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Generation of Dye (Rhodamine B) Laser by Optical Pumping and Study Its Effect on Solid-State Nuclear Track Detector CR-39

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Abstract: The work includes the study of some optical and physical properties of dye (Rhodamine B) in ethanol solvent at different concentrations ($1x10^{-5}$ - $5x10^{-3}$ mol/l), study and calculate the density and energy of the generated laser and its effect on nuclear track detector. The UV absorption spectra and the emission intensity of the dye fluorescence were determined at different concentrations. The results shows that the peaks of the intensity and wavelength of the absorption spectrum for rhodamine B depends on increasing the dye concentration, leading to increasing the interference between the absorption spectra and fluorescence (emission spectra). Also it was found that, the laser intensity decreased, when the concentration of rhodamine B increased, so we have an optimum threshold for dye concentration .

Keywords: Dye laser, Rhodamine B laser, Nd:YAG laser, Nuclear Track Detector, Ethanol solvent.

INTRODUCTION

The Rhodamine dyes are dyes derived from xanthene, rhodamine 610 was synthesized as early as 1887. Generally they are very efficient and cover the wavelength rang from (500-700) nm [1]. Tunable dye lasers plays an important role in many scientific fields like, laser isotope separation , spectroscopy, medicine and many other applications [2-3]. In 1966, the first organic dye laser was reported. With the rapid developments in laser science, relevant technology and dye laser physics have undergone significant development since then. A major characteristic of liquid laser is, its generation of phase-locked short pulses and broad spectral emission. Also Dye lasers provide the ability of simultaneously multiple wavelengths operation, expandable energy, simplicity versatility usually and would be able to cover a wavelength range amongst (30 & 50) nm. Accurately selecting from over 200 obtainable laser dyes permits the design of tunable dye lasers from (320 - 1200) nm. Dye (liquid) lasers can be operated in CW or pulsed mode, normally optically pumped by flash lamps or other laser [4]. In this research, the (Rhodamine 610) dye laser system is designed to enable us to collect the maximum amount of the generated laser radiation by using two types of mirrors put in two different angles to the Nd:YAG laser pumping line, the 1st mirror was at 45 degree, while the 2nd mirror was vertical. Absorption and emission are very important properties in dye lasers, enabling us to choose the appropriate pumping source depending on the location of the absorption peak. Finally, an experimental study was done for the effectiveness of the emitted pulsed dye laser on CR-39 track detector.

Rhodamine B Dye

One of the xanthene tinctures was used, a Rhodamine B. This dye is in the form of solid green crystals or as a purple-red solution and can be dissolves well in water and alcohol. The Rhodamine B dye has a strong

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absorption range in the visible area and is excited by optical pumping. Typical energy levels in dye lasers consist of two types of electronic levels (single-link electronic levels) (S0, S1, S2) and other three-link electronic levels (T1, T2) because each of these levels is in the form of a broad beam that includes vibratory and rotational levels , when the active medium is pumped, the dye molecules travel from The stable level (S0) to the first excited electronic level (S1), meaning that these atoms will absorb energy, and as a result, a process of irritation of the liquid atoms will lead to the transfer of these atoms to the higher levels. It is worth noting that the wavelength of the emitted laser beam depends primarily on the starting point of the falling of the particles from the level S1 to the point of stability of the electronic levels (S0, S1) see fig. (1) [5] . Rhodamine dyes are used as an active medium for laser radiation in the visible region of the light spectrum. The molecular formula of Rhodamine B (RB) is $\mathbf{C_{28}H_{31}ClN_2O_3}$ with molecular weight of 479.02 gm/mol. Rhodamine dyes are used extensively in biotechnology applications such as fluorescence microscopy, fluorescence correlation spectroscopy. RB is tunable around 610 nm when used as a laser dye. In addition, the chemical structure of Rhodamine B is reported in Fig. (2) [6].

