Optical Nonlinear Properties and Optical Limiting Effect of Congo red dye under CW Laser

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Abstract

Nonlinear optical properties of congo red dye in tetrahydrofuran (THF) solvent are studied employing different optical techniques. Experiments are performed using the diode laser beam at 532 nm wavelength and 40mW power. The effect of nonlinearity of congo red dye in broadening the laser beam is observed. The optical limiting behavior is investigated by measuring the transmission of the samples. The nonlinear absorption coefficient is calculated using the open aperture Z-scan data, while its nonlinear refractive index is measured using the closed aperture Z-scan data. The nonlinear refractive index and absorption coefficient are found to be in the order of 4.14×10^{-8} cm^2/Watt , 1.99×10^{-3} cm/Watt, respectively. The results indicate that congo red dye is a potential candidate for low-power optical limiting application. The optical limiting behavior of the solvent of azo dye is also demonstrated.

Keyword: Optical limiting , nonlinear refraction index , Z-scan , azo dye

1. Introduction:

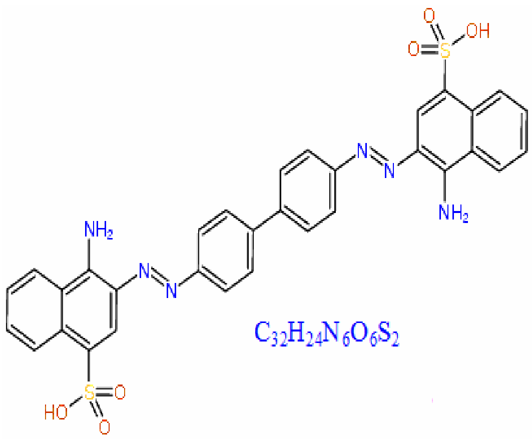
Nonlinear optics has received considerable attention due to their variety of applications in optoelectronic and photonic devices. Especially, nonlinear optical materials exhibiting strong two-photon absorption (TPA) are in great demand, due to their applications in three-dimensional fluorescence imaging and multi- photon microscopy, eye and sensor protection, frequency up conversion lasing, optical signal reshaping and stabilizing fast fluctuations of laser power [1–5]. A wide variety of materials have been investigated for third-order nonlinear optics, among which organic materials are attractive because of their optical and electronic properties which can be tuned and tailored by structural modification. The large and ultra fast nonlinear optical response has made organics particularly attractive candidates for high band width applications. There is quest to design and develop the novel nonlinear materials with large molecular two-photon absorption cross-sections to meet the present demand [6]. Optical limiting is a nonlinear optical process in which the transmittance of a material decreases with increased incident light intensity. It has been demonstrated that optical limiting can be used for pulse shaping, smoothing and pulse compression [7]. The potential applications of optical limiting devices are optical sensor and eye protection [8].

In this study, optical nonlinearity induced in dye congo red by continuous waveguide (cw) diode laser with an output power of 40 mWatt at 532 nm was studied using Z-scan technique, based on the sample-induced changes in beam profile at the far field. Our goal is study optical nonlinearity in dye bye using (tetrahydrofuran)THF solvent. The nonlinear refractive indices and nonlinear absorption coefficients were measured.

The optical limiting behavior of the dye has been studied.

2. Experimental

The molecular structure of the congo red dye (azo dye) is shown in Fig. 1. The linear absorption spectrum of the dye solution with the concentration of 0.05 mM in chloroform is shown in Fig.2,which was measured in our laboratory using a UV–VISNIR spectrophotometer (Type: CECEL 3500) .



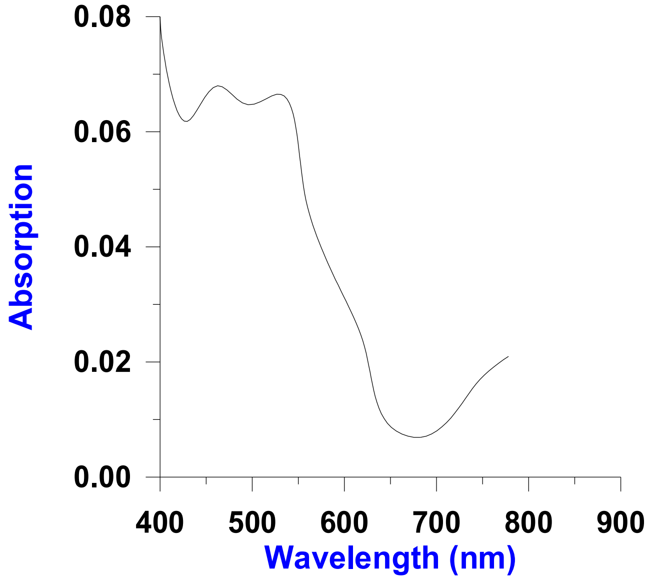


Fig. 1. The molecular structure of the congo red dye[9].

Fig. 2. The absorption of dye in THF with the concentration 0.05mM.

ISSN-1994-697X

The schematic diagram of Z-scan technique is as shown in figure 3. By properly monitoring the transmittance change through a small aperture at the far field position (closed aperture). By moving the sample through the focus without placing an aperture at the detector (open aperture) one can measure the intensity dependent absorption of the sample. When both the methods (open and closed) are used in measurements of the nonlinear refraction of the sample.

