JOURNAL OF KUFA – PHYSICS Vol.1 No.1
A Special Issue for the 2nd Conference of Pure & Applied Sciences (11-12) March 2009

The effect of BDN-I dye ground-state absorption cross-section in Nd:YAG giant laser pulse power

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Abstract:

The Nd:YAG laser system at 1.064 μm has been operated. The BDN-I dye has been prepared and dissolved in many pure polar organic solvent such as (Carbon-tetra-chloride,Chloroform,Acetone,Dioxane and Pyridine), and in a mixture of Carbon-tetra-chloride with other solvent at 1:1 , and 2:1 mixing ratios, to act as liquid passive Q-Switch for Nd:YAG laser. The energy and duration of Q-Switching laser pulse has been measured at different molar concentration of the dye dissolved in solvents which mentioned above. The values of ground-state absorption cross-section σ of the saturable absorber (S.A) at different values of dye molar concentration (M).The effect of (M) on (σ) , and its relation with giant laser power (P , have been studied .The increasing of (M)causes (P) increasing and (σ) decreasing. The (σ) results have been interpreted according to polarity of used solvent. However the giant laser power results may be explained according to used solvent density. Pyridine solvent is an efficient solvent ,has been concluded because there is no need to higher (M) of dye by using it , and its mixture has high (σ) compared to other solvents . The main conclusion is the mixing way of Carbon-Tetra-Chloride with other solvent at different mixing ratios , is an ideal way for improving the giant laser pulse power higher , and obtaining high (σ) of (S.A).

Key word: Q-switching , saturable absorber , Nd-YAG laser

Introduction:

The Q-switching technique has been implemented on Nd:YAG laser by the saturable absorbers to achieve giant laser pulses which are more useful than which are obtained in free-running operation . There are many materials have been used as a passive Q-switches for Nd:YAG laser . These materials may be solids as (Cr,Nd) saturable absorber in (YAG) gain medium which are demonstrated a compact , efficient, highly polarized , and highly stable Q-switched laser [1-3], Cr:YAG crystal has been performed as a saturable absorber for Nd:YAG laser [4-9],Cr^{+4}:GSGG saturable absorber [10], V:YAG crystal [11-12], or gases such as narrow-band of (CS_2) vapor saturable absorber [13]. The semiconductors could also be used as a Q-switches for Nd:YAG laser as InGaAs [14-15].Many dyes which are dissolved in different solvents , used as a liquid Q-switches for Nd:YAG laser .

The nickel complex BDN-I is used as a saturable absorber for Q-switching neodymium lasers. It is particularly attractive for their good photochemical stability , the possibility of tailoring their ground-state recovery (GSR) time by the appropriate choice of solvent [16], where the optical properties of the BDN-I dye substantially differ depending on the host material [16],or the solvents which is dissolved in them [17-19].

BDN-I dye has the chemical name of Bis(4-dimethylaminodithiobenzil)nickel , and the molecular formula $C_{32}H_{30}N_2NiS_4$ (629.55) molecular weight , melting point of (270-280)C° [19].

The BDN-I dye was homemade and used to Q-switch the Nd:YAG laser at 1997 [20]. The study of using PMMA foils doped with mixture of BDN-I in different solvents as a solid Q-switches for Nd:YAG laser has been implemented experimentally and theoretically in

2001 [21], and the measurement of the threshold energy damage of them are achieved in 2003 [22]. A method of preparing complexes based on BDN-I as a Q-switches for the solid-state lasers ,as, these complexes have resonance absorption bands near the emitted wavelength laser to produce saturable absorber dyes which are cover a wide range of resonance wavelengths, has been introduced in 2002[23].

In this research we'll introduce a study on the effect of Ground-state absorption cross-section of the (S.A) in the Q-switching laser pulse power. The BDN-I solution is used as a passive Q-switch for the Nd:YAG laser at 1.064μm wavelength.

Theory:

The giant laser pulse generation can be understood by the absorption dynamics discussion as follow : the excitation pulse of pump source populates the upper laser level . As soon as the upper laser level population crosses the low threshold population , laser action sets in , and the generated laser radiation excites the saturable absorber molecules to the first excited-state (2) , higher excited – state (4) . The excited molecules relax fastly to a state (3) , and then to the ground – state , as shown in fig.1 . If the intensity of the generated laser radiation approaches the saturation intensity of the absorber , the absorption will be stopped , and the saturable absorber may be bleached . Finally , the resonator losses are reduced , and strong amplification of the radiation occurs . The generated radiation depletes the upper laser level population rapidly , and the resulting high gain generates an intense giant pulse [24] .

Where(σ) is the ground-state absorption cross-section of the (S.A) which can be calculated by :

$$\sigma = 3.85x10^{-21}\left(-\frac{\ln\left(\frac{I}{I_o}\right)}{MZ} \right) \qquad ....(1).$$

Where Io is the incident intensity on a (S.A) , I is the absorbed intensity by it . M is the molar concentration of dye , and Z is the thickness of the (S.A) cell .

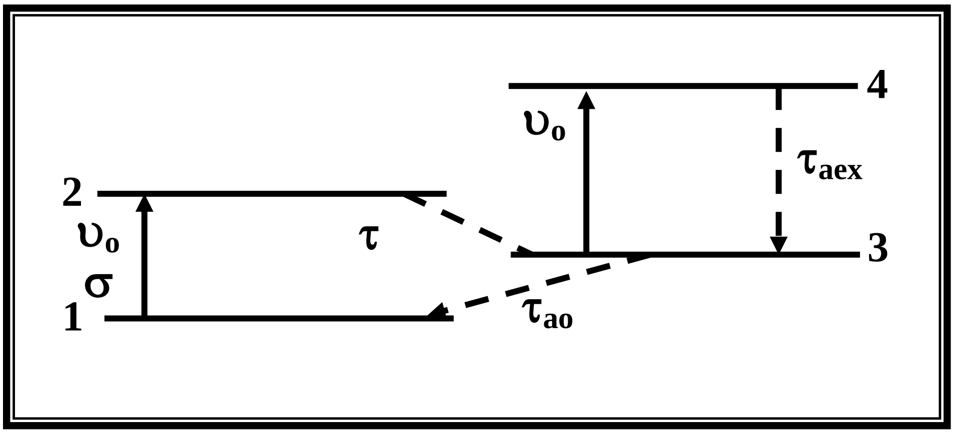

Fig.1 : The absorption dynamic of the saturable absorber [24] .

Experimental part :

The system used to Q-switch the Nd:YAG laser at (1.064μm) is shown in fig.2 , so it shows (5cm)long,(5mm)diameter of Nd:YAG rod with (54%) reflected mirror ,while the total reflected mirror is a retra-reflected prism, and The used resonator was of elliptical shape with (12.6cm)long. Kr-flash lamp was used to pump the Nd:YAG rod.

