J.Basrah Researches (Sciences) Vol. 33. No.4.(1 – 15) DEC. (2007)

The study of the $Cr^{4+}:Y_2SiO_5$ crystal coupling coefficients as a solid Q-switch for the chromic solid-state lasers

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ISSN –1817 –2695

(Received 30/4/2006 , Revised 23/8/2007 , Accepted 23/10/2007)

Abstract:

The passively Q-switching method has been used for the chromic solid-state lasers such as (Ruby , Alexandrite , Cr:LiCAF , Cr:LiSAF) lasers with $Cr^{4+}:Y_2SiO_5$ solid-state crystal. We have studied the saturable absorber crystal properties which are used in passive Q-switching all these lasers . The molar extinction coefficient (ε) , coupling coefficient of the saturable absorber (Ka) , the optical density (d) , the ground-state absorption cross-section (σ_a) of $Cr^{4+}:Y_2SiO_5$, and the Q-switching efficiency (η) of the chromic solid-state lasers is calculated first, when the pumping rate (Rp) was variable and other parameters (as reflectivity of output coupler (R) and the number of molecules in the ground-state (N_{ao}) were constant) and second , (η) is calculated when (R) was variable and other parameters were constant . The results of $Cr^{4+}:Y_2SiO_5$ crystal which is used with all these lasers are compared each others , and the behavior of (ε), and (Ka) had been interpreted according to (σ), and (d) , respectively . The $Cr^{4+}:Y_2SiO_5$ Q-Switched Cr:LiSAF laser has a better passive Q-Switching performance than other used laser systems . The main conclusion in this research is that the molecular weight of the chromic ion host laser crystal acts as an important role in Q-Switching efficiency where it is directly proportional with the Q-switching efficiency.

Introduction:

A big technical commotion had been occurred by the laser discovering in 1960 [1], because of its utility in many different applications [2,3].

The short duration , and the highest power of output laser pulse are the main requirements for several domains such as range-finder[4] remote sensing[5] surgery [6], …… etc ;Therefore, many efforts had been directed to a technique that will be able to converse output laser pulse to " giant pulse " which has short duration and high power . This technique was named as " Q-Switching " [7] .

A Q-Switching technique may be achieved by an optical –Shutter inserted inside the cavity which prevents a laser oscillation by the optical losses increasing inside the resonator for a short period limited by the optical shutter saturation , and the maximum population inversion reaching time . After that, the upper excited state decay suddenly and giant laser pulse can be generated.

The Q-switching technique is achieved either , mechanically by the Rotating- mirror [8] , or electro-optically by Bockl`s cell [9,10] , or acousto-optically by (RF) oscillator [11].These active methods of a large size and they require an outside trigger circuit which are dependent on the time . So that , a passive Q-Switching technique is more benefit for operation in the laser systems [12] by situating the cell containing the saturable absorber inside the cavity .

The saturable absorbers may be liquids [13,14] , solids[15] , semi-conductors[16] , or gases[17] .

Passive Q-Switching of solid-state lasers with solid- state saturable absorbers have received much attention in the past years, and several solid-state passive Q-Switches have been developed for the solid – state lasers operating at various wavelengths [18].

The Cr^{4+}:Y_2SiO_5 crystal was demonstrated to be an effective saturable absorber Q-Switch for the Cr:LiSAF laser(at 880nm) [19] , the Cr:$BeAl_2O_4$ laser(at 750 nm) [20] , the Cr:LiCAF laser (near 780 nm) [21] , and the ruby laser(at 694.3 nm) [22] .

Theoretical expressions of important parameters such as the laser population inversion in different time periods , the peak photon number inside the laser resonator , the output energy and the pulse duration of the Q-Switched laser pulses are derived , and used to evaluate the characteristics of the Cr^{4+}:Y_2SiO_5 Q-Switched Cr: $BeAl_2O_4$ laser [18] , Ruby laser [22] , Cr:LiSAF [19] , and then Cr:LiCAF laser systems [21,23].

In this paper, the behavior of the Cr^{4+}:Y_2SiO_5 molar extinction coefficients, and coupling coefficients as functions of the pumping – rate, and the reflectivity of the output coupler will be studied.

Characteristics of the used lasers:

The Ruby (Cr:Al_2O_3) laser was the first working laser which was introduced by Theodore H.Maiman in 1960 [1]. The ruby laser is a three-level laser; that is, a photon is created when two inverted populations are found in the laser crystal where the lower laser level is the ground- laser level [12] . It is capable of generating high-energy , visible and red pulses , which is powerful tool for the removal of tattoos and disfiguring pigmented lesions from the skin , and can also generates high-energy pulses from a compact package , which makes the ruby laser a valuable tool for holographic , non _ destructive testing , double – pulse holography , and plasma diagnostics [23] .

Alexandrite (Cr:$BeAl_2O_4$) , which is biaxial with emitted light polarized parallel to the b(axis) , can act either as a three – level laser system or as a four – level vibronic laser system [20,24] . It is highly efficient , and has important applications in medical surgery , water – vapor , temperature differential absorption lidar , solid- state laser pumping , and generation of ultraviolet laser radiation because it can be tuned at least from (700 nm) to (818 nm) [18].Since Cr:$BeAl_2O_4$ has a broad absorption band in the visible spectral range , it can be efficiently pumped with flash lamps [25].On the other hand , a compact Cr:$BeAl_2O_4$ laser system may be pumped by the laser diode [25].

