the CaF2 passively Q-switching 1.353  $\mu\text{m}$  wavelength**





*Figure 5, Dependence of the Q-switching pulse Width and pulse Energy on the Pumping power with Passively CaF2 application*

**4.1 Calculation of saturable absorber coefficients**

In the case as the aim of this investigation, the quantity of the saturable absorption coefficients are defined with respect of the two most important parametric, the absorption recovery time ( $\tau_A$ ) and the laser pulse power ( $p$ ), which is well evaluated from figures 3-4, . Both of these two parametric can be related together and estimated by the following equation:

$$dP / dt = - [ \{ (q - q_0) / \tau_A \} + \{ (q \times p) / E_{sat} \} ] \dots\dots\dots (20)$$

Where,  $q_0$  is the corresponding quality of the satiable absorptions coefficients in the equilibrium with no interaction power, i.e  $P \approx 0$ .

$E_{sat}$  is denoted as the absorber saturation energy which is represented as the production of the absorber saturation influence and the effective laser mode area on the satiable absorber ..

The above equation can be solved for the time elapsed during pulse as:

$$E_{sat} = F_{sat} * A_{eff} \dots\dots\dots (21)$$

Where,  $F_{sat}$  is the influences of the saturation absorption i.e the full absorption effect, which is used to evaluated the corresponds of the pulse influence and very important to study with regard to one of the main goals for this investigation.

$A_{eff}$  here is the effective absorption which can be bleaching the satiable absorption equal to  $1/e$  of the maximum amount of the absorption ( with the interaction of the pumping power which is denoted as,  $q$ ).

In such CaF2 crystal material, the absorber recovery time can be designed within a wide range, therefore we can assume that the absorber time to recovery the pulse of the laser ( $\tau_A$ ), must be shorter than the cavity round-trip time. According to this our estimated which is also valid for all semiconductor material, it is possible to neglect the relaxation term in the above equation during the time of the pumping laser pulse to pass the CaF2-absorber crystal material and the absorber is fully recovered before the next pulse reach the absorber crystal again.

The loss in the pulse energy for only one trip ( $L_{Ep}$ ), , which is caused by the crystal material absorption is, also be an important parameter for the field of such investigation and can be evaluated by the following expression :

$$L_{Ep} = (q_0 / E_p) (F_{sat} \times A_{eff}) [ 1 - \exp\{ E_p / (F_{sat} \times A_{eff}) \} ] \dots (22)$$

Where,  $E_p$  is the energy of the pulse.

From the above relations, it is can be assumed the following expression to evaluated the nonlinear reflectivity with the regard pulse energy, ( $R_{Ep}$ ), which is also important parameter for this Q-switching laser operation:

$$R_{Ep} = 1 - [ \Delta R \{ (F_{sat} \times A_{eff}) / E_p \} ] \dots \dots \dots (23)$$

According to the definition of the pulse energy, which is the pulse energy per unit of the effective area, the nonlinear reflectivity expression can be rewrite with the regard of the pulse energy influence ( $F_{Ep}$ ), as in the following equation:

$$R_{Ep} = 1 - [ \Delta R (F_{sat} / F_{Ep}) ] \dots \dots \dots (24)$$

**4.2 Evaluating of the optimal parameters with the CaF<sub>2</sub>-model**

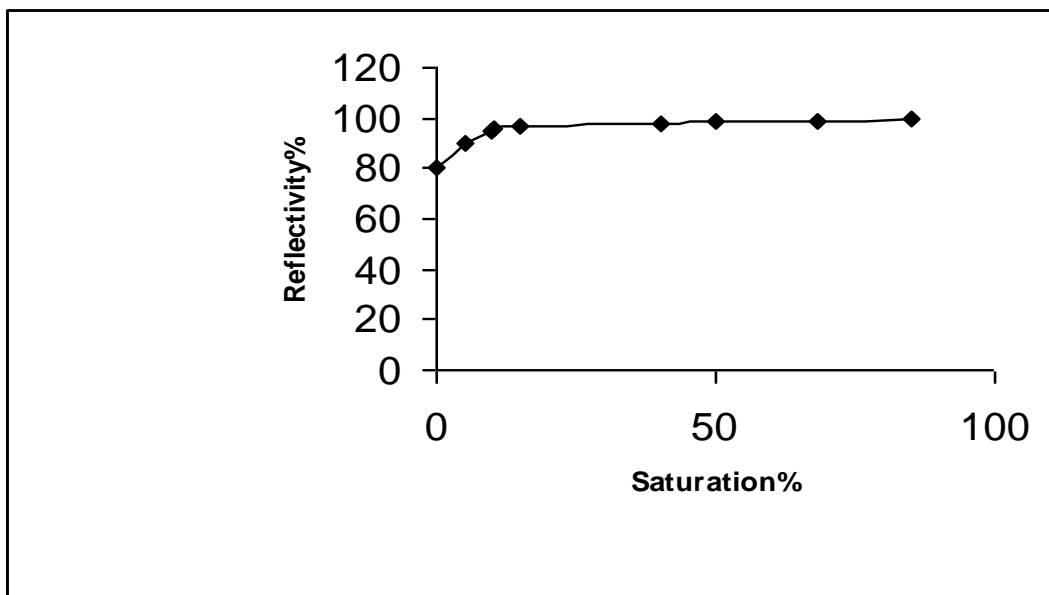
By means of these previous derivation equations the calculations, estimations and well theoretical treatments have applied on 10 mm CaF<sub>2</sub> –satiabile absorber crystal, The require parametric values are evaluated as listed in table (4) below, which have been used as the input data for developing the earlier our programmer application and used for the plotted as shown in the figures 5-6.