An ED-200 genetic Joulmeter which was supplied by (EG&G) company, has been used to measure the laser pulse energy . It has been connected to a fast oscilloscope model(TDS 500) which was supplied by Tektronix company . The P-i-n detector which was connected to oscilloscope is used to detect the transmitted photons from the dye cell. The cell is filled by BDN-I dye dissolved in one of each (CCl_4 , $CHCl_3$, Acetone , dioxane , and Pyridine) pure solvent or in a mixture of (CCl_4) with one of each other solvents at 1:1 and 2:1 mixing ratios . It was putted firstly , inside the resonator to measure the intensity (I) energy, and duration of the Q-switched laser , and secondly outside it to measure the incident intensity (I_i) on it . The beam splitter (expander) is used to separate the photons array outside the resonator to two arrays in order to reduce the energy arrived to detector. The incident intensity of the laser had been measured by removing the dye cell from the system, and we find that I_i of (59.36×10^{-3} photons/cm^2.sec) intensity.

Fig.3 shows the free-running Nd:YAG laser pulse of (75.8mJ) energy and (35μsec) duration , has been obtained by system operating without dye cell.

The Q-switching has been implemented using BDN-I dye with different concentration ,dissolved in many solvents pure and in a mixture of CCl4 with other. These solutions have been modulated in a dye cell inside the resonator . Fig.4 is explained one of giant laser pulse which was generated using Q-switching operation .

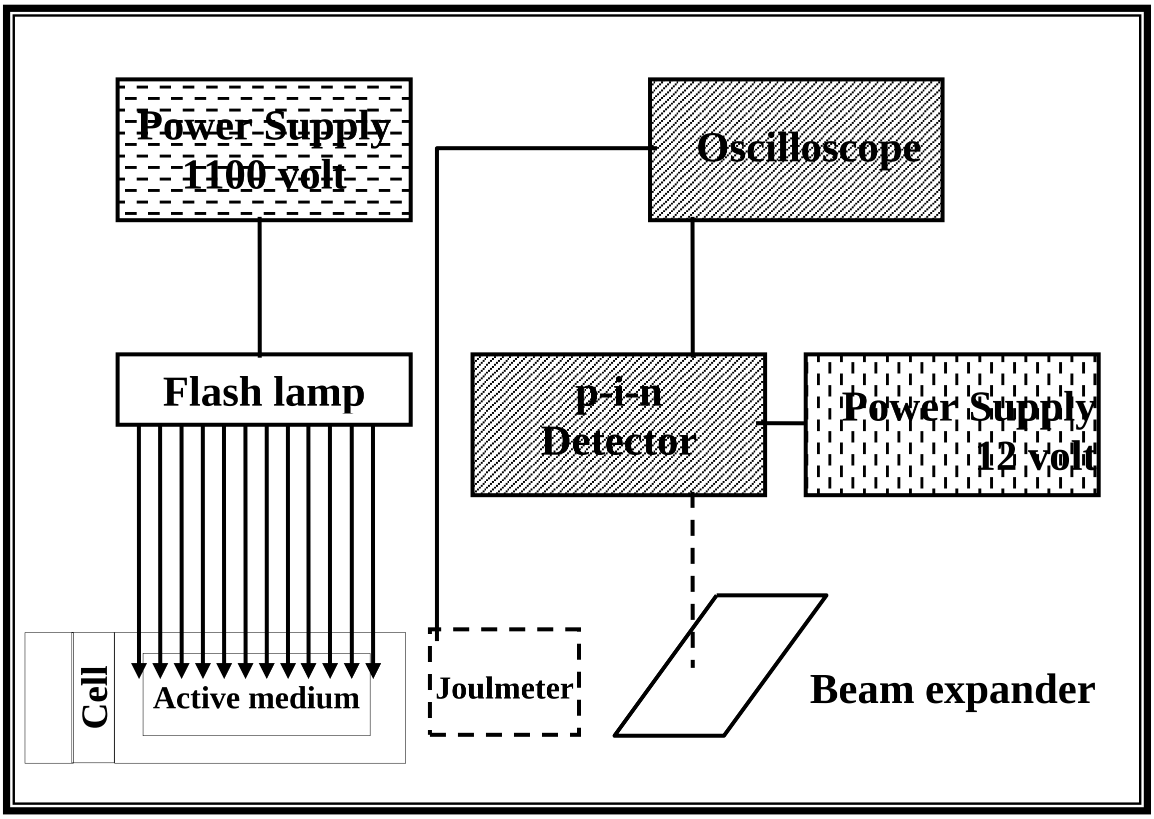

Fig.2 : The experimental setup of a passively Q- switched Nd:YAG laser system.