The Cr:LiCAF (Cr:$LiCaAlF_6$)solid-state laser was developed by Payne et al. in 1988 [21] .Laser diode pumping of the Cr:LiCAF laser has also been demonstrated in 1991 and ; hence , a compact Cr^{4+}:Y_2SiO_5 Q-Switched Cr:LiCAF laser system is feasible [23] . As a transition – metal vibronic laser the Cr:LiCAF has a broad emission spectrum , long lifetime of the upper laser level , low nonlinear refractive index , low thermal lensing , and low excited state absorption that make it a unique source for tunable or short pulse lasers [21].

The Cr:LiSAF (Cr:$LiSrAlF_6$) solid-state laser , discovered by Payne el al. in 1989 is widely tunable from (780 nm) to (920 nm) [19].The Cr:LiSAF has similar Cr:LiCAF crystal properties explain as below that make it an important tunable and pulsed laser source [19] . The material properties of four lasers above are listed in table.1.

Table (1):Characteristics of the chromic lasers.

Lasers / Characteristics	Ruby [22]	Alexandrite [18,20,23-25]	Cr:LiCAF [21,23]	Cr:LiSAF [19]
Fluorescence life time	3 msec.	260 µsec .	170 µsec.	67 µsec .
Laser wave length	694.3 nm	(700-818)nm peak(750 nm)	(725-840)nm peak(780nm)	(780-920)nm peak(850nm)
Stimulated emission cross-section	$(2.5x10^{-20})$ cm^2 at (694.3)nm	$(7.0x10^{-21})$ cm^2 at (750)nm	$(1.3x10^{-20})cm^2$ at (780)nm	$\sim(4.8x10^{-20})cm^2$
Chemical formula	$Cr:Al_2O_3$	$Cr:BeAl_2O_4$	$Cr:LiCaAlF_6$	$Cr:LiSrAlF_6$
Molecular weight	51	71.98	100.98	148.52

Characteristics of the Cr^{4+} :Y_2SiO_5 Crystal :

The (Cr^{4+}:Y_2SiO_5) is a pure tetravalent chromium system . It is a blue in color and is a biaxial solid-state crystal [22].Some of its important material parameters are as follow : It has a melting point as high as (2070 ºC) , Cr atoms/mole % as ($9.7x10^{19}$ atom/cm^3) , density as (4.6 gm/cm^3) , refractive index as (1.8) , and the damage threshold as high as (30 J /cm^2) [23,25] .

Spectroscopic studies of the Cr^{4+} :Y_2SiO_5 , and the observation of laser action from (77) up to (257ºK) was reported by Deka et al. in 1992 [18] . Room-temperature laser operation of the Cr^{4+} :Y_2SiO_5 was reported subsequently by Koetke et al . [18] .

It has four absorption bands peaked near (390nm),(595nm),(695nm),and (750nm)[23] as shown in fig.(1). It's absorption spectrum covers the visible , and near infrared spectral region and , hence , can be used as a saturable absorber Q-Switch for the ruby , alexandrite , Cr:LiCAF , and Cr:LiSAF lasers [19,23] .

This Q-Switch crystal has an emission life time of (0.7 µsec) at room temperature [23] which is long compared to the duration of the Q-Switched laser pulses . Therefore , Cr^{4+}:Y_2SiO_5 can be classified as a slow-relaxing saturable absorber [23] .

The Cr^{4+}:Y_2SiO_5 crystal has many absorption cross-sections at a few different wave lengths for several Solid-state lasers as explained in table (2).

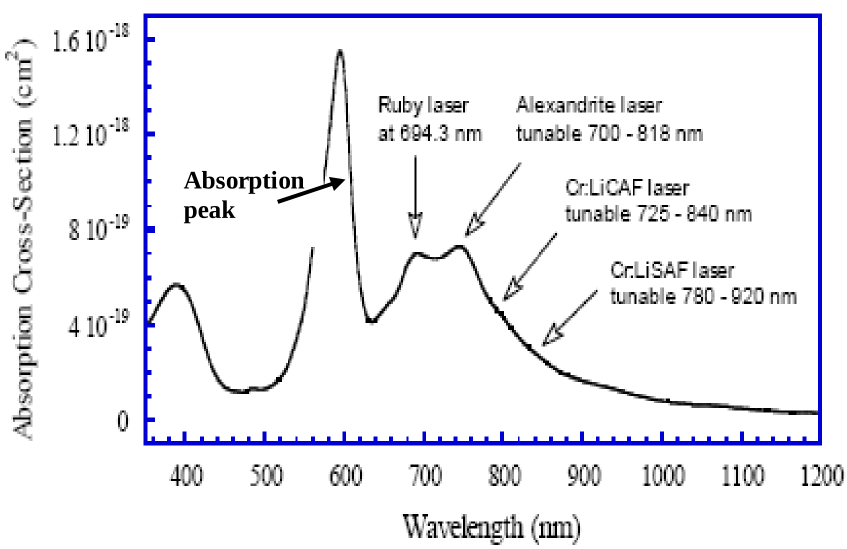


Fig. (1) :Cr^{4+}:Y_2SiO_5 absorption spectrum [23] .