Nuclear Track Detector (CR-39)

It`s one of the most frequently used of Solid-State Nuclear Track Detectors (SSNTDs) and it`s a thermoset plastic made by polymerization of the allyl di glycol carbonate monomer [64], this polymer have chemical composition $\mathbf{(C_{12}\ H_{18}\ O_7)}$[7-8]. It`s molecular weight 274.27 g/mol, density 1.32g.cm^{-3}, refractive index n=1.504, and ionization potential I=1.702.2 eV. This detector is characterized homogenous, isotropic, visually transparent, high purity, insoluble and infusible except if the chemical bonds are broken, and the main reason for the high sensitivity of the detector is the presence of carbon bonds in the polymer CR-39 where it is weak and break easily when exposed to radiation. It is also has a low detection threshold as a result of the features of this detector, it has been used in many applications, such as measure radon and thoron concentrations in building materials, indoor building, water, soil, food and agricultural materials[8].

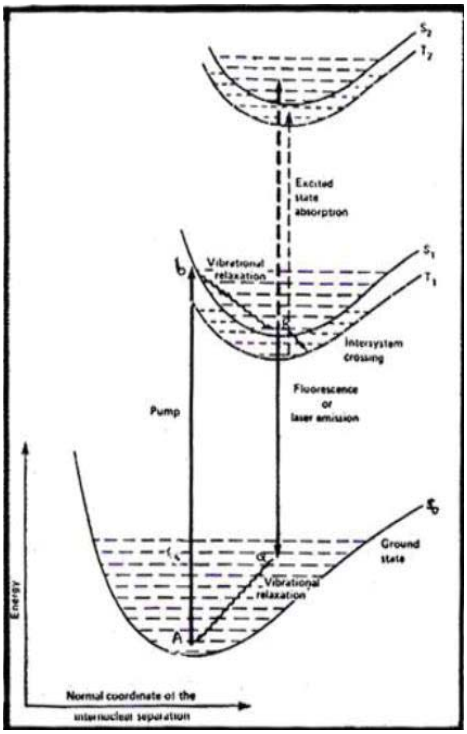


FIGURE 1. scheme energy levels in the dye laser [5]

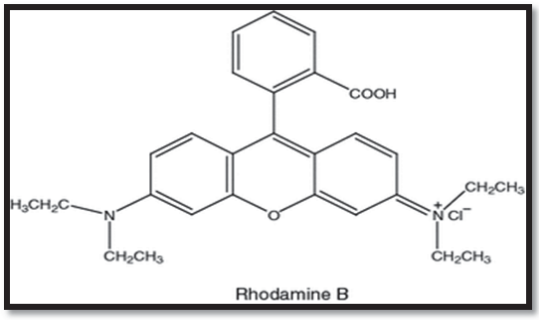


FIGURE 2. Chemical structure of Rhodamine B.[6]

EXPERIMENTAL PROCEDURE

Materials

The materials used in this research are shown in table (1)

TABLE 1. Materials and their specifications.

Materials	Specifications	
RB dye	Constitution	2-[6-(Diethylamino)-3-(diethylimino)-3H-xanthen-9-yl] benzoic acid-Rhodamine 610
	Moleculare formula	$C_{28}\,H_{31}\,Cl\,N_2\,O_3$
	Moleculare weight	479.02 g/mol
	Color	Appearance when buying: green, Crystalline solid Appearance when diluted with ethanol solvent: red and its gradients Appearance when pumping: orange
	$\lambda_{Abs\ (max)\ \&}$ in ethanol	550 nm
	$\lambda_{Flu\ (max)}$ in ethanol	625nm
SSNTD	Type Detector	CR-39
	Thickness & Density	1.5 mm & 1.32 g/cm3
	Color	White transparent
	Chemical composition	**$C_{12}\,H_{18}\,O_7$**
Ethanol	Molecular formula	C_2H_5OH
	Appearance & Purity	Colorless liquid & 99.9%
	Molar mass	46.07 g / mol
NaOH	Form , Color & Molar mass	Pellets , White or waxy & 39.9971 g/ mol
	Other names	Caustic soda, Lye , Ascarite ,White caustic and Sodium hydrate
	Odor & Density	Odorless & 2.13 g/cm^3

Preparation of Dyes by Using Solvents

To prepare rhodamine B or any other dye, one must follow the steps below: **1. The first step is to weigh the dye material using a sensitive scale (up to 4 digits) ,** Then the dye is dissolved by using ethanol solvent with purity (99.9%) or any other suitable solvent (DD H_2O, methanol, acetone,..) in the required size of a glass flask. According to the prepared concentration one can obtain the mother sample according to the following relationship [9]:

$$\mathbf{W = M_w .V. C /1000} \qquad (1)$$

W: The weight of the dye to be prepared (R_B=0. 5988 gm).