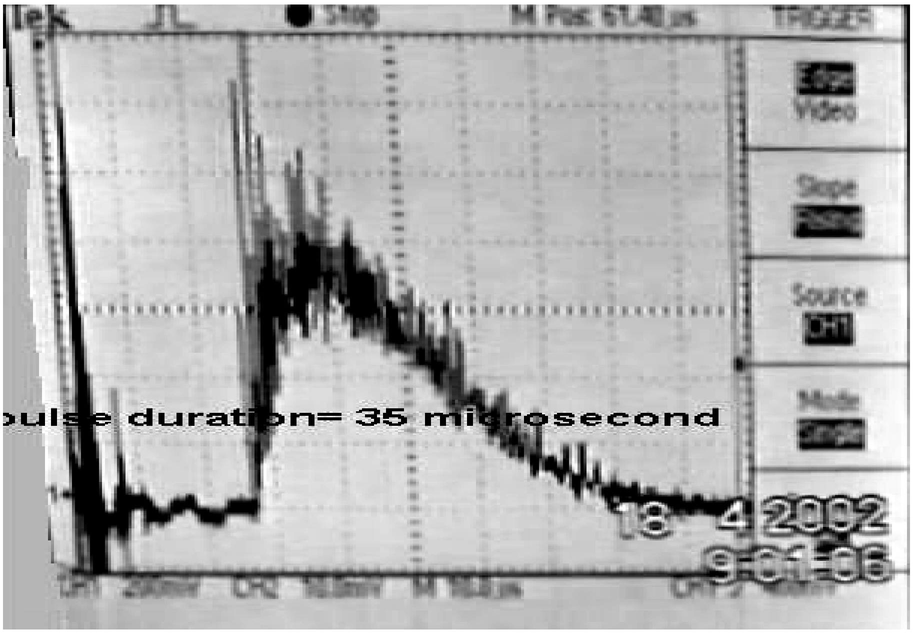

Fig.3: The free-running pulse of Nd:YAG laser

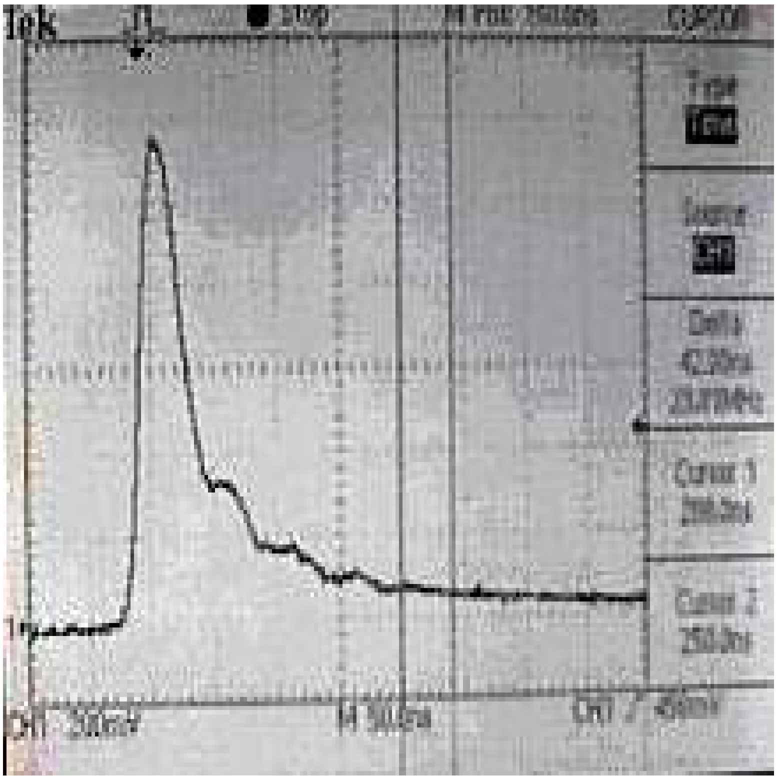

Fig.4 The Q-switched laser pulse _

Calculations and results:

The Q-switched laser pulse power has been calculated according to the energy ,duration measurements . The ground –state absorption cross-section of the dye has been obtained using eq.1 , where Io of (59.3 x 10-3 photons\cm2.sec) , Z of (1mm), while I is experimentally measured . Figs.(5-7) , show the effect of (M) changing on (σ) and Q-switched laser pulse power .

Discussion :

Figs.(5-7) are show the ground-state absorption cross-section (σ) of the saturable absorber (S.A) , and the giant laser pulse power (P) as a fuctions of dye molar concentration (M) ,where we found that (σ) is decreasing ,and (P) is increasing with (M) is increasing for each used solvent ; pure or mixed with CCl_4 at 1:1 and 2:1 mixing ratio . This behavior can be interpreted that the (M) increasing means the ground-state molecules is crowded with them , so the probability of incident photon absorption by one molecule has been decreased . while that this congestion causes delaying for dye bleaching , where the high number of molecules , need more time to absorb and excite to higher states . This explains giant laser pulse power increasing with (M).

The Pyridine solution give highest value of (σ) of (41.83 cm^2) , while(30.48 cm^2 and 26.02 cm^2) ground state absorption cross-section for(Acetone and Chloroform),respectively , are the less value of than Pyridine . Dioxane and CCl_4 have the lowest value of (σ) of (24.542,24.106)cm^2 , respectively , as shown in fig.(5-a,b,c,d,e). Fig.(6-a,b,c,d) explains the mixture of Pyridin at 1:1 has (66.96 cm^2)(σ) ,which is highest value than Chloroform of (66.46 cm^2)and Acetone of (64.70 cm^2), while Dioxane mixture has lowest value of (58.93 cm^2) of (σ) .

We found that Acetone mixture with CCl_4 at (2:1) is highest solution of(106.31cm^2) (σ) than (103.16 cm^2 , 100.37 cm^2 and 96.57 cm^2) of (Chloroform , Pyridine and Dioxane), respectively . As explained in fig (7-a,b,c,d). The dependence of (σ) values on solvent type , can be interpreted according to solvent polarity , where the solvent of lowest value of polarity , gives highest (σ) , and vise, inverse , due to the random of positive and negative charges of such molecule , increases it's probability to absorb the incident photon on it . Pyridine solution was give higher (σ) than Acetone , in spite of the Pyridine polarity has higher value than for Acetone , that are caused by the molecular weight of Pyridine molecule is higher than for Acetone .All the polarity and molecular weight values of solvents are shown in appendix.1[25] , and appendix.2[26,27] , respectively.

The highest values of power are (7.80 , 6.46 and 5.43)X10^5 watt have been obtained using (CCl_4 , Chloroform and Dioxane) , respectively , but Acetone and Pyridine were give (5.35 , 2.3 x 10^5) watt of power , when using it as a pure solvent for dye , as shown in fig.(5-a,b,c,d,e).

The best mixtures of CCl_4 with other solvent at 1:1 mixing ratio , is the Chloroform and Acetone , because they results highest laser power of (4.59x10^5 watt , and 4x10^5 watt) , respectively . Whereas the less power obtained by using Dioxane and Pyridine of (3.92 X10^5 watt) and (2.35X10^5 watt) power , respectively.

The dye solutions of 2:1 CCl_4 with other are contributed in generation highest laser power of (16 x10^5 watt) than Acetone and Pyridine of (12 and 10)x10^5 watt ,respectively . However , Dioxane mixture appeared lowest (σ) than above of (8x10^5watt) .

The laser power behavior according to solvent type ,can be illustrated that the solvent molecule of higher molecular density ,appears higher (P) , and vise inverse , because that this molecule has more electrons which act as an efficient ways to energy transfer inside the solutions of what were realized highest population inversion in active medium and highest laser pulse power was generated . The mixture of Acetone has higher (P) than Pyridine in though the density of second is highest than first , so the electro negativity of (O) atom of (3.5) in Acetone molecule is higher than of (N) atom of (3) electro negativity in Pyridine molecule.

The density values of solvents are shown in appendex.3[27]. We are choosed CCl_4 to mix with other solvent because it is more efficient solvent (has more electrons)than other . The mixing way is the best in the obtaining of higher laser pulse power with the same dye weight in solution .

Conclusions:

To improve giant laser pulse characteristics , we must increase the dye molar concentration . The best dye solutions which act as a liquid passive Q-switch for the laser, is one of lowest value of ground-state absorption cross-section . We are concluded that the mixing solvent with an efficient solvent , is considered as a best way to obtaining higher laser pulse power at same weight of dye . The Pyridine is established as an adequate solvent , because it contributes in higher laser power generation by using less molar concentration of dye when using it .

