Linear and Nonlinear Optical Properties of the Dye Laser (Acridine Dye)

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ABSTRACT

The spectral characteristics and the nonlinear optical properties of the laser dye acridine has been determined. The spectral characteristics are studied by recording their absorption and fluorescence spectra. The nonlinear optical properties were measured by z-scan technique, using Q-switched Nd: YAG laser with 532 nm wavelength. The results showed that the optimum concentration is responsible for increasing the absorption and the emission bandwidth to full range by the energy transfer process, also the efficiency of the process was increased by increasing the concentration. The obtained nonlinear properties results of the acridine dye showed a negative nonlinear refractive index and tow photon absorption. All the nonlinear optical parameters are linearly dependent with concentration. The origin of optical nonlinearity in the dye may be attributed to laser-heating induced nonlinear effect.

Keywords: Nonlinear optics; concentration effect; Z-Scan technique

INTRODUCTION

There is considerable interest in understanding the optical nonlinearities of dyes for widespread applications. Dye molecules are used mostly to generate tunable laser sources and optical shutters, optical signal-processing devices [1,2], two-photon microscopy[3], up conversion lasers [4,5], optical limiting [6,7], optical data storage[8,9] and three-dimensional micro fabrication[10]. The basic absorption processes in dyes could be divided into: 1) linear absorption; 2) saturation of absorption (SA) and 3) reverse saturable absorption (RSA). Saturation of absorption is vital for use of the dyes in mode-locking. The most important application of RSA is for optical limiting devices that protect sensitive optical components, including human eye, from laser-induced damage [11,12,13]. Laser dyes, either as solutions or vapors, are the active medium in pulsed and CW dye lasers as well as ultrafast shutters for Q-switching and passive mode-locking. They emit in a comparatively narrow spectral region (typically 30 nm); thus a variety of dyes is necessary to cover the entire (visible) spectral range [14]. Laser dyes are promising compounds for nonlinear optical applications because they exhibit strong nonlinear-optical behavior. Materials with nonlinear optical properties are under investigation due to their applications in optical communications, image processing, switching, 3D data storage and optical limiting [15].

Acridine is separated from coal tar by shaking out with dilute sulfuric acid, and then precipitating from sulfuric acid solution with potassium dichromate. The resulting acridine dichromate is decomposed in the final step by ammonia. Acridine and its homologues are stable compounds of weakly basic character. Acridine has a pKa value of 5.6, similar to that of pyridine. The synthesis of acridine and analogues hasattracted considerable attention from organic and medicinal chemists for many years, as a number of natural sources have been reported to have this heterocyclic nucleus. Chemically, acridine is an alkaloid from anthracene. It is also known by the names of dibenzopyridine, 2,3,5,6-dibenzopyridine and 10- azaanthracene. Acridine has an irritating odor. It crystallizes in colorless to light yellow needles with melting point of 110C and boiling point of 346C. It is characterized by its irritating action on skin and by the blue fluorescence showed by solutions of its salts [16].

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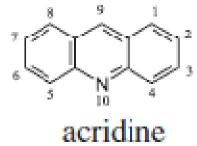

Fig. 1: Acridine dye structure

The z-scan technique can be used to obtain the nonlinear absorption coefficient and the sign and magnitude of refractive index. This technique is an increasingly popular method for the measurement of the nonlinear absorption coefficient (*β*) and the nonlinear refractive index (n_2) of the samples. It has many advantages like simplicity, high sensitivity, quick and other advantage [17].The objective of this work is to study the absorption and fluorescence spectra of acridine dye at different concentrations also measuring the nonlinear optical parameter of this dye z-scan experiment at 532 nm.

EXPERIMENTAL METHOD

Five concentrations were prepared for acridine dye. The concentrations are $1x10^{-3}$ M , $5x10^{-4}$ M , $1x10^{-4}$ M , $5x10^{-5}$ M ,$1x10^{-5}$ M.

The absorption and fluorescence spectra of acridine dye recorded by a UV–VIS–NIR spectrophotometer (SP3000) and SL 147 spectrophotometer.