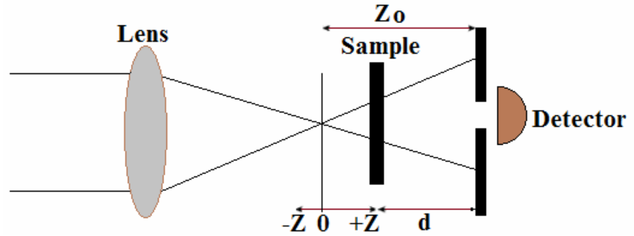


Fig. 3. Z - scan experimental setup.

3. The nonlinear optical measurement

The nonlinear coefficients of the congo red dye was measured by using Z scan technique, which is a well-known technique that allows the simultaneous and the nonlinear β measurement of both nonlinear absorption coefficient . n_2 refractive coefficient -

A spatial distribution of the temperature in the surface is produced due to the localized absorption of tightly focused beam propagation through the absorbing sample. Hence a spatial variation of the refractive index, Δn, is produced which acts as a thermal lens resulting in the phase distortion of the propagating beam [10].The difference between normalized peak and valley transmittance ΔT_{P-V} can be measured by Z-scan technique. The peak to valley ΔT_{P-V} is linearly related to the on- axis phase distortion $\Delta\varphi_o$ of the radiation passed through the sample [11]. The relation is defined as [12,13] ,

$$\Delta T_{P-V} = 0.406(1-S)^{0.25}|\Delta\Phi_0| \quad \text{..................... (4)}$$

and

$$\Delta\Phi_0 = kn_2 I_0 L_{eff} \quad \text{..................... (5)}$$

where

.... (6)

is the aperture linear transmittance with ra is the aperture radius and ω_a is the beam radius at the aperture in the linear region[14] , $I_\circ$ is the intensity of the laser beam at focus $z = 0$,

$$L_{eff} = (1-\exp(-\alpha_0 L))/\alpha_0 \quad \text{..................... (7)}$$

is the effective thickness of the sample[15], L is the thickness of the sample, (αo=1.331cm-1) is linear absorption coefficient of the congo red dye solution and

ISSN-1994-697X

$k = 2\pi / \lambda$ is the wave number. The nonlinear refractive index n_2 can be obtained from equations 4 and 5.

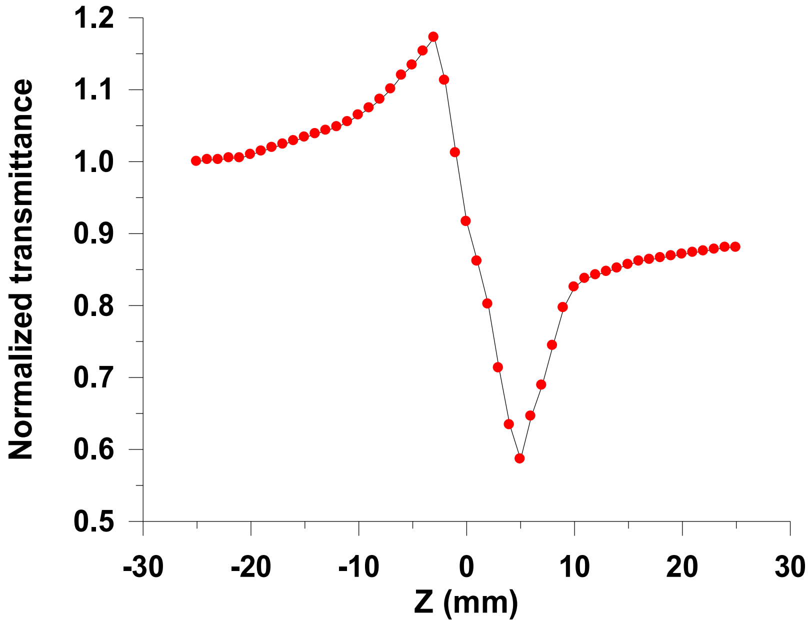


Fig. 4. Closed aperture Z-scan data for congo red dye when the concentration of the solution is 0.05 mM at 1 mm thickness.

Fig.4 shows the closed aperture (CA) Z-scan curve of congo red dye solution. From the asymmetric curve there is obvious nonlinear absorption existing in the solution and the close transmittance is affected by the nonlinear refraction and absorption.

In the Z-scan measurement, the effective thickness of the sample was Leff = 0.93 mm. The linear transmittance of the aperture was S=0.41 and the optical intensity at the focus point is 5.443 kWatt/cm2.

The nonlinear absorption coefficient β can be estimated from the open aperture Z-scan data [16].

$$\beta = \frac{2\sqrt{2}\Delta T}{I_{\circ} L_{eff}} \quad \text{................ (8)}$$

In general, the measurements of the normalized transmittance versus the sample position for the cases of the closed and open aperture allow for the determination of the nonlinear refractive index, n_2, and the nonlinear absorption coefficient β, since the closed aperture transmittance is effected by the nonlinear refraction and absorption.

is less straight forward from the closed aperture n_2 The determination of scans. It is necessary to separate the effect of the nonlinear refraction from that of the nonlinear absorption. Fig.5 shows the open aperture (S=1) Z-scan curve of sample.