$\mathbf{M_W}$: The molecular weight of the dye to be prepared (RB M_W = 479.02 gm/mol).

V: Solvent volume (250 ml).

C: Molar concentration of the mother pigment to be prepared (C.RB = $5X10^{-3}$ mol/l).. **2.** After preparing the mother sample (In the liquid state of the dye), the solution is shaken and we consider it as the first concentration solution, and the second concentration solution is withdrawn from it, which will be drawn from the third concentration solution and thus we continue the dilution process,.. according to the dilution relationship [10]:

$$C_1 V_1 = C_2 V_2 \quad (2)$$

C_1 Primary Focus (High), C_2 second focus (low), V_1 first volume before dilution and V_2 second volume after dilution (volume of beaker to be prepared). In this research, concentrations (10^{-3} -10^{-5}) were selected according to the previous studies of Rhodamine B dye.

The Dye Laser Setup

The dye laser setup shown in Fig. 3. The pumping source is a second harmonic generation (SHG) of Q-switched Nd: YAG laser operating at 1064 nm with repetition rate of 10 Hz . The dye laser generation system is simply composed of a lens that collects Nd:YAG pumped laser beams on the liquid dye that is placed in a rectangular quartz glass container, its dimensions . Two mirrors were used to collect the generated laser from the dye material, the first is a concave mirror placed perpendicular to the optical pumping axis and the second an ellipse mirror placed at an angle of about 45 degrees with the optical axis, the mirrors were placed opposite to collect the largest amount of generated radiation.

All parameters of the dye laser have been studied, such as the absorption spectrum and the emission spectrum (fluorescence) for all concentrations used in this research. Also, the generated dye laser spectrum by using a specialized spectrum analyzer (550 nm) from (Ocean Optics co.) has been recorded, and the pulses of both, the pumping laser and Laser dye were also recorded .

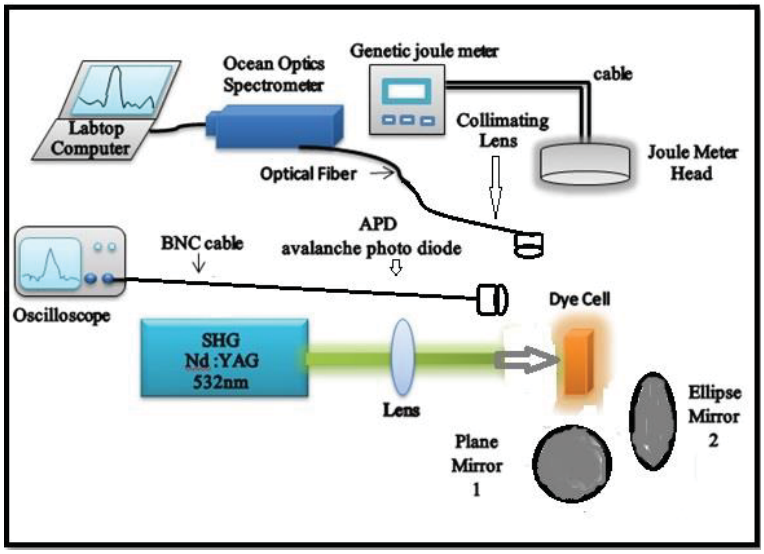


FIGURE 3. shows dye laser generation setup.