Figure(2) shows the experimental z-scan setup. It consists of a 30 ns Q-switched Nd:YAG laser operating at 532 nm wavelength with energy of 19.7 mJ. Laser pulse energy was measured by the detector. The laser beam passes through a lens of 15 cm focal length.

Sample was moved through the beam waist of laser beam along the z axis distance using a translating stage. The transmitted laser beam was splitted via a beam splitter, a reflected laser beam from beam splitter was sent to a first joule meter (D1). This arrangement represents an open –aperture z-scan to measure nonlinear absorption properties. The transmitted laser beam from beam splitter was sent through an aperture (iris) which clips roughly half of the beam intensity. After the aperture, a second energy meter detects the remainder of the beam. The normalized transmittance through an aperture in the far field is monitored as a function of the sample position with respect to the focal position .This arrangement represents a closed–aperture z-scan to measure nonlinear refractive index properties.

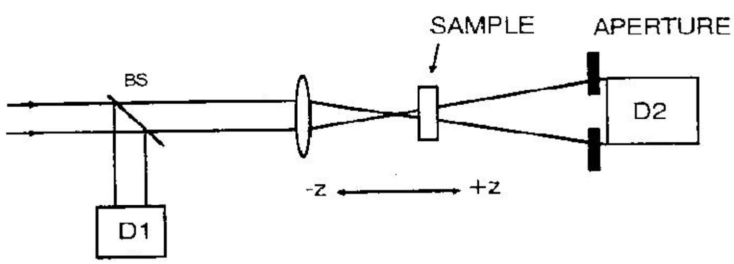

Fig. 2: Schematic diagram of a single beam z-scan setup: L: Lens; S: Sample; A: Aperture; D1, D2: Detectors; BS: Beam Splitter.

To obtain nonlinear absorption coefficient by using equation (3), and closed aperture to obtain nonlinear refractive index by using equation (4).

$\beta_1 = 2.83 * T_{min} / I_o * L_{eff}$ …….(1)

$\beta_2 = (5.2 * T_{min} / (I_o * L_{eff})^2)^{1/2}$ …….(2)

$\beta = \beta_1 + \beta_2$ …….(3)

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$n_2 = \Delta\Phi_o / k * I_o * L_{eff}$ ....(4)

$P_{peak} = E / \Delta t$ ....(5)

$I_o = P_{peak} / \pi (w_o)^2$ ....(6)

where: $\Delta\Phi_o = \Delta T / 0.406$, $\Delta T = T_{peak} - T_{valley}$ ....(7)

where: $k = 2\pi / \lambda$ ....(8)

k: is the wave number, λ: is the wavelength of the beam. n_2: the nonlinear refractive index of the material, I_0: the intensity of the incident beam at focus, $\Delta\Phi_o$:the nonlinear phase shift and L_{eff} the effective length of the material

$L_{eff} = (1-e^{-\alpha o L}) / \alpha_o$ ....(9)

L: the sample length, α_o : linear absorption coefficient.

RESULTS AND DISCUSSION

1-The linear optical properties.

1.1 **absorption spectra**

UV-VIS absorption spectra was obtained for a acridine dye. The behavior is shown in Fig.(3).

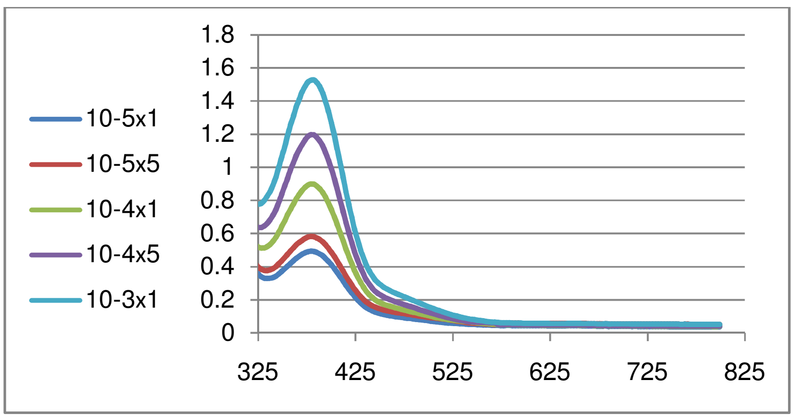

Fig. 3 show absorption spectra for acridine dye.