Appendix . 1 :

The polarity values for used solvents[25]:

solvents		Temperature C^o	Polarity x10 $^{-23}$ cm^3
The name	The formula		
Tetra-Chloro-Carbon	CCl_4	18	11.2 , 10.5
Dioxane	$C_4H_8O_2$	25	10
Chloroform	$CHCl_3$	25	9.5
Pyridine	C_5H_5N	0	7.3
Acetone	C_3H_6O	25	6.33,6.4, 6.39

Appendix.2:

The molecular weight of used solvents[26]:

solvents		Molecular weight
The name	The formula	
Tetra-Chloro-Carbon	CCl_4	153.838
Dioxane	$C_4H_8O_2$	88.104
Chloroform	$CHCl_3$	119.389
Pyridine	C_5H_5N	79.098
Acetone	C_3H_6O	58.087

Appendix. 3:
The density values of used solvents[27] :

solvents		Temperature C^o	Density (gm\ml)
The name	The formula		
Tetra-Chloro-Carbon	CCl_4	15 25 30	1.60370 1.5842 1.57480
Dioxane	$C_4H_8O_2$	20 25	1.03375 1.02687

Chloroform	$CHCl_3$	15 20 30	1.49845 1.4892 1.47060
Pyridine	C_5H_5N	15 30	0.98783 0.97281
Acetone	C_3H_6O	20 25	0.79079 0.78508

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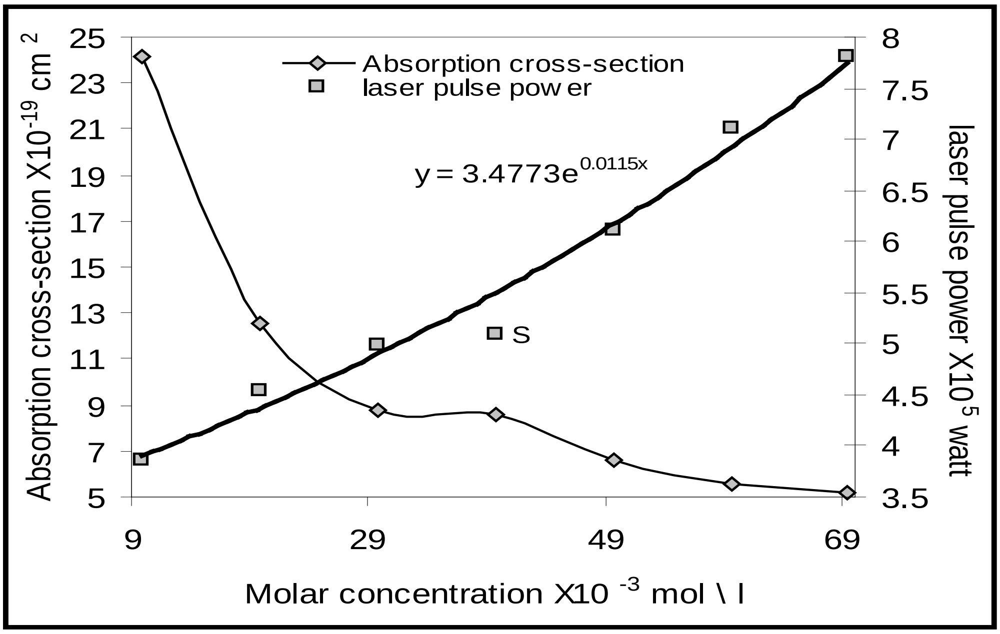
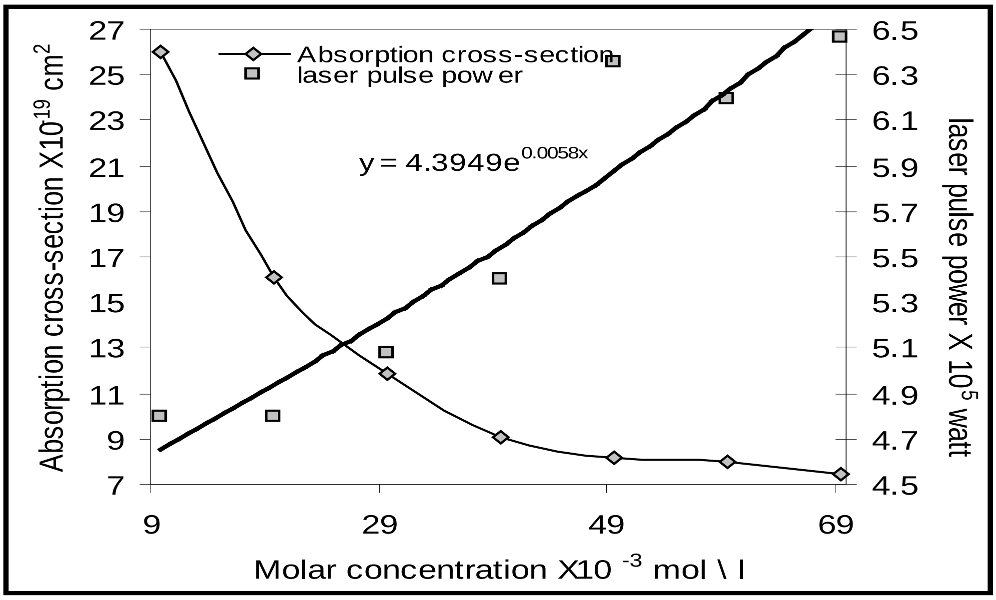
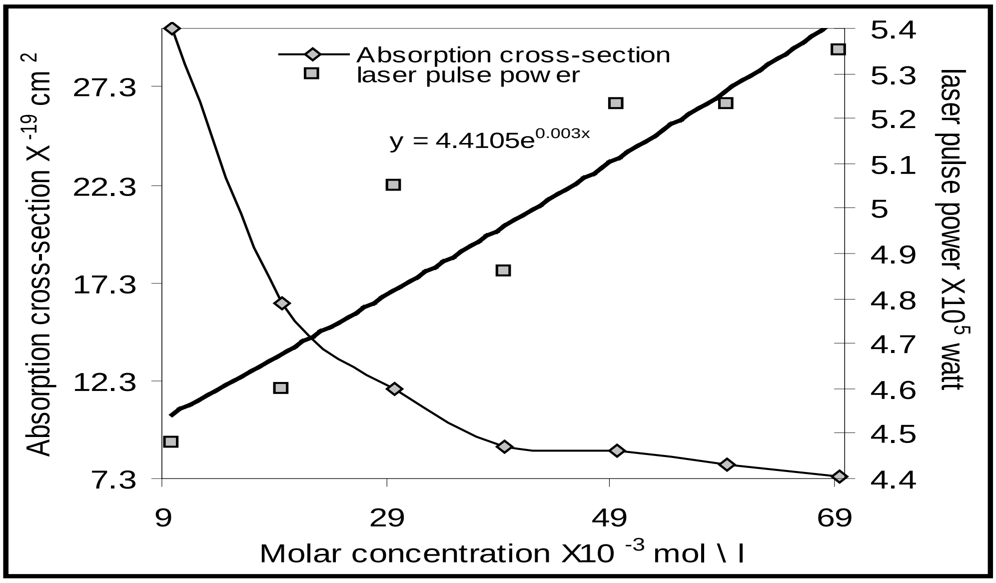