Table (2): $Cr^{4+}:Y_2SiO_5$ absorption cross-section at the used lasers wavelengths [22,19-21,24,25]

State of crystal Q-switch	Lasers	Wavelength	Absorption cross-section of the Q-switch	Ref.
Polarization along (n_1)axis .	Ruby	694.3 nm	$9.9x10^{-19}$ cm^2	[22]
Polarization along (n_2) and (n_3) axes.	Ruby	694.3 nm	$7.0x10^{-19}$ cm^2	[22]
Polarization along (n_1) axis .	Alexandrite	680.4 nm	$9.2x10^{-19}$ cm^2	[24]
Polarization along (n_2) and (n_3) axes .	Alexandrite	680.4 nm	$6.5x10^{-19}$ cm^2	[24]
For all three principal axes (n_1,n_2 and n_3).	Alexandrite	750 nm	$7.2x10^{-19}$ cm^2	[25]
=	Alexandrite	694 nm	$7x10^{-19}$ cm^2	[20]
=	Cr:LiCAF	745 nm	$7.3x10^{-19}$ cm^2	[21]
=	Cr:LiCAF	840 nm	$2.7x10^{-19}$ cm^2	[21]
=	Cr:LiSAF	850 nm	$1.67x10^{-19}$ cm^2	[19]

Calculations and results:

The transmitted radiation power through $Cr^{4+}:Y_2SiO_5$ crystal is calculated as below :

P (watt) = Q-switched laser pulse energy (mJ)/Q-switched laser pulse duration (nsec) ………….(1)

We are depended on the experimental results of energy and duration of the Q-switched laser pulse , in Q-switched laser pulse power (P) calculation. The data of the Q-switched laser pulse energy and duration are functions of pumping rate (Rp) and reflectivity of output coupler(R) which are shown in fig (**3-9**, **15-19**, **4-5** , **3-5**) in references [**18**,**19**,**21** and **22**], respectively .

Appendix 1 (a,b) shows The energy and duration values of the $Cr^{4+}:Y_2SiO_5$ Q-switched lasers which we are depended on them in this study and (P) results which are calculated from eq.(1) The $Cr^{4+}:Y_2SiO_5$ molar extinction coefficient (ε) at variable (Rp) and (R) can be calculated by substituting (P) values in the Beer-Lambert law as below [26]:

$$\varepsilon = [1/C\,\ell]\ \log_{10}(P_o/P) \qquad \text{………………(2)}$$

Where P_o is the incident radiation power of (733 , 600 , $51.8x10^{-3}$, $78x10^{-3}$) watt for ruby , alexandrite , Cr:LiCAF , and Cr:LiSAF lasers , respectively [22,19,23,27] . ℓ is the $Cr^{4+}:Y_2SiO_5$ thickness of (1mm) for all used lasers . C is the molar concentration of the $Cr^{4+}:Y_2SiO_5$ saturable absorber which may be calculated by using eq.(3) [28]:

N_{ao} = molar concentration x Avogadro's number……..(3)

Where N_{ao} is the initial ground-state population of the saturable absorber of ($1x10^{16}$, $4x10^{15}$, $4x10^{15}$, and $2.3x10^{16}$) $Molecule.l^{-1}$ used with ruby , alexandrite , Cr:LiCAF , and Cr:LiSAF lasers , respectively [22,19,23,27] and Avogadro's number is equal to $6.022x10^{23}$ $Molecule.mol^{-1}$.

The $Cr^{4+}:Y_2SiO_5$ saturable absorber coupling coefficient (Ka) is calculated at different (R_p) in one time , and in different (R) in another time for each (Ruby ,Alexandrite , Cr:LiCAF and Cr:LiSAF) lasers as below [28]:

$$K_a = 2\ \sigma_{g.s.a} / \tau_r A_a \quad \text{……………(4)}$$

Where $\sigma_{g.s.a}$ is the ground-state absorption cross-section of the $Cr^{4+}:Y_2SiO_5$ saturable absorber which can be calculated by substituting all resulted **ε** values from eq.(2) in eq (5) [28] :

$$\sigma_{g.s.a} = 3.85 \times 10^{-21}\ \varepsilon \quad \text{…………. (5)}$$

τ_r is the cavity round –trip transit time which is calculated as below :

$$\tau_r = 2L / c \quad \text{………….(6)}$$

Where c is the light velocity and L is the optical distance between the reflectors of 30 cm , 30 cm , 34 cm , and 42 cm for the ruby , alexandrite , Cr:LiCAF and Cr:LiSAF lasers , respectively [22,23,19,21] .

And A_a is the effective laser spot area on the $Cr^{4+}:Y_2SiO_5$ crystal because it has circular shape ,A_a can be calculated as below :

$$A_a = \pi r^2 \quad \text{…………….. (7)}$$

Where r is the radius of the laser beam of 2mm, 2mm , 2mm and 0.5mm for ruby , alexandrite , Cr:LiCAF and Cr:LiSAF lasers , respectively [22,23,19,21] .

We are shown the P,Ka and **ε** of the $Cr^{4+}:Y_2SiO_5$ at different values of (R) in one time and (Rp) in another time , as shown in fig (2) and fig (3) , respectively.

Fig (4) shows the ground-state absorption cross-section of the $Cr^{4+}:Y_2SiO_5$ as a function of (R) and (Rp), in order to interpret the variation of ε with variation of (R) and (Rp) .

The $Cr^{4+}:Y_2SiO_5$ Q-switch optical density (d) may be calculated at different values of (R) and (Rp) by substituting all ε values which are resulted from eq.(2) in eq.(8) as following [28] :

$$d = \varepsilon\ C\ \ell \quad \text{………….. (8)}$$

For interpretation the K_a behavior with (R) and (Rp) variation , we drew all (d) results as functions of (R) and (Rp) as shown in fig.(5) .