RESULTS AND DISCUSSION

The absorption and fluorescence spectra of the dye rhodamine 610 with concentrations ($1x10^{-5}$ - $5x10^{-3}$) mol/l, are shown in the fig. (4), where the fluorescence spectrum shifted to longer wavelength (red shift) with increasing the concentration and the absorption spectrum shifted to short wavelength (blue shift) and this corresponds to Beer - Lamberts law, which states that the amount of light absorbed is proportional to the number of particles absorbed to it and to the concentration of the medium along the path. Table (2) shows the absorption, fluorescence λ_{max} (nm), absorbance, intensity and stock shift at different concentrations. Fig. (4) shows that the dye (RB) absorption spectrum has a wide spectral range at wavelength range between (530-550) nm . The absorption and fluorescence shift for samples are shown in Fig. (4). Concentration affects the energy state where the higher the concentration the more particles per unit volume. When the concentration increases, the Stokes shift will increase, and this will decrease the overlap between the emission and absorption spectrum and this case reduce self-absorption process observed table (2) and fig. (4). With an increase in the concentration of the dye rhodamine 610, the width of the absorption curve increases and the width of the emission curve decreases see fig. (4). Fig. (5) (A) shows that, the increasing in concentration will cause a shift in the fluorescence wavelengths duo to the forming of the excimer molecules or dimmer molecules in solution, collision diffusion processes, leading to a decrease in the quantum efficiency, since its fluorescence causes a shift towards the longest wavelength of the (red shift) at (550) nm, the change in the concentration of rhodamine B affects the fluorescence spectra as shown in fig.(5)(B). Fig.(3) shows, when the input pumping energy increased, the output energy also increased, which especially designed to produce high output power and short time period to build the pulse, in addition to that the dye laser has a highly transformative efficiency, therefore a short pulse can be obtained from it as shown in fig.(6).These dye laser pulses can reach the nanoseconds and the picoseconds, however, the lasers are “open” systems and can be used differently for the absorption measurements. The dye laser pulse at concentration ($4X10^{-5}$) mol/l is shown in fig.6. The effective dye concentration was ($4x10^{-5}$) mol /l, while the intensity, wavelength, energy and bandwidth of the emitted laser was shown in table (3) and fig.7. The dye emissions were collected from the side of the container (cuvette) using a collecting fiber and spectrally analyzed using a spectrometer (0-1100 nm).

TABLE 2. The stock shift between fluorescence and absorption of RB at different concentrations

Fig.4	Dye concentration (mole/l)	Absorption λ_{max} (nm)	Abs.	Fluorescence λ_{max} (nm)	Intensity (a.u.)	Stock shift (nm)
A	$1x10^{-5}$	550	0.871	565	999.9491577	565-550=15
B	$2x10^{-5}$	545	1.607	562	999.9802246	562-545=17
C	$4x10^{-5}$	545	2.467	562	1000.020691	562-545=17
D	$1x10^{-4}$	530	3.015	586	982.5301514	586-530=56
E	$5x10^{-4}$	530	3.074	604	353.5133667	604-530=74
F	$1x10^{-3}$	530	3.125	610	129.1325684	610-530=80
G	$5x10^{-3}$	530	3.275	625	82.03205872	625-530=95

TABLE 3. The maximum wavelength of absorption and fluoridation with the shift Stokes.

Fig.4	Dye concentration (mole/l)	Absorption λ_{max} (nm)	Fluorescence λ_{max} (nm)	Stock shift (nm)
A	$1x10^{-5}$	550	565	15
B	$2x10^{-5}$	545	562	17
C	$4x10^{-5}$	545	562	17
D	$1x10^{-4}$	530	586	56
E	$5x10^{-4}$	530	604	74
F	$1x10^{-3}$	530	610	80
G	$5x10^{-3}$	530	625	95