Absorption cross-section
laser pulse pow er
y = 3.4773e^0.0115x
S
25
23
21
19
17
15
13
11
9
7
5
8
7.5
7
6.5
6
5.5
5
4.5
4
3.5
9
29
49
69
Absorption cross-section X10^-19 cm^2
laser pulse power X10^5 watt
Molar concentration X10^-3 mol \ l

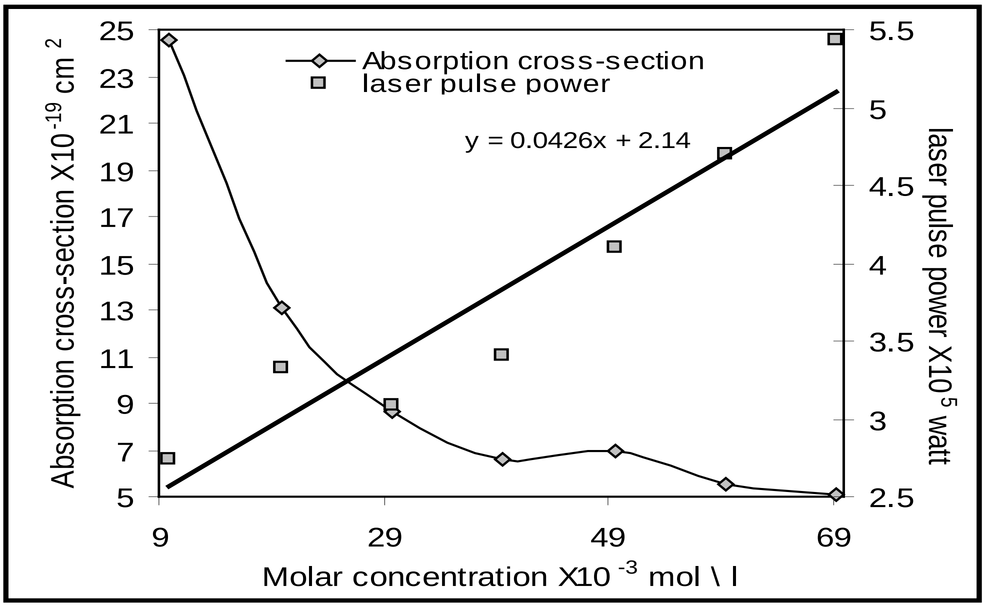
(a)


Absorption cross-section
laser pulse pow er
y = 4.3949e^0.0058x
27
25
23
21
19
17
15
13
11
9
7
6.5
6.3
6.1
5.9
5.7
5.5
5.3
5.1
4.9
4.7
4.5
9
29
49
69
Absorption cross-section X10^-19 cm^2
laser pulse power X 10^5 watt
Molar concentration X10^-3 mol \ l

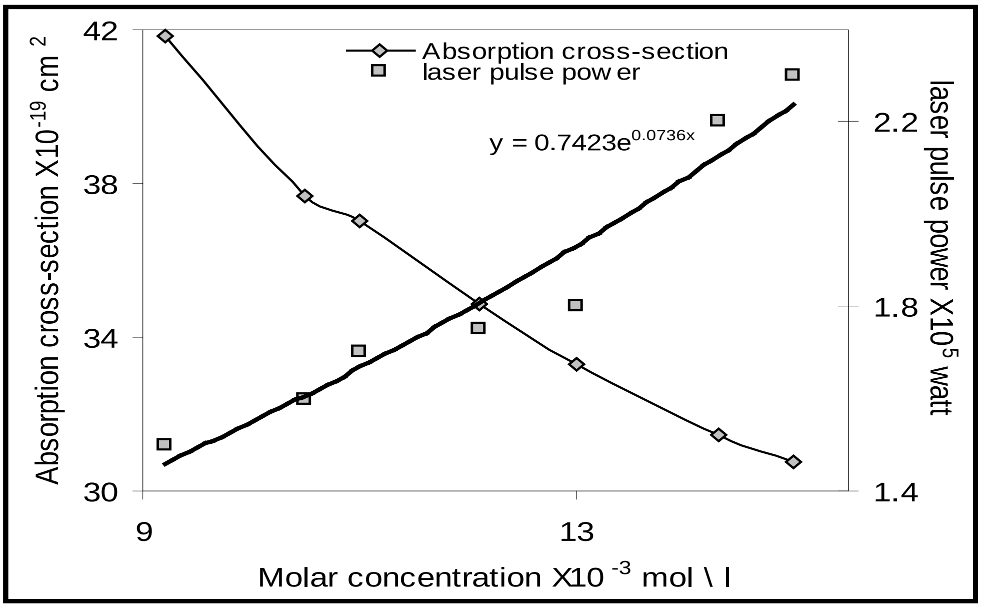
(b)


Absorption cross-section
laser pulse power
y = 4.4105e^0.003x
Absorption cross-section X^-19 cm^2
laser pulse power X10^5 watt
Molar concentration X10^-3 mol \ l
27.3
22.3
17.3
12.3
7.3
5.4
5.3
5.2
5.1
5
4.9
4.8
4.7
4.6
4.5
4.4
9
29
49
69

(c)