To specify the best solid-state laser Q-switching with $Cr^{4+}:Y_2SiO_5$, the Q-switching efficiency of the used lasers can be determined by using the following relationship [20]:

$$\text{Q-switching efficiency } (\eta)\ \% = \frac{\text{The values of the output Q-switched laser energy}}{\text{free-running energy}} \quad \text{……. (9)}$$

The values of free-running energy of 110 mJ , 80 mJ , 60 mJ , and 98 mJ , for ruby , alexandrite , Cr:LiCAF ,and Cr:LiSAF lasers , respectively [22,19,23,27] .The η results are listed in table.3 .

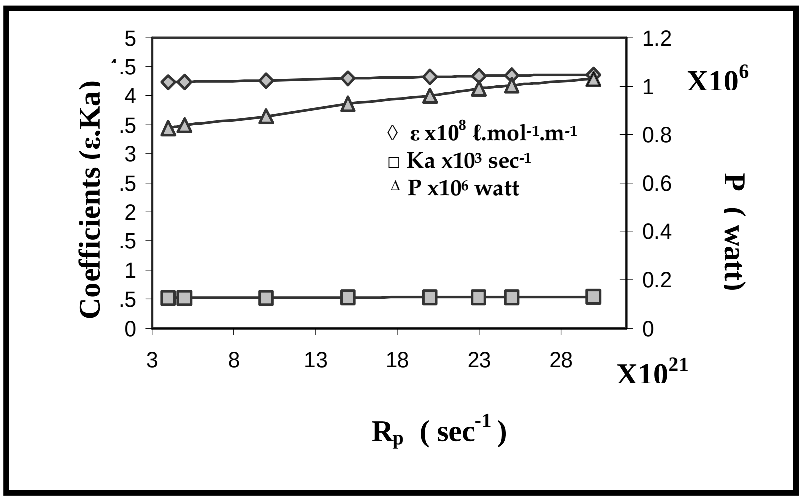
Table.3:The Q-switching efficiency of the chromic-solid state lasers by $Cr^{4+}:Y_2SiO_5$.

-a-

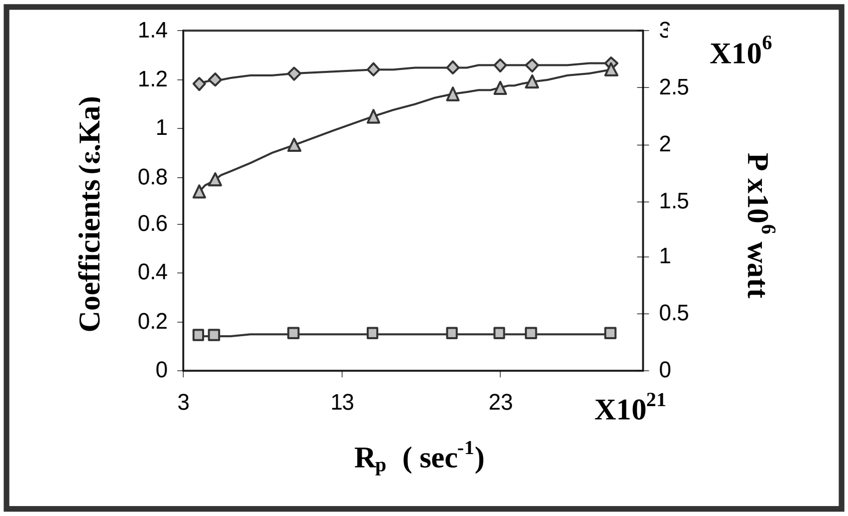
R	Ruby %	Alexandrite %	Cr:LiCAF %	Cr:LiSAF %
0.3	-	1.71	0.96	14.2
0.4	-	1.72	0.98	13.2
0.5	-	1.73	0.98	12.2
0.6	0.40	1.68	0.96	9.6
0.7	0.34	1.62	0.95	7.6
0.76	0.30	1.56	0.93	6.5
0.8	0.29	1.43	0.88	6.1
0.86	0.23	1.25	0.78	4.08
0.9	0.20	1.12	0.71	3.06
1	-	0.56	0.33	-

-b-

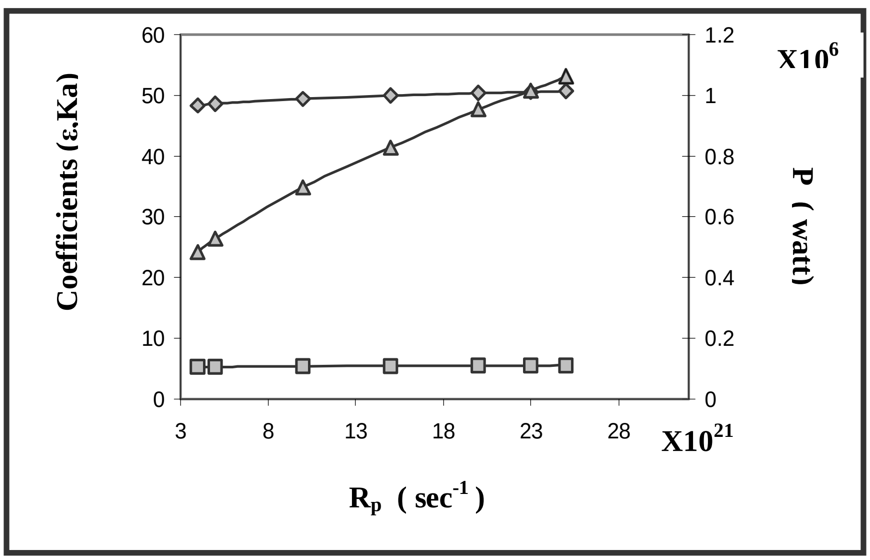
R_p	Ruby %	Alexandrite %	Cr:LiCAF %	Cr:LiSAF %
4	0.17	1.28	0.73	5.35
5	0.17	1.32	0.78	5.56
10	0.17	1.42	0.88	6.02
15	0.18	1.51	0.96	-
20	0.18	1.58	1.05	-
23	0.19	1.61	1.08	-
25	0.19	1.62	1.11	-
30	0.19	1.66	1.13	-



