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NONLINEAR OPTICAL PROPERTIES STUDY IN FLUORESCEIN WITH DIFFERENT CONCENTRATIONS

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ABSTRACT

The nonlinear optical properties of the Fluorescein solution were studied using single beam Z-scan technique with a continuous-wave Diode laser radiation at 473 nm. The optical response was characterized by measuring the intensity-dependent refractive index (n_2) of the medium using the Z-scan technique. The sample showed negative and large nonlinear refractive index values of the order of $10^{-7}cm^2/W$ and reverse saturable absorption with high values of the nonlinear absorption coefficient of the order of 10^{-4} cm/W. The results show that the solution of Fluorescein exhibits large nonlinear refractive index and nonlinear absorption coefficient. These results show that the solution of Fluorescein have potential application in nonlinear optics.

KEYWORDS: Fluorescein ; Z-scan; Diode laser; nonlinear refractive index.

INTRODUCTION

The search for optimum nonlinear material is active since forty years, through the combined efforts of physics, material science, and chemistry researchers by carrying out continuous nonlinear experiments on various possible materials and this field is very active in research and a promising tool for future photonics technology. Great effort has been made in order to explain the behavior of light beams propagating through in terraces separating optical media with different nonlinear refractive indexes. Development of high power laser sources has motivated an extensive research in the study of nonlinear optical properties and optical limiting behavior of materials [1]. Organic molecules with high nonlinear optical properties are required for photonic applications including optical switching, data storage and optical information processing [2-4]. The study of linear and nonlinear optical coefficients is very important to tune the nonlinear optical (NLO) properties by the appropriate design of organic systems at the molecular level [5–7]. Nonlinear absorption can be classified in to two types: first, transmittance increases with increasing optical intensity, this nonlinear absorption corresponds to saturable absorption (SA). Second transmittance reduces with increasing optical intensity; this nonlinear absorption includes two photon absorption (TPA) and reverse saturable absorption (RSA) [8,9]. The physical origin of nonlinear refraction can be electronic, molecular, electro strictive or thermal [10]. The first optical limiter was based on thermal mechanism with a CW laser; the thermal effects have been shown to be efficient even with nanosecond pulses [11–13]. The aim of this article is to present the characterization and investigation of the third-order NLO properties of the Fluorescein solution using Z-scan technique at 473 nm wavelength.

2. EXPERIMENT

2.1 Uv- Visible Spectroscopic

The linear measurement was carried out in a 1 mm thick cell. The linear absorption spectra of Fluorescein solution is shown in Fig. 1. The Ultraviolet-Visible (UV-Vis) absorption spectra of the sample was recorded at room temperature using UV- visible spectrophotometer (using Cecil Reflected- Scan CE 3055 reflectance spectrometer) in the spectral range 350 – 600 nm. The optical absorption for the Fluorescein in the solvent chloroform with different concentrations 2, 4 and 8 mM, respectively, shows absorption peak at 461 nm as can be seen in Fig. 1. Also it can be seen that the absorbance of the sample increases with increasing the concentration due to the increase in the number of molecules per unit volume, so the absorbance will be increased.

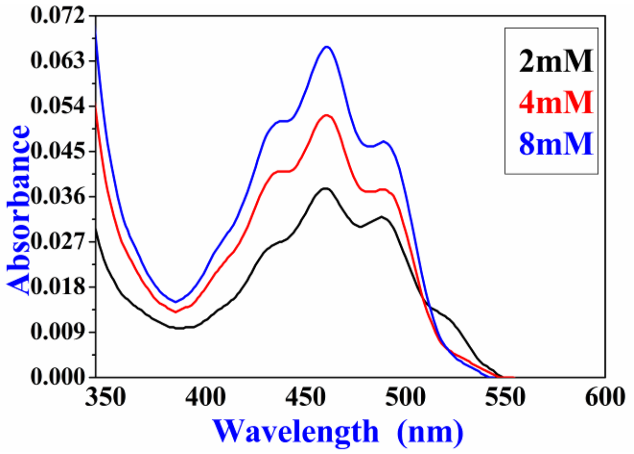

Fig. 1 Absorption spectra of Fluorescein solution with different concentrations.