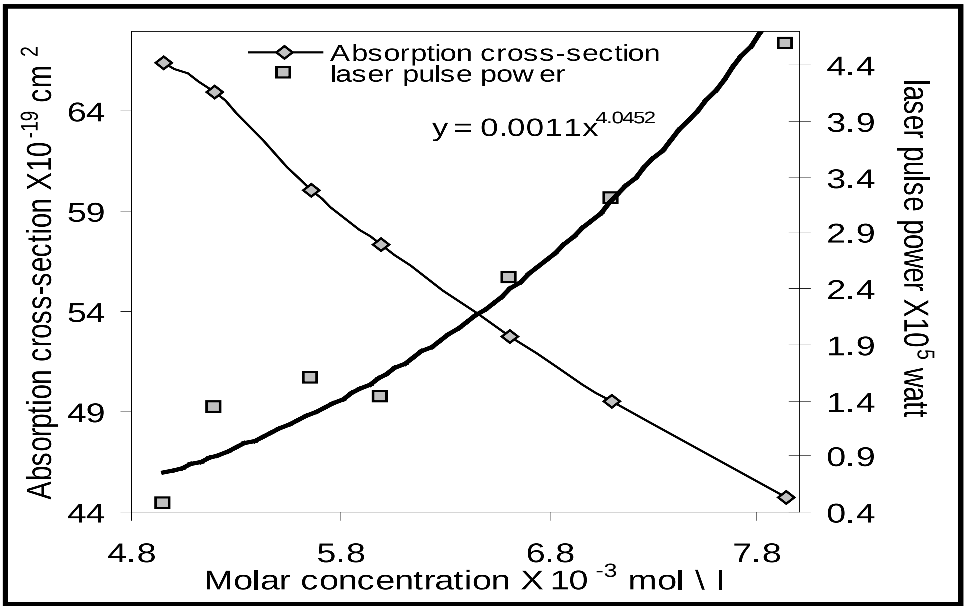

Absorption cross-section
laser pulse power
y = 0.0426x + 2.14
Absorption cross-section X10^-19 cm^2
laser pulse power X10^5 watt
Molar concentration X10^-3 mol \ l
25
23
21
19
17
15
13
11
9
7
5
5.5
5
4.5
4
3.5
3
2.5
9
29
49
69

(d)

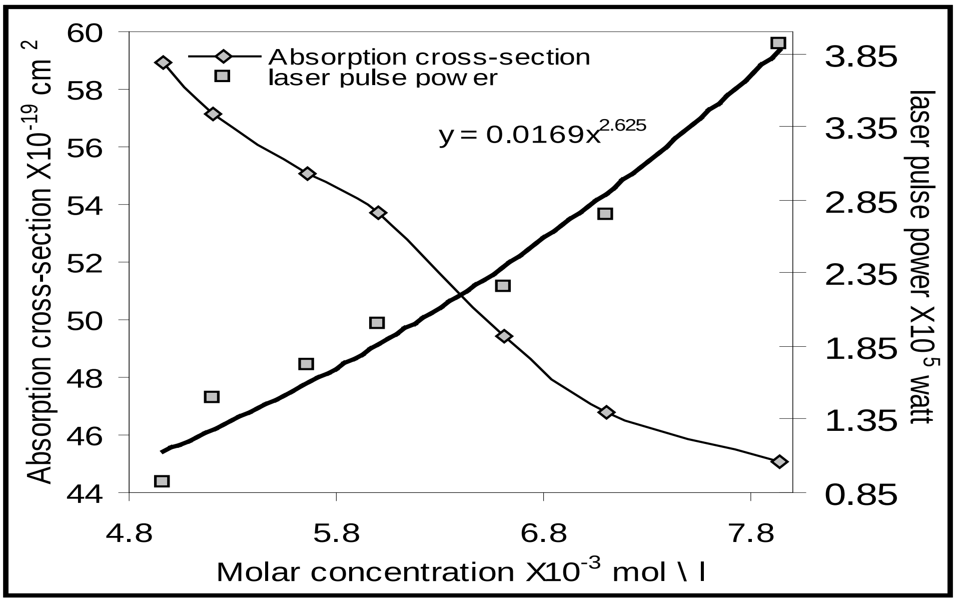


(e)

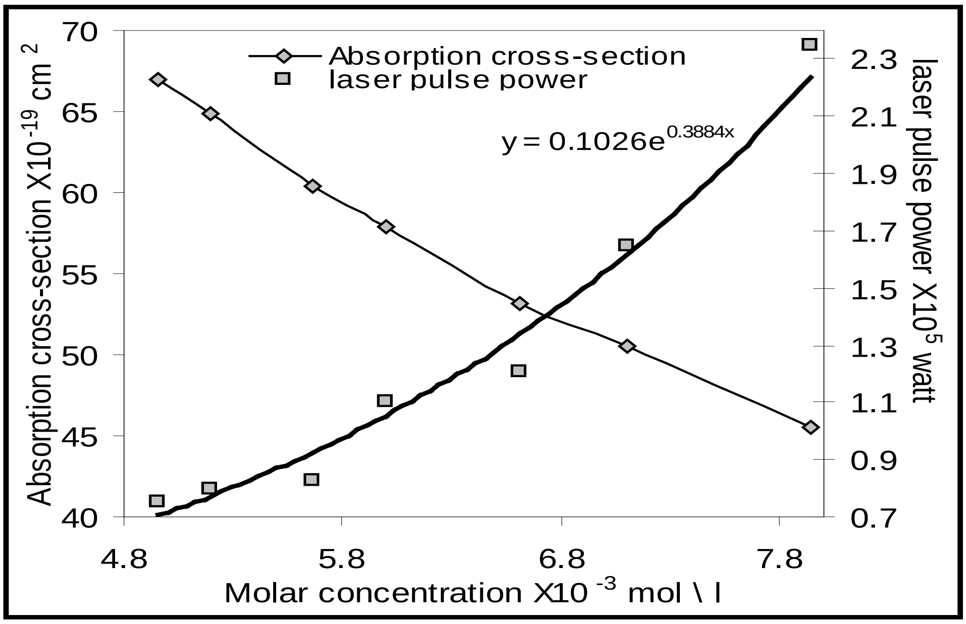
Fig . 5
The dependence of each of absorption cross-section and laser pulse power on the molar concentration of the BDN-I dye when it dissolved in pure organic solvents as :
(a) carbon tetra-chloride
(b) chloroform
(c) Acetone
(d) dioxane
(e) pyridine



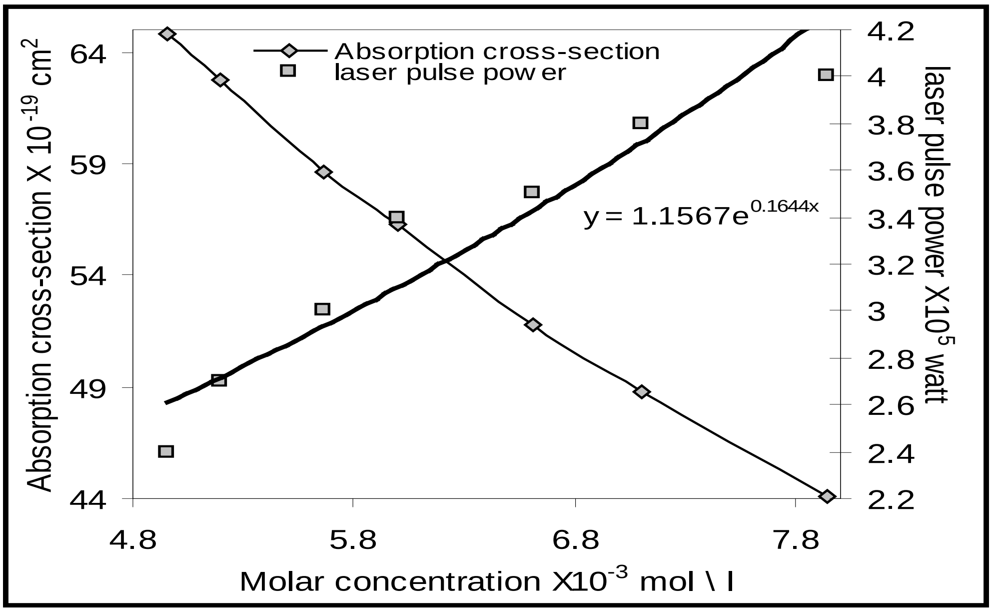
(a)