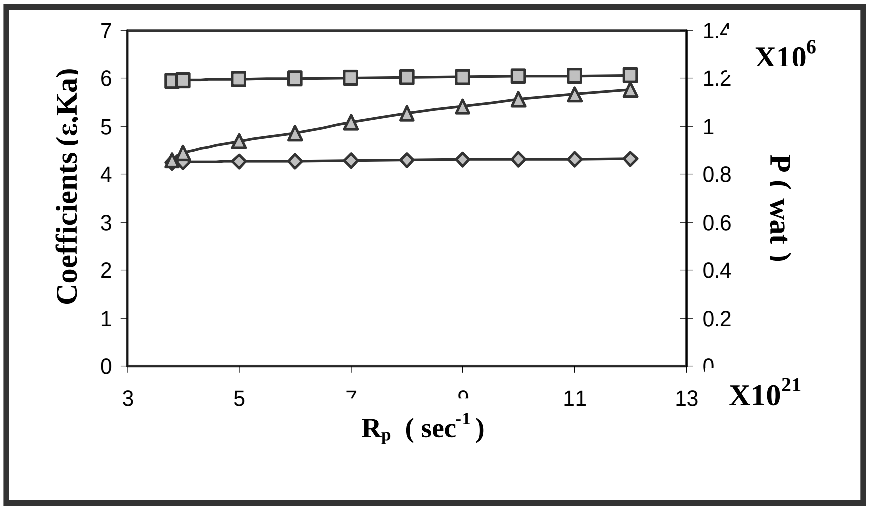
(A)


1.4
1.2
1
0.8
0.6
0.4
0.2
0
Coefficients (ε.Ka)
3
2.5
2
1.5
1
0.5
0
X10^6
P x10^6 watt
3
13
23
X10^21
Rp (sec^-1)

(B)

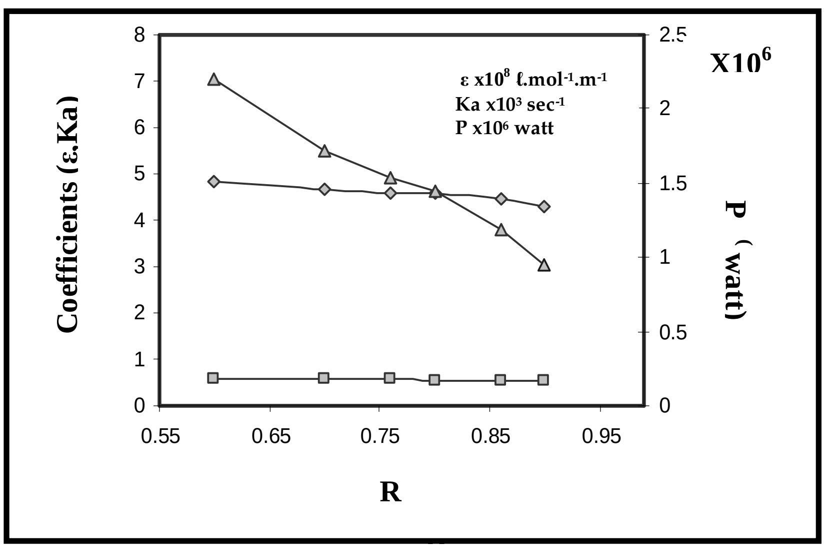

60
50
40
30
20
10
0
Coefficients (ε.Ka)
1.2
1
0.8
0.6
0.4
0.2
0
X10^6
P (watt)
3
8
13
18
23
28
X10^21
Rp (sec^-1)

(C)

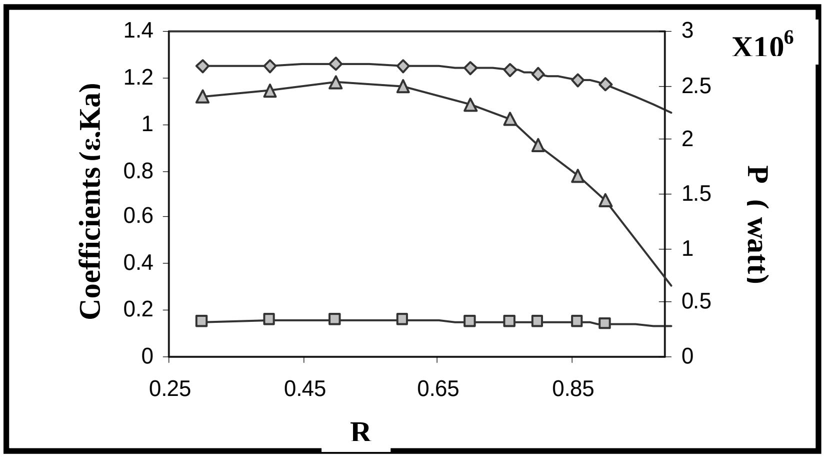


(D)