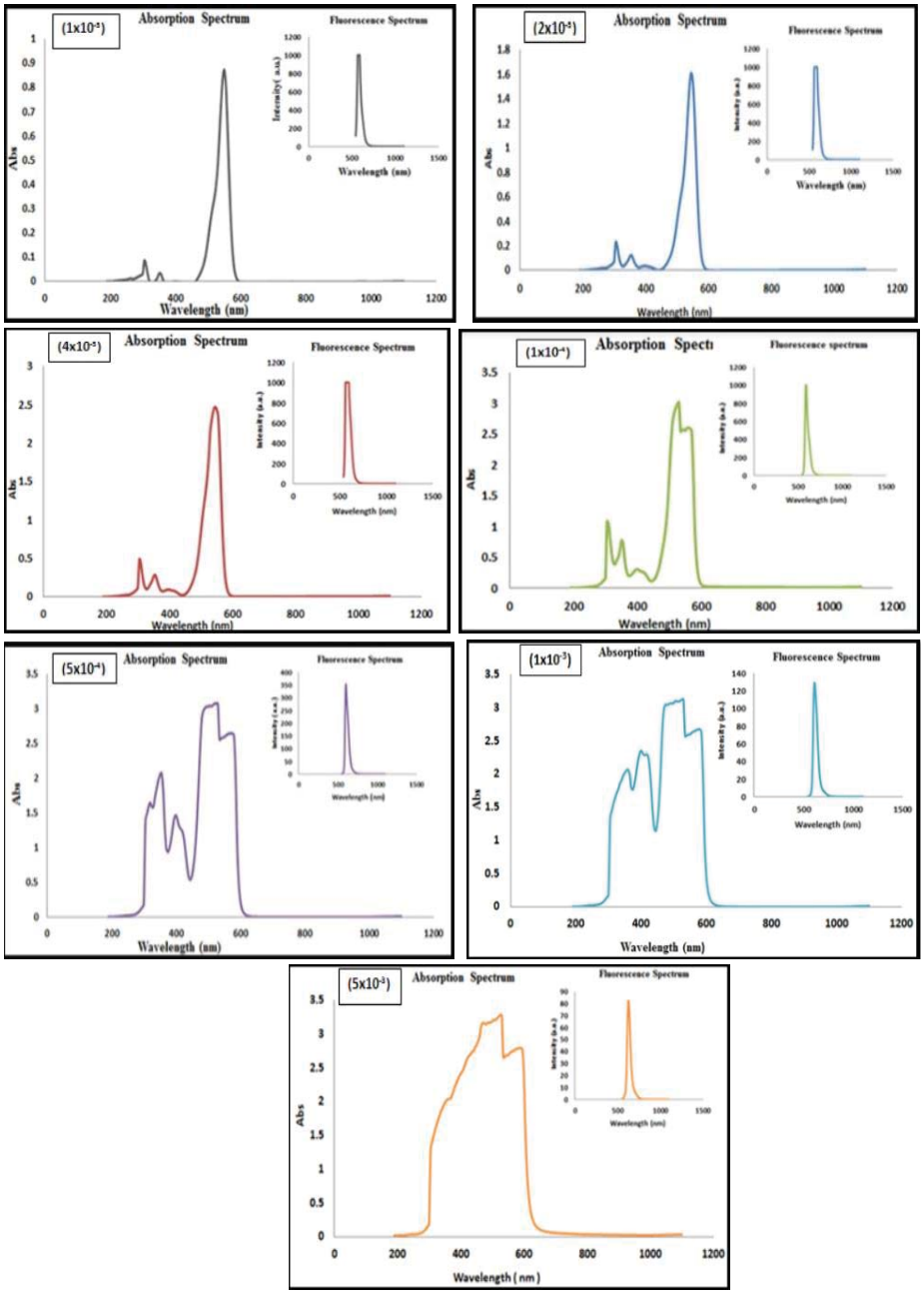


FIGURE 4. Draw the absorption and fluorescence spectrum at different concentrations.