*Table 4, Nonlinear parameters evaluations for CaF<sub>2</sub> model*

<i>Parameters title</i>	<i>Saturation influence</i>	<i>Modulation depth</i>	<i>Recovery time</i>
<i>Value</i>	<i>46.9</i>	<i>17.45</i>	<i>15.4</i>
<i>Unit</i>	<i>m J / cm<sup>2</sup></i>	<i>%</i>	<i>PSc</i>

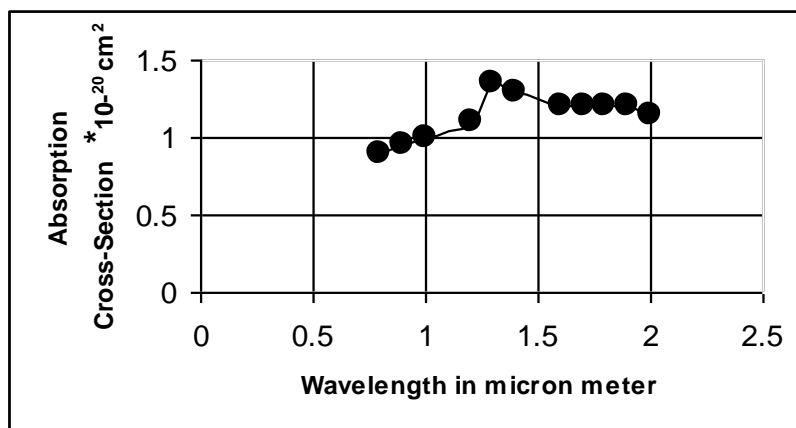
Dependence of the reflectivity of a this satiabile absorber on the saturation parameter are evaluated from the above derivation equations, and plotted as shown in figure (5) below, from this figure, we can well seen that the nonlinear reflectivity is begun as worth value from  $\approx 81\%$  to full maximum value  $\approx 99.5\%$  with saturation parametric approximately equal to 12.5%.

The above estimated results are applied to calculate the non-satiabile losses as well as the modulation depth (maximum change in reflectivity) which are 0.5% and 18.5% respectively.



*Figure 5, Nonlinear Reflectivity against the saturation absorption*

The dependence of the absorption cross section of this 10 mm CaF<sub>2</sub> with the x-axis crystal on the tuning infrared wavelength range also were plotted as shown in figure (6) below.



*Figure 6, Dependence of the absorption cross section of the CaF<sub>2</sub> crystal on the wavelength*

## 5. Results and Discussion

From this above figure, it is very clear to evaluated the absorption cross-section of this CaF<sub>2</sub> material with polarization along x-axis, its maximum value equal to  $1.4 \times 10^{-20} \text{ cm}^2$  with the wavelength equal to 1.353  $\mu\text{m}$ . These result are précised with the values, which are obtained by the derivation equations as shown in table (4) as well as, it is strongly agreement of the interpolation of these work results with those were earlier calculated and experimentally measured by several different researchers groups [24-27], with the sharp wave length equal to 1.353 $\mu\text{m}$ .

Owing to applied the wide range wavelength as well as, the over estimated with some negligible treatments during the different steps of this work, the errors percentages are approximated only ( $\pm 8-10\%$ ), which is seem to slightly and satisfied for purposes of the main goals of this work.

In order to have an effective passive Q-switching performance the population reduction factor of the 1.353  $\mu\text{m}$  laser which is regarded as, a four-level system must be equal a value of one. Owing to the calculations and estimated treatments, the 10mm thickness was very suitable chooser.

The (10 mm- U<sup>+4</sup> - CaF<sub>2</sub>) is proved to be an effective satiable absorber Q switch for the wide range tunable cover all the infrared and far infrared, but the optimum performance is obtained around 1.353  $\mu\text{m}$  wavelength.

The peak power and the energy of the out put laser pulse are increasing with the wider absorption cross-section and longer optical path, owing to high influence absorption of the satiable absorber in the range of this wavelength, the optimal thickness of this CaF<sub>2</sub> type material for this goal is estimated as  $\approx 8.5 \text{ mm}$  to 12 mm .

The maximum out put energy pulses and the minimum recovery time is the optimum condition to produce (giant) Q-switching laser pulse, i.e dramatic highest peak power pulses with this our proposal model is shown according to the dependence of theses above parameters around the 1.353  $\mu\text{m}$ .

To approach the optimal passive Q-switching performance, i.e., a shorter pulse can be obtained, the thicker satiable absorber was used i.e elongated the optical path of the light, in order to increase the activity of this satiable absorber sample by effective of the absorption influence.

Finally, it is worth to recommend that, the fast satiable absorption, i.e the recovery time less than the output pulse duration is necessary for passively Q-switching while, the most other

giant pulses techniques such as mode locking laser operation and cavity damping types can be achieved only with a slow saturable absorption as well as to approach the optimum higher output energy pulses, it must be looking for the best conditions to yielding the decreasing in the initial transmission percentage for less than 50% .

The dependence of satiable absorber performance on its effective temperatures to combined the nonlinear optics application as, frequency doublers, with the linear optics application as, Q-switching operation at 1.353  $\mu\text{m}$  will be the extended goals for this topic

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