Absorption cross-section
laser pulse power
y = 0.0169x^2.625
Absorption cross-section X10^-19 cm^2
laser pulse power X10^5 watt
Molar concentration X10^-3 mol \ l
60
58
56
54
52
50
48
46
44
3.85
3.35
2.85
2.35
1.85
1.35
0.85
4.8
5.8
6.8
7.8

(b)


Absorption cross-section
laser pulse power
y = 0.1026e^0.3884x
Absorption cross-section X10^-19 cm^2
laser pulse power X10^5 watt
Molar concentration X10^-3 mol \ l
70
65
60
55
50
45
40
2.3
2.1
1.9
1.7
1.5
1.3
1.1
0.9
0.7
4.8
5.8
6.8
7.8

(c)

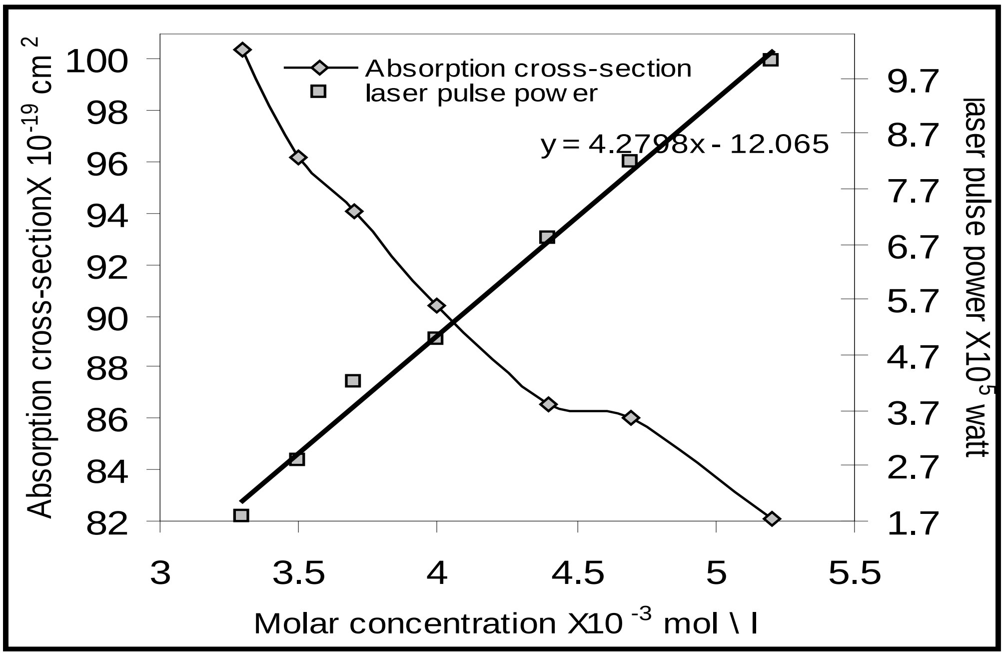


(d)

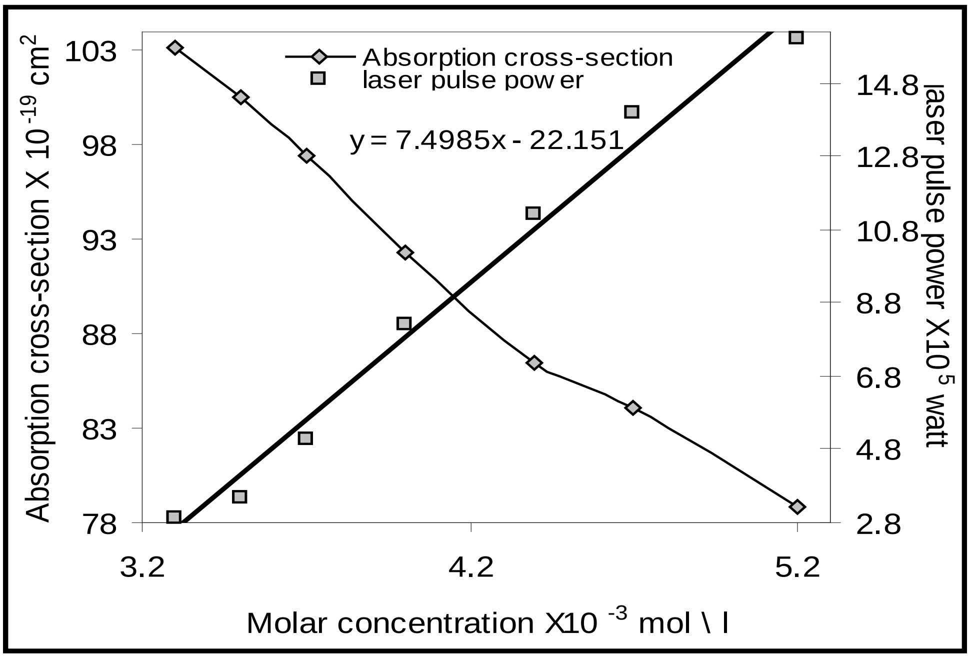
Fig .6

The dependence of each of absorption cross-section and laser pulse power on the molar concentration of the BDN-I dye when it dissolved in a mixture of carbon-tetra-chloride with other solvent at 1:1 mixing ratio as :