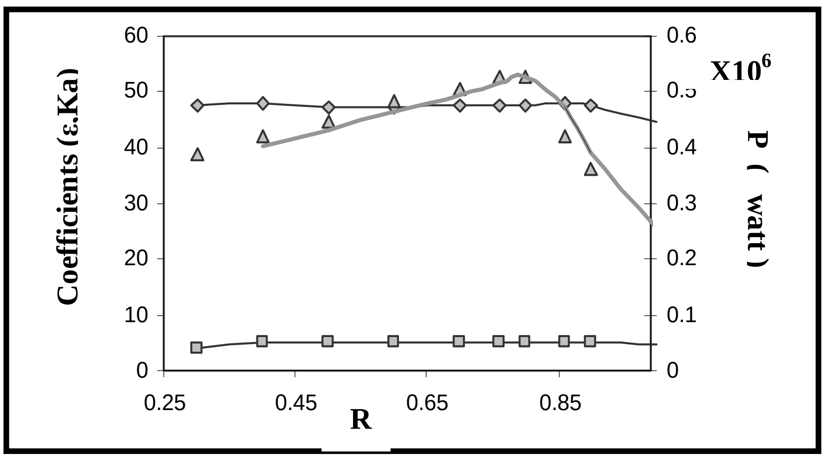
Fig.(2):The Cr $^{4+}$:Y_2SiO_5 saturable absorber coupling coefficients (Ka) , and molar extinction coefficients(ε) as a function of pumping rate (Rp) at the wavelength of : (A)-Ruby laser. (B)-Alexandrite laser. (C)- Cr:LiCAF laser . (D)-Cr:LiSAF laser.



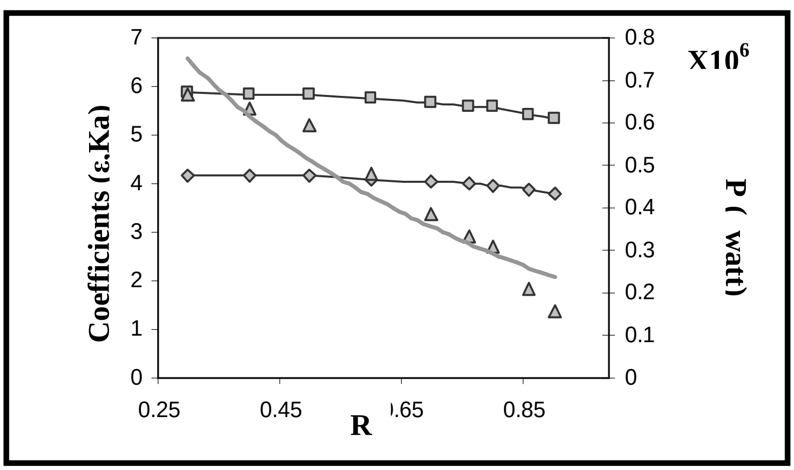
(A)



(B)



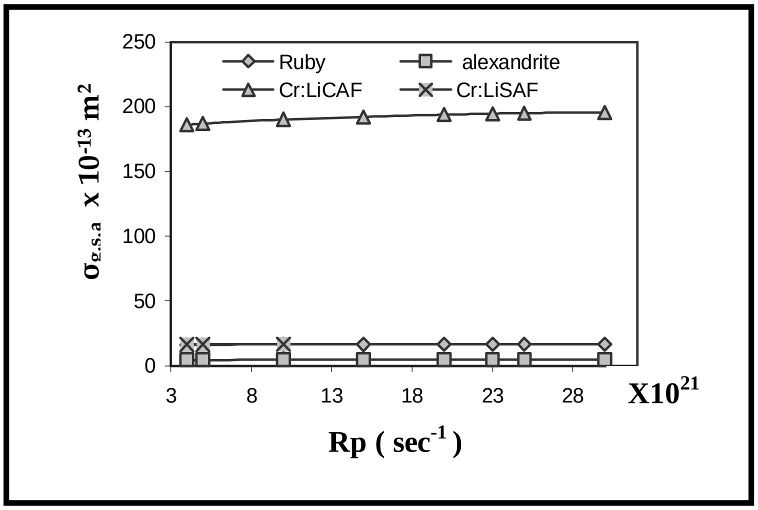
(C)



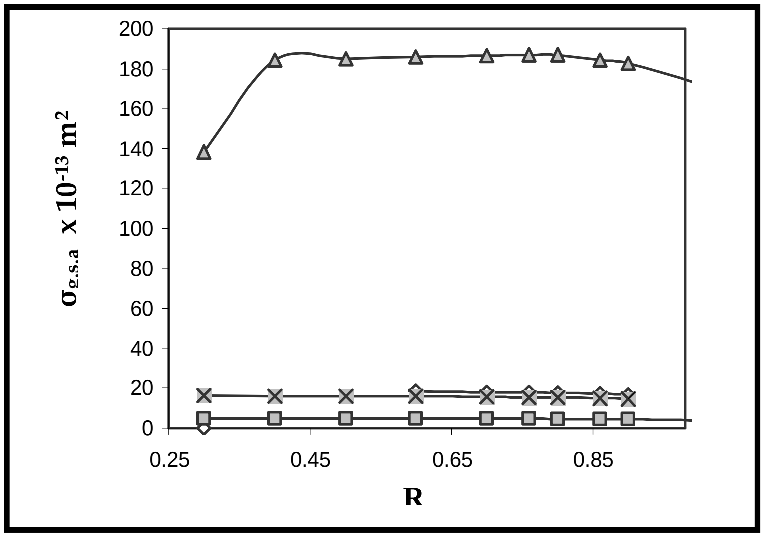
(D)

Fig.(3):The behavior of the Cr $^{4+}$:Y_2SiO_5 Q-switch coupling coefficients(Ka),and molar extinction coefficients (ε) ,at different values of reflectivity of output coupler when it used with:

(A)-Ruby . (B)-Alexandrite laser.
(C)-Cr:LiCAF laser. (D)- Cr:LiSAF laser.