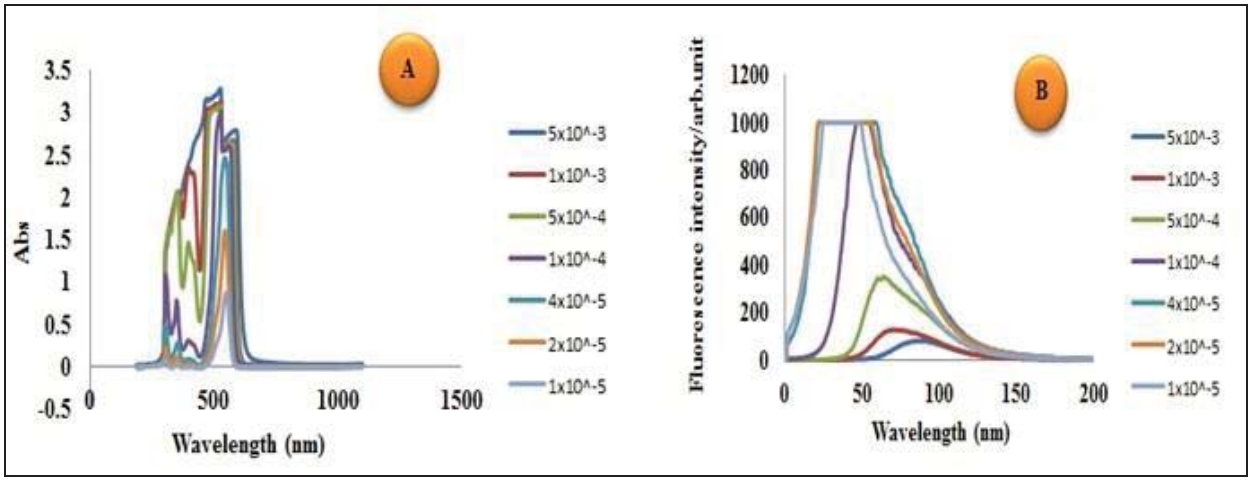


FIGURE 5. All absorption and emission measurements of the dissolved RB dye in ethanol at different concentrations.

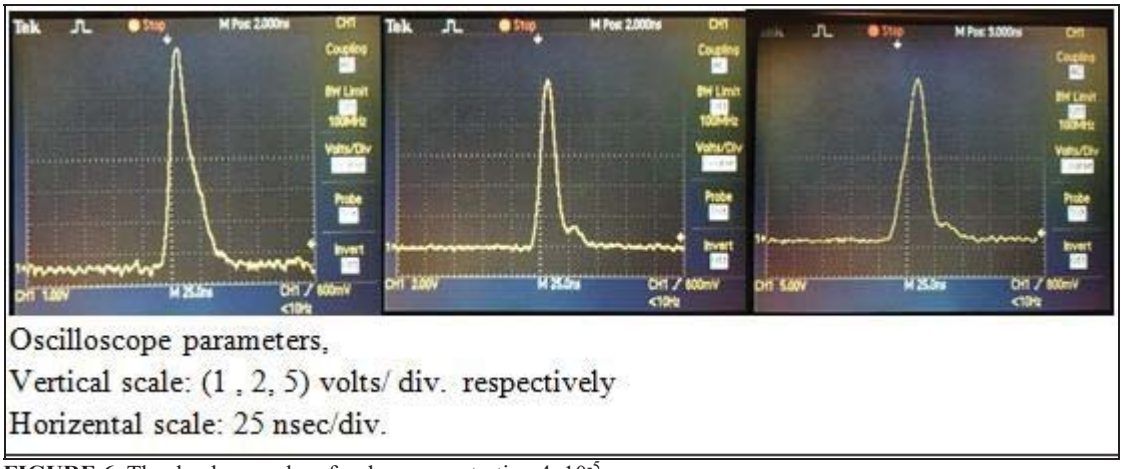


FIGURE 6. The dye laser pulses for dye concentration $4x10^{-5}$.