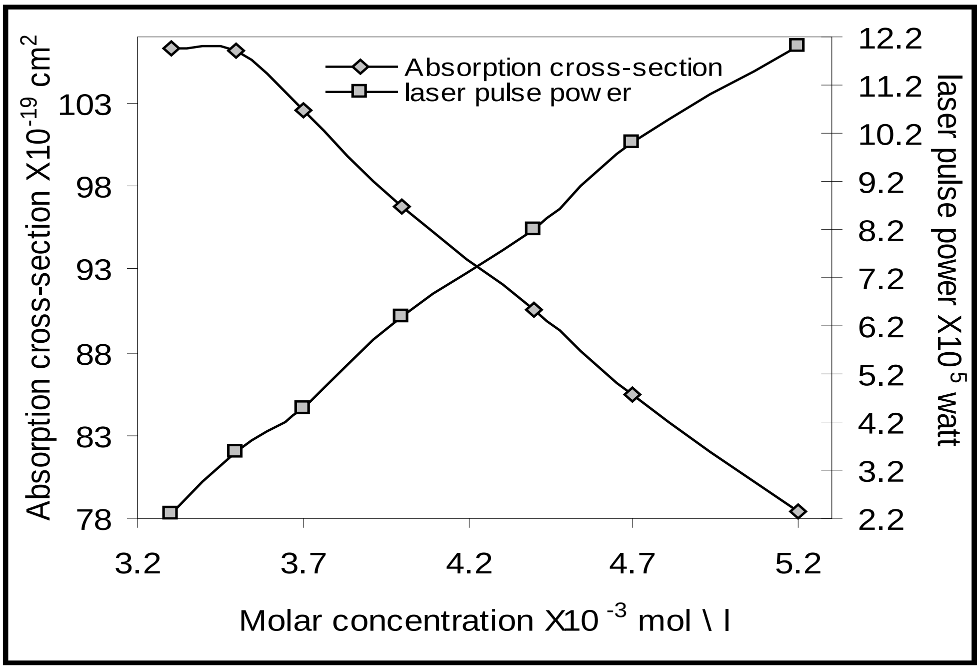
(a) ccl4 + chloroform
(b) ccl4 + dioxane
(c) ccl4 + pyridine
(d) ccl4 + acetone



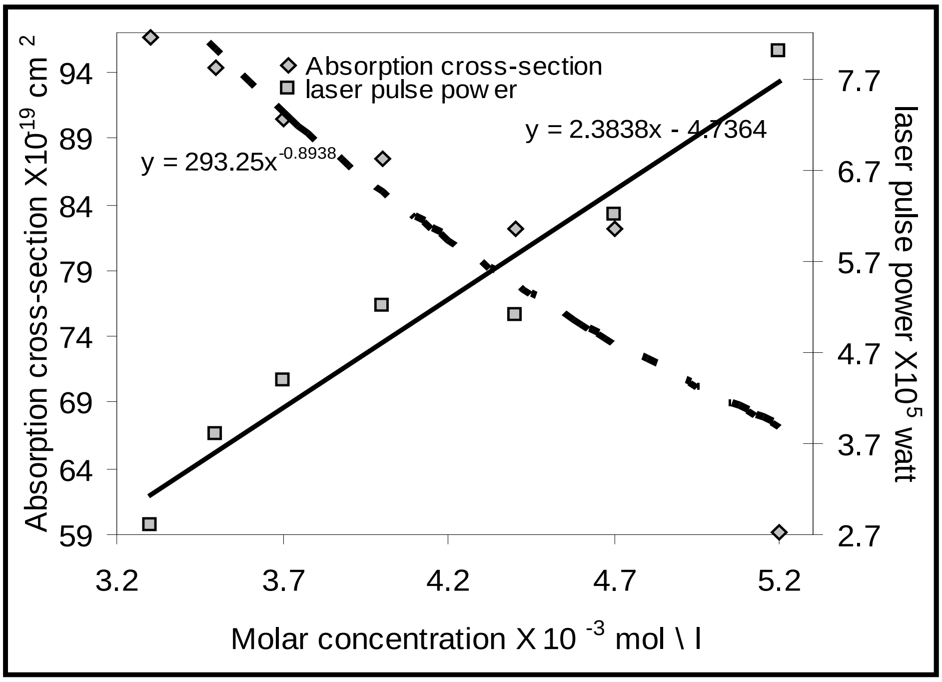
(a)


Absorption cross-section
laser pulse power
y = 7.4985x - 22.151
Absorption cross-section X 10^-19 cm^2
103
98
93
88
83
78
laser pulse power X10^5 watt
14.8
12.8
10.8
8.8
6.8
4.8
2.8
3.2
4.2
5.2
Molar concentration X10^-3 mol \ l

(b)


Absorption cross-section
laser pulse power
Absorption cross-section X10^-19 cm^2
103
98
93
88
83
78
laser pulse power X10^5 watt
12.2
11.2
10.2
9.2
8.2
7.2
6.2
5.2
4.2
3.2
2.2
3.2
3.7
4.2
4.7
5.2
Molar concentration X10^-3 mol \ l

(c)



(d)
Fig.7
The dependence of each of absorption cross-section and laser pulse power on the molar concentration of the BDN-I dye when it dissolved in a mixture of carbon-tetra-chloride with other solvent at 2:1 mixing ratio as :
(a) ccl4 + pyridine
(b) ccl4 + chloroform
(c) ccl4 + acetone
(d) ccl4 + dioxane

تأثير المقطع العرضي الامتصاصي لصبغة BDN-I في قدرة نبضة ليزر Nd:YAG العملاقة

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الخلاصة:

شغلت منظومة ليزر النيوديميوم-ياك عند الخط μ 1.064 . حضرت صبغة BDN-I وأذيبت في عدة مذيبات عضوية قطبية نقية مثل(رابع كلوريد الكاربون ، الكلوروفورم، الأسيتون ، ثنائي الأوكسجين فضلا عن البيريدين) ، وفي مزيج من رابع كلوريد الكاربون مع مذيب آخر بنسبة 1:1 و 2:1 ، كي تعمل كمفتاح نوعية سلبي لليزر النيوديميوم-ياك . قيست طاقة وأمد نبضة التشغيل ألمفتاحي عند تراكيز مختلفة للصبغة مذابة في تلك المذيبات المذكورة أعلاه . حسبت قيم المقطع العرضي الامتصاصي للمستوي الأرضي للصبغة الماصة المشبعة السائلة (σ) عند قيم مختلفة من تركيز الصبغة المولاري (M) . درس تأثير (M) على (σ) وعلاقته بقدرة نبضة الليزر العملاقة الناتجة (P) .إن زيادة (M) تعمل على زيادة (P) وتقلل من قيم (σ) . فسرت نتائج (σ) على أساس قطبية المذيب المستخدم. أما نتائج (P) فقد فسرت على أساس كثافة المذيب المستخدم. تم الاستنتاج ان مذيب البيريدين هو مذيب فعال وذلك لعدم الحاجة إلى تركيز عالي من الصبغة باستخدامه ، ولامتلاك مزيجه (σ) عالي جدا مقارنة مع المذيبات الأخرى . إن الاستنتاج الرئيس هو ان طريقة مزج رابع كلوريد الكاربون مع مذيب آخر وبنسب مزج مختلفة هي طريقة مثلى في تحسين (P) للنبضة العملاقة والحصول على (σ) أعلى للصبغة .