(A)

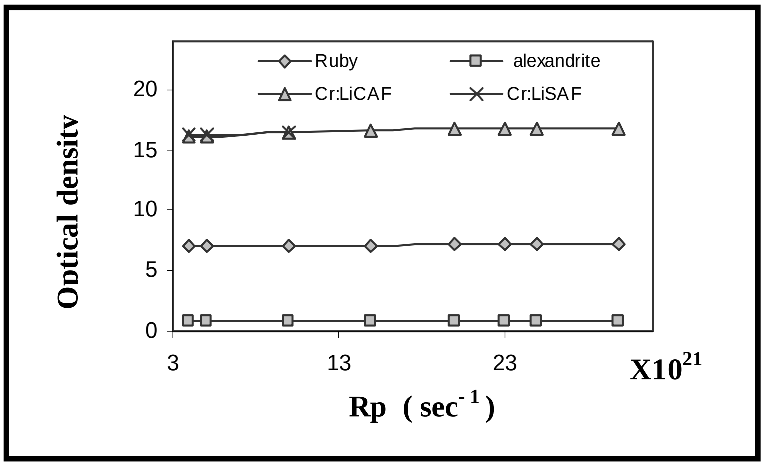


(B)

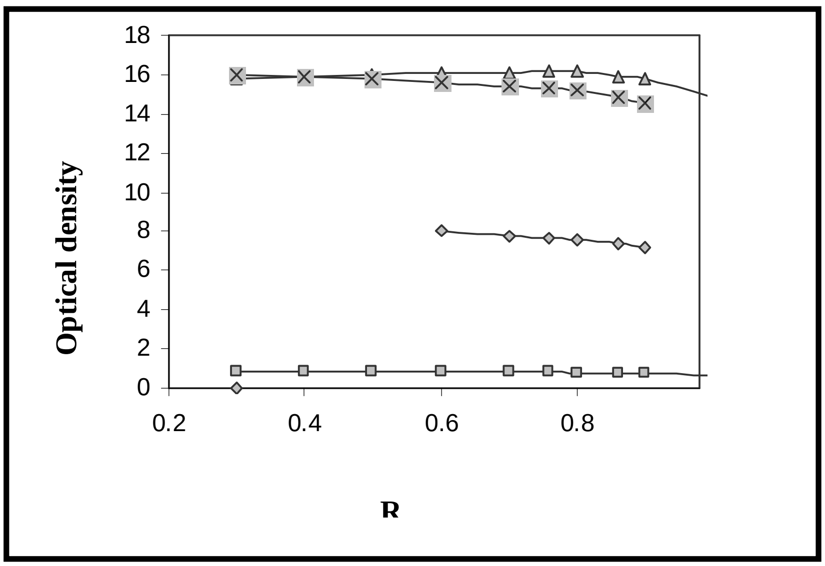
Fig.(4): The variation of the ground-state absorption cross-section of the saturable absorber used to Q-switch chromic solid state lasers, with variation of :

(A) – pumping rate (Rp).

(B) – reflectivity of output coupler .



(A)



(B)

Fig.(5):The optical density of the Cr^{4+}:Y_2SiO_5 crystal used for Q-Switching the solid state lasers , as a function of:
(A) – Pumping rate . (B) – reflectivity of out put coupler .

Discussion :

It is obvious from the fig.2 that the high values of (ε) , (Ka),power , and (η) may be obtained with a higher pumping rate .As indicated in fig.3 , when that the output coupler reflectivity increasing , the molar extinction coefficient , coupling coefficient , the output laser power , and the Q-switching efficiency decreasing , except when used $Cr^{4+}:Y_2SiO_5$ with Cr:LiCAF , and alexandrite lasers , where these parameters initially increasing and finally decreasing , that may be interpreted that initially increasing of reflecting didn't affect the total optical resonator losses .The $Cr^{4+}:Y_2SiO_5$ Q-switched Cr:LiCAF laser has higher value of molar extinction coefficient (ε) than for other chromic-lasers , because it has higher value of absorption cross-section , as shown in fig.4, and this means that hurriedly excitation , and faster decay of the saturable absorber after the population inversion reaches maximum , may occur . The highest coupling coefficient (Ka) of the $Cr^{4+}:Y_2SiO_5$ is obtained with Cr:LiSAF laser and less values of (Ka) for Cr:LiCAF , ruby, and alexandrite , respectively, due to it has optical density toward Cr:LiSAF laser wavelength (i.e. it has higher absorptivity at the wavelength of the Cr:LiSAF laser) more than other lasers as shown in fig.5 .

The Cr:LiSAF has better passive Q-switching efficiency because of chromic ion host laser crystal has highest molecular weight , while the ruby has less efficiency , and that results from its lowest molecular weight , shown in table.3.

We must note that the previous experimental, and theoretical researches are restricted this study to limited values of (Rp) , (R) , and (N_{ao}) for different lasers .

Conclusion:

We can conclude that the high molar extinction coefficient , and coupling coefficients of the Cr:YSO crystal as a saturable absorber for the chromic –solid state lasers may be obtained using a high pumping rate , and low output coupler reflectivity at the same number of saturable absorber molecules in the ground-state , and that will cause a better passive Q-switching performance (highest power , shortest pulse duration) . It is obvious that the Cr:YSO is a more effective solid-state saturable absorber Q-switch for the Cr:LiSAF laser at (850 nm) than with other lasers , due to the highest molecular weight of the chromic-ion host Cr:LiSAF laser crystal than other lasers , and it does not need a pumping rate more than half of needing for other lasers .