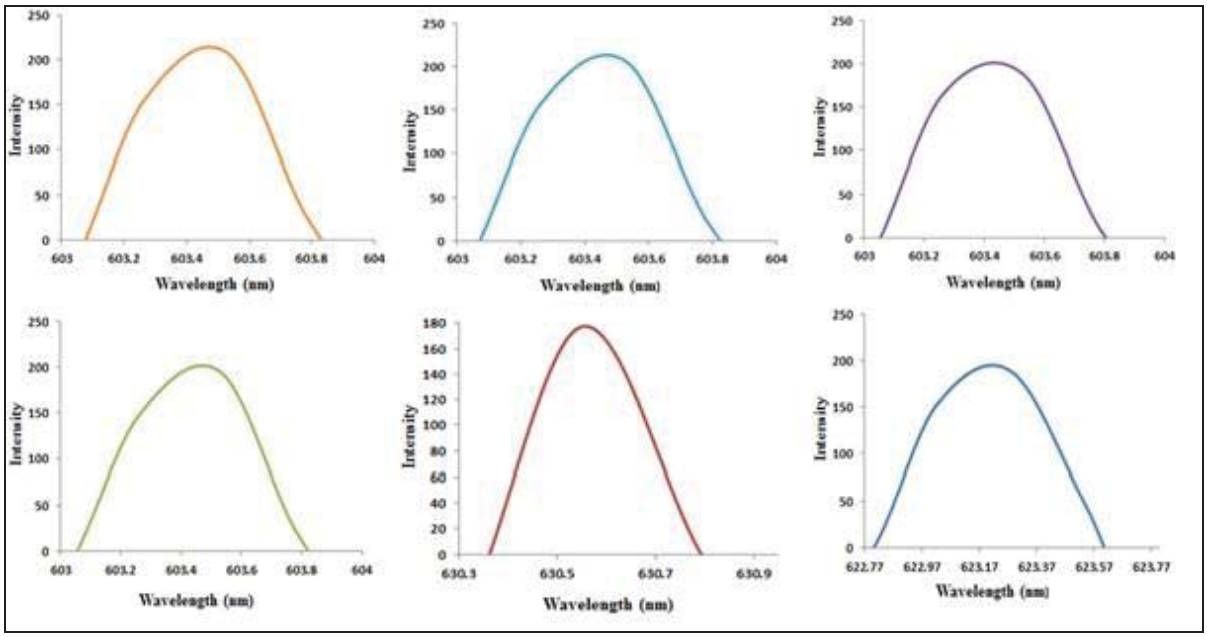


FIGURE 7. Graphics shows the output RB dye laser at concentration ($4x10^{-5}$) mole/l.

The Properties of Track detector (CR-39) Irradiated by Dye Laser

This work study the effect of dye laser on CR-39 track detector for a specified period and also including the optical properties for it.

a. Before Irradiation

Solid-State Nuclear Track Detector (SSNTD) is a special type of radiation detector, which generally used to records tracks of heavy charged particles ($Z \geq 1$) in insulating or dielectric solids. This type of detector has the ability to store the effect of ionizing radiation for a relatively long period of time in the form of damage to its internal structure, which can be seen by optical microscopy and by chemical etching method, and the damaged areas tracks can be seen by optical microscope. It is clear from fig.(8), which shows the image of the detector before irradiation by dye laser. One can notice from electron microscope photos in table (5), that there is no tracks in the detector, because there are no interaction of any type of radiation affected the CR-39 detector.

FIGURE 8. Detector CR-39 before irradiation.

b. After Irradiation

In this work, a CR 39 detector with a thickness of 1.5 mm was used, the detector sheet was cut into a number of pieces with a dimension of 1 x 1 cm. The time of irradiation by the dye laser was about 3 minutes in the air to see the laser effect on the detector, as shown in fig. (8). The medium can`t absorb all the laser energy but only weakens its intensity . The track detector medium cannot absorb all the laser pumping energy but only weakens its intensity. The influence of the laser on the detector material and transformation processes happen with increase of the absorbed laser intensity. Then atomic displacements and excitation of phonons, due to transformation into plasma, and interaction of laser radiation with plasma all this dependent on, the laser interaction with detector material at different range of intensities, laser pulse duration, the time scale of energy relaxation processes such as the electron-to-lattice energy transfer, heat diffusion and hydrodynamic motion. Also on some material specifications, like, ionization, temporal distribution of intensity and the detector material geometry, the detector track will increase when the laser energy increased, as shown in table (5) [11]. The effect of dye laser on the CR-39 detector was studied by two methods, the first method (UV method) the detector was examined by a UV-Vis Spectrophotometer (Labomed, Inc. American), all its output information are shown in table (4), while the second method (Etch chemical method), where the (track) detector was examined by a microscope and all the output information are shown in table (5). There are also factors specific to the detector, like the abrasive solution NaOH and others that affect the sensitivity of nuclear detectors such as, the purity of the monomer, the molecular structure of the polymer, the polymerization conditions as well as the resistance to oxidation. Some of these factors may be before, during or after irradiation of the charged particles, some of which lead to improvement of each of the conditions etching and the sensitivity of nuclear detectors .The effect of radiation on polymers is their dissolution and this type of reactions broken the chemical bonds between the atoms in the main strings of the polymer leading to a loss of its elasticity, compliance, or

strength of its structure and reduces its molecular weight. Certain physiological changes that occur in the polymer molecule as a result of radiation lead to discoloration, absorbance, or insoluble products or interlocking product.