2.1. Z-scan measurements

The reliable Z-scan technique, first introduced by Shiek-Bahae et al. in 1989, is a simple but sensitive single - beam method to determine both the nonlinear refractive index and nonlinear absorption coefficient of a given material [14]. It is also useful for characterizing nonlinear absorption (NLA). The *Z*-scan method has gained rapid acceptance by the nonlinear optics community as a standard technique for separately determining the nonlinear changes in index refraction and changes in absorption. This acceptance is primarily due to the simplicity of the technique as well as the simplicity of the interpretation. In most experiments the index change, Δn, and absorption change, $\Delta\alpha$, can be determined directly from the data without resorting to computer fitting [15]. However, it must always be recognized that this method is sensitive to all nonlinear optical mechanisms that give rise to a change of the refractive index and/or absorption coefficient [16], so that determining the underlying physical processes present from a *Z*-scan is not in general possible [17-20]. This method utilizes a tightly focused laser beam that is intense enough to access nonlinearities in a sample. The sample with thickness smaller than the diffraction length of the focused beam (a thin medium) passes through the focal point of the beam and we measure the transmittance of a nonlinear medium as a function of the sample position ***z*** measured with respect to the focal plane. The experimental setup was prepared according to Hussain and Noor Al-huda [7]. These changes in its transmittance due to NLA and NLR are measured by an open aperture and closed aperture, respectively. For NLR we measure the transmittance of a nonlinear medium through a finite aperture in the far field as a function of the sample position *z* measured with respect to the focal plane. The converging and diverging of the beam (allowing more and less of the beam to pass through the aperture, respectively) made changes in the refractive index [21]. In fact, nonlinear refractive index of the sample when its thickness is smaller than the diffraction length of the focused beam, makes it to act as a thin lens with variable focal length [22]. A prefocal valley and postfocal peak is observed for a positive change in refraction and a preffocal peak and a post-focal valley is observed for a negative change in refraction. In the open aperture technique after the beam is passed through the sample it is focused directly into a detector. As the sample travels through the focus of the initial beam, the transmittance either increases or decreases (depending on the nonlinearity of the sample) and the detector receives more or less light than the linear transmittance, yielding a hump or dip in the curve of transmittance as a function of sample position [23-26].

3. RESULTS AND DISCUSSION

3.1 The absorption coefficient (α)

The absorption coefficient (α) was obtained directly from the absorbance against wavelength curve using the relation [27-30]

$$\alpha = 2.303\frac{A}{L} \qquad (1)$$

where L is the sample thickness and A is the absorbance. The value of absorption coefficients (α) at 473 nm for Fluorescein solution has been calculated using Eq. 1 to be 0.713, 0.944, 1.174 cm^{-1}.

3.2 Third nonlinear optics

In this work, we presented our studies of nonlinear optical properties of Fluorescein with various concentrations which were prepared by dissolved in chloroform solvent. The optical nonlinearity of the solutions is measured by *Z*-scan technique. The nonlinear refractive index and nonlinear absorption coefficient are investigated using a continuous wave laser beam with wavelength λ = 473 nm. *Z*-scan measurements are carried out in three different concentrations of the same thickness (1mm) of samples.

The nonlinear absorption is evaluated under an open aperture configuration [31] as:

$$\beta = \frac{2\sqrt{2}\Delta T}{I_{\circ} L_{eff}} \qquad (2)$$

where ΔT is one-valley transmission for the open aperture. The nonlinear absorption coefficient β (cm/W) for solution is calculated from the open aperture normalized transmittance in Fig. 2 and the values of β are given in Table1.

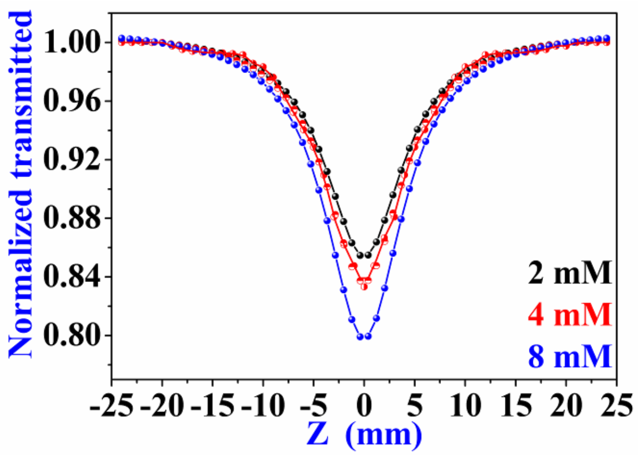

Fig. 2 Open-aperture Z-scan.

Fig.3 show the closed aperture Z-scan data for 2, 4, 8 mM concentrations of Fluorescein in chloroform solvent at incident intensity $I_{\circ}$=1.652 kW/cm^2. The scan of all samples has peak-valley configuration, corresponding to negative nonlinear refraction index, i.e. self-defocusing occur. The defocusing effect is attributed to a thermal nonlinearity resulting from the absorption of a tightly focused beam traversing through the absorbing dye medium that produces spatial distribution of the temperature in the sample and, consequently, a spatial variation of the refractive index that acts as a thermal lens resulting in phase distortion of the propagating beam [32].