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Appendix 1 :
The energy , duration and power of the Q-switched laser pulse at different :
(a) - (R) values.
(b) - (Rp x10^{21}sec^{-1}) values .

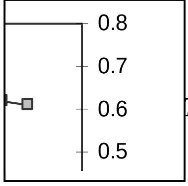
lasers	Ruby [22]			Alexandrite [18]			Cr:LiCAF [21]			Cr:LiSAF [19]		
R	E* (mJ)	Tp** (nsec)	P*** (Mwatt)	E (mJ)	Tp (nsec)	P (Mwatt)	E (mJ)	Tp (nsec)	P (Mwatt)	E (mJ)	Tp (nsec)	P (Mwatt)
0.3	-	-	-	137	57	2.403	58	150	0.386	14	21	0.666
0.4	-	-	-	138	56	2.464	59	140	0.421	13	20.5	0.634
0.5	-	-	-	139	55	2.527	59	132	0.446	12	20.2	0.594
0.6	44	20	2.2	135	54	2.50	58	120	0.483	9.5	19.8	0.479
0.7	38	22	1.72	130	56	2.321	57	113	0.504	7.5	19.5	0.384
0.76	34	22	1.54	125	57	2.192	56	108	0.527	6.5	19.4	0.335
0.8	32	22	1.45	115	59	1.949	53	106	0.528	6	19.3	0.310
0.86	26	22	1.18	100	60	1.666	47	112	0.419	4	19.1	0.209
0.9	22	23	0.95	90	62	1.451	43	118	0.364	3	19	0.157

(a)

lasers	Ruby [22]			Alexandrite [18]			Cr:LiCAF [21]			Cr:LiSAF [19]		
Rp	E (mJ)	Tp (nsec)	P (Mwatt)	E (mJ)	Tp (nsec)	P (Mwatt)	E (mJ)	Tp (nsec)	P (Mwatt)	E (mJ)	Tp (nsec)	P (Mwatt)
3.8	-	-	-	-	-	-	-	-	-	5.2	6.05	0.859
4	19.1	23	0.826	103	65	1.584	44	91	0.483	5.25	5.9	0.889
5	19.2	22.9	0.838	106	63	1.682	47	89	0.528	5.45	5.8	0.939
6	-	-	-	-	-	-	-	-	-	5.55	5.7	0.973
7	-	-	-	-	-	-	-	-	-	5.65	5.55	1.018
8	-	-	-	-	-	-	-	-	-	5.75	5.45	1.055
9	-	-	-	-	-	-	-	-	-	5.85	5.4	1.083
10	19.6	22.4	0.875	114	57	2	53	76	0.697	5.9	5.3	1.113
11	-	-	-	-	-	-	-	-	-	5.95	5.25	1.133
12	-	-	-	-	-	-	-	-	-	6	5.2	1.153
15	20.3	21.9	0.926	121	54	2.240	58	70	0.828	-	-	-
20	20.8	21.5	0.96	127	52	2.442	63	66	0.954	-	-	-
23	21	21.2	0.99	129	51.5	2.504	65	64	1.015	-	-	-
25	21.2	21.1	1.004	130	51	2.549	67	63	1.063	-	-	-
30	21.4	20.7	1.03	133	50	2.66	68	62	1.096	-	-	-

(b)

Where * E is the energy of the Cr:YSO Q- switched chromic solid-state laser pulses measured in (mJ).
Tp is the duration of the Cr:YSO Q- switched chromic solid-state laser pulses **measured in (nsec) .
P is the power of the Cr:YSO Q- switched chromic solid-state laser pulses measured in *(Mwatt).**



الخلاصة:

استخدمت طريقة إحكام النوعية لليزرات الحالة الصلبة مثلا Ruby، Alexandrite ، Cr:LiCAF و Cr:LiSAFبوساطة بلورة $Cr^{4+}:Y_2SiO_5$. درست خصائص البلورة الصلبة الماصة المشبعة المستخدمة في احكام النوعية السلبي لتلك الليزرات. تم حساب كل من معامل الاضمحلال المولاري (ε) , ومعامل الارتباط (Ka) للصبغة الماصة المشبعة , و كذلك المقطع العرضي الامتصاصي (σ_a), و الكثافة البصرية (d) ل $Cr^{4+}:Y_2SiO_5$, فضلا عن كفاءة إحكام عامل النوعية (η) لليزرات الحالة الصلبة الكرومية أولا عندما كان معدل الضخ متغيرا و بقية المعاملات (مثل انعكاسية مرآة الخرج الليزري (R) وعدد جزيئات الصبغة الماصة المشبعة في المستوي الأرضي N_{ao}) ثابتة , وثانيا عندما كانت (R) متغيرة وبقية المعاملات ثابتة . قورنت النتائج الخاصة ببلورة $Cr^{4+}:Y_2SiO_5$ المستخدمة مع كل الليزرات المستخدمة . فسر سلوك (ε)و (Ka) طبقا ل(σ) و (d) على التوالي. إن ليزر Cr:LiSAF المحكم عامل نوعيته بوساطة بلورة $Cr^{4+}:Y_2SiO_5$ يمتلك أفضل أداء تحويل لعامل النوعية من الأنظمة الليزرية المستخدمة الأخرى . إن الاستنتاج الرئيس هو إن الوزن ألجزيئي لبلورة الوسط الفعال المضيفة لايون الكروم له دور مهم في فعالية الإحكام , إذ إنه يتناسب طردياً مع كفاءة الأحكام .