TABLE 4. Properties of CR-39 Detector Irradiated Laser (UV method).

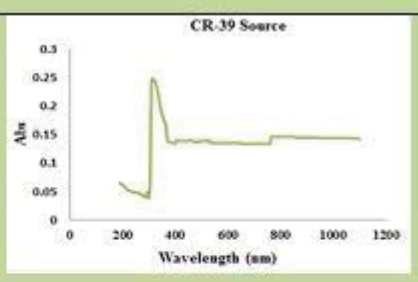
Type detector	CR-39	Image for CR39 without laser dye
Thickness	1.5 mm	
Concentration	$4x10^{-5}$	
Time of irradiation	3 min	
Product laser energy	11.5 mJ	
Product laser source	Nd:YAG with RB	
Absorbance for CR-39 with Nd:YAG laser	0.241	
Absorbance for CR-39 with Nd:YAG with RB laser	0.076	
λ max (nm) for CR-39 with Nd:YAG laser	325	
λ max (nm) for CR-39 with Nd:YAG with RB laser	310	

Image for CR-39 with laser dye

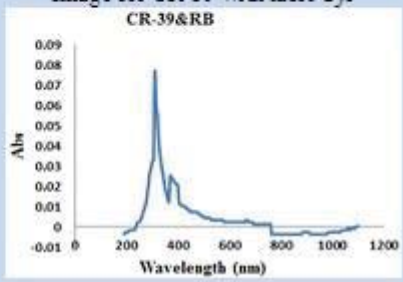
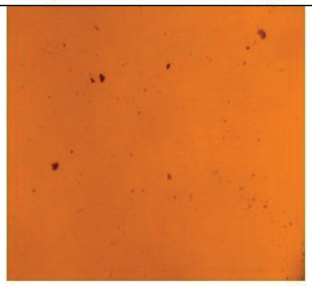


TABLE 5. Properties of CR-39 Detector Irradiated with Laser product (Etch method).

Type detector	CR-39	Image before skimming	Image after skimming
Thickness	1.5 mm		
Concentration	$4X10^{-5}$		
Time of irradiation	3 min		
Product laser energy	11.5 mJ		
Skimming temperature	70°C		
Product laser source	Nd:YAG with RB		
Time for skimming	3 hours		
Solution	NaOH		

CONCLUSIONS

In order to reach a high-efficiency laser resonator with in visible and ultraviolet rays and understanding of the behavior of bandwidth dye lasers created with RB dye and to allow others to use the behavior characterized to make a laser of thier desired characteristics. We studied the effect of the interaction of these beams laser on the detector CR-39. bandwidth is very sensitives to small changes in intensity. In the time domain (laser), a pulse has light energy that can only be estimated over a short period of time close to zero. .Define the pulse duration, as the full width at Half maximum "mid-height"(FWHM), That is, the width of the interval in which the power is at least half the peak power .The pulse shape (energy versus time)often has a relatively simple shape,

described as a Gaussian function, so the short pulse duration pulse energy, and wavelength makes the light pulses of lasers very interesting, in many applications, such as communications or ultra-measurements. Precision of all kinds, and the high spatial coherence of these laser beams allows focusing laser pulses on very small spots, sometimes with areas less than 1 micrometer. The combination of a small spot size and a short pulse duration results in very high laser optical intensity, even in the pulse energy is moderate. Deposition of energy with extremely high concentration in poth space and time is essential for applications in material processing, where ultrashort pulses have the advantage of creating a very small area affected by heat around the cutting area. We deduced from the effect of laser beams on the detector-CR39 that laser beam, the thermal effect on the detector CR-39 is the predominant, and the color change leads to redness (tends to burn) so we did not notice the effect on the detector CR-39.

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