In Fig. 3 the absorption peaks for acridine dye solutions are 379nm, we show absorptance increasing with increase concentration.

Transmission Spectra

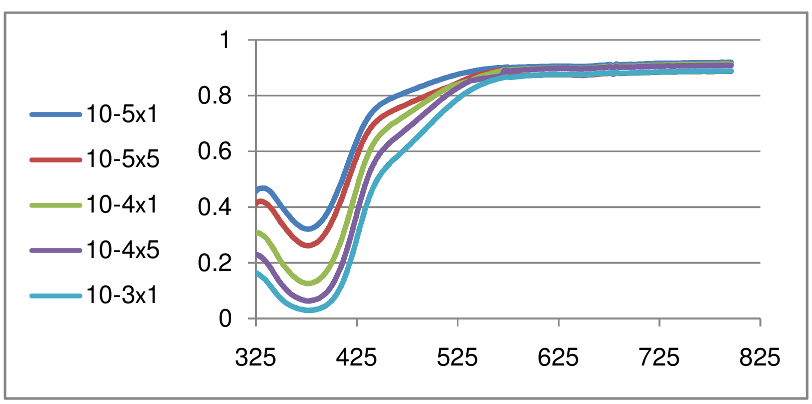

Fig. (4) show the transmission spectrum of the acridine dye.

The transmission spectra of the samples' were analyzed using UV-VIS spectrophotometer. Fig. (4) shows the transmission spectrum of the acridine dye.

The optical transmission of the acridine dye samples are shown a variable behavior of the transmission as a function of the incident wavelength. At the wavelength 532 nm the transmission for acridine dye with different concentration $1*10^{-5}$, $5*10^{-5}$, $1*10^{-4}$, $5*10^{-4}$ and $1*10^{-3}$ m/l the transmission behavior is 88%,85%,84%,84% and 80%) respectively

The linear absorption coefficient (α_o) & linear refractive index (n_o) obtained from eq.(10), eq.(11) The linear refractive index and linear absorption coefficient of acridine dye listed in Table(1).

$$\alpha_o = \frac{1}{t}\ln(\frac{1}{T}) \qquad \text{............ (10)}$$

.... (11)

Where t is the thickness of sample, and T is the transmittance.

$$n_o = \frac{1}{T} + [(\frac{1}{T^2} - 1)]^{1/2}$$

Table(1):Refractive index and linear absorption coefficient of acridine dye

Concentration M	Wavelength nm	Linear Transmission T%	Linear absorption coefficient (αo)	Linear refractive index (no)
$1x10^{-5}$	532	0.88231	0.12	1.6
$5x10^{-5}$	532	0.852813	0.15	1.7
$1x10^{-4}$	532	0.8485003	0.16	1.81
$5x10^{-4}$	532	0.8431156	0.17	1.84
$1x10^{-3}$	532	0.807530	0.2	2

The Nonlinear Optical Properties

The non linear refractive index (n2).

The nonlinear refractive index of the acridine dye in different concentrations ($1x10^{-5}$, $5x10^{-5}$, $1x10^{-4}$,$5x10^{-4}$ and ($1x10^{-3}$)Ml were measured by the z-scan technique. The measurements were done at 532nm.

Figures 5 has behavior z-scan. The peak-valley configuration indicates the negative sign of (n_2). The scan started from distance far away from the focus, the beam irradiance is low. As the sample is brought closer to focus. The beam irradiance increases, leading to diself-lensing in the sample. Table 2 shown nonlinear, phase shift and nonlinear refractive index versus the fluence at 532 nm.