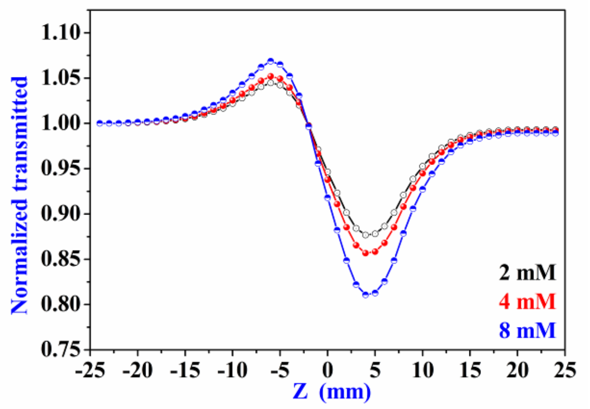

Fig. 3 Closed-aperture Z-scan.

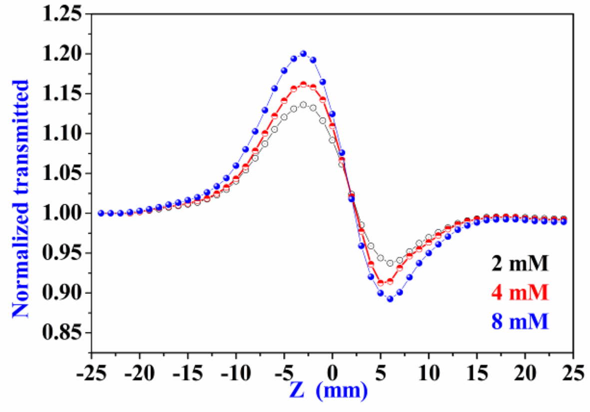

Fig. 4 Pure Z-scan data.

The measurable quantity ΔT_{P-V} can be defined as the difference between the normalized peak and valley transmittances, $T_P - T_V$. The variation of this quantity as a function of $\Delta\phi_{\circ}$ is given by [33,34]:

$$\Delta T_{P-V} = 0.406(1-S)^{0.25}\Delta\phi_{\circ} \tag{3}$$

where $S = 1-\exp(-r_a^2/\omega_a^2)$ is the aperture linear transmittance (=0.32) with r_a denoting the aperture radius and ω_a denoting the beam radius at the aperture in the linear regime [35]. $\Delta\phi_{\circ}$, the on-axis phase shift is related to the third-order nonlinear refractive index by [36]:

$$\Delta\phi_{\circ} = kn_2 L_{eff} I_{\circ} \tag{4}$$

where k=2π/λ, $L_{eff} = (1-\exp(-\alpha L))/\alpha$ is the effective thickness of the sample [37], α the linear absorption coefficient, L the thickness of the sample, $I_{\circ}$ the on-axis irradiance at focus and n_2 is the third-order nonlinear refractive index. The difference in amplitude of the Z-scan curves for the solution can be due to the difference in absorption coefficient at the λ =473 nm wavelength. In Z-scan measurement, the transmittance of the sample measured without an aperture gives information on purely nonlinear absorption coefficient whereas the apertured scan contains the information of both the nonlinear absorption coefficient and nonlinear refractive index nonlinearities [38,39] .

The ratio of the normalized closed aperture and open aperture scans generates a Z-scan due to the purely nonlinear refractive index [40,41] and results are shown in Fig.4. Also, Δn can be related to the total refractive index of the medium n and the background refractive index no, as follows [42]:

$n = n_o + \Delta n$ and $\Delta n = n_2 I.$ (5)

The nonlinear refractive index n_2 (cm^2/W) for the samples are calculated from the closed aperture normalized transmittance in Fig.4 and the values obtained are given in Table1.

Table 1. The nonlinear optical parameters.

Concentration (mM)	β x 10^{-4} (cm/W)	n_2 x 10^{-7} (cm^2/W)	$\Delta n \times 10^{-4}$
2	26.4	-0.29	0.48
4	29.8	-0.34	0.57
8	37.3	-0.47	0.78

CONCLUSIONS

Prepared, UV-Vis characterization, and the Z-scan measurements of Fluorescein using a CW diode laser at 473 nm wavelength have been presented. The nonlinear refraction, n_2, and the nonlinear absorption coefficient, β, for Fluorescein in solvent chloroform have been measured using the Z-scan technique. The measured absorption curves indicate that the nonlinear absorption is a saturation absorption process. The results of Z-scan indicate that the samples have a large optical nonlinearity .The studied sample exhibits self-defocusing property with a negative value of nonlinear refractive index.

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