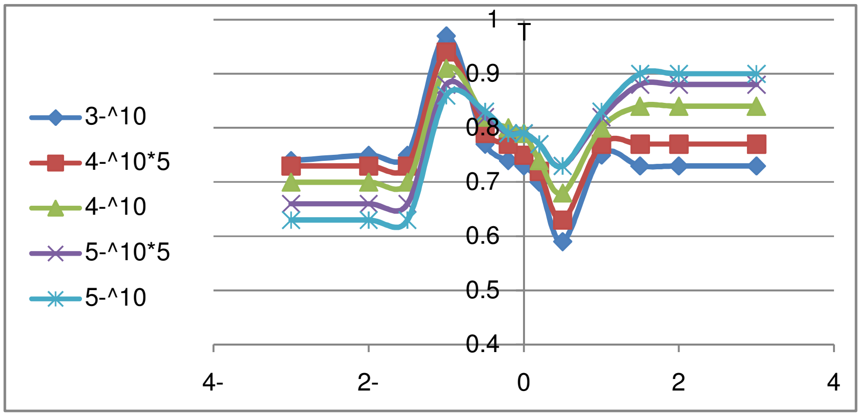

Fig. 5: shows a closed-aperture z-scan

Table 2. Nonlinear phase shift and nonlinear refractive index.

Concentration Ml	Fluence J/cm^2	T_{Peak}	T_{Valley}	$\Delta\Phi$	n_2 $^{*10-6}$ cm^2/GW
1x10^{-5}	19.7	0.97	0.75	0.073891	1.1767
5x10^{-5}	19.7	0.94	0.77	0.14778	2.3570
1x10^{-4}	1.97	0.91	0.8	0.27093	4.3231
5x10^{-4}	19.7	0.88	0.82	0.41871	6.6845
1x10^{-3}	19.7	0.86	0.83	0.54187	8.668

A) *Nonlinear absorption coefficient (β).*

To investigate the nonlinear absorption coefficient, at wavelength 532nm. Figure(6) shows open-aperture z-scan at different concentrations at 532nm, 20 mJ.

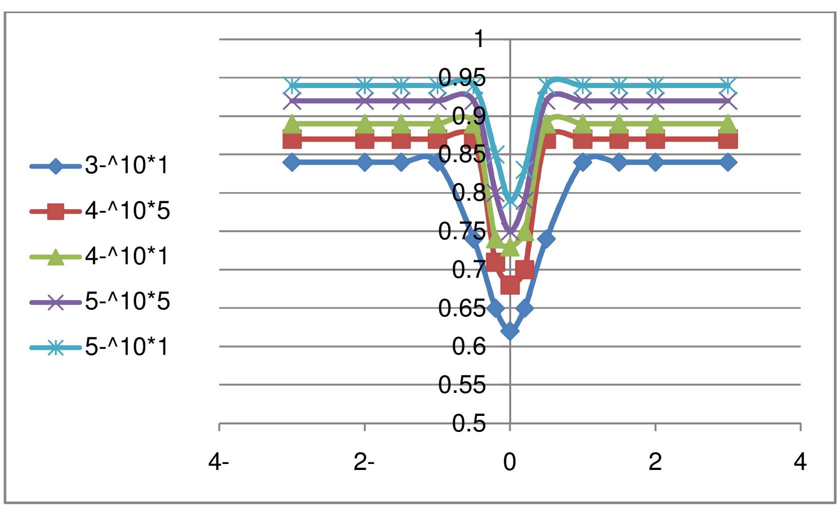

Fig.(6): Open-aperture z-scan at different concentrations of acridin dye.

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The behavior of transmittance started linearly at different distances from the far field of the sample position (-Z). At the near field the transmittance curve begins to decrease until it reaches the minimum value (T_{min}) at the focal point, where Z=0 mm. Afterward, the transmittance begins to increase toward the linear behavior at the far field of the sample position (+Z).

The open-aperture z-scan defines variable transmittance values, which used to determine absorption coefficient at 532nm. This can be reported in Table (3)

Table 3. Nonlinear absorption coefficients different concentrations of acridin dye

Concentration Ml	Fluence J/cm^2	T_{min}	β cm/GW
$1x10^{-5}$	19.7	0.79	8.01174
$5x10^{-5}$	19.7	0.75	7.71434
$1x10^{-4}$	1.97	0.73	7.55975
$5x10^{-4}$	19.7	0.68	7.53665
$1x10^{-3}$	19.7	0.62	6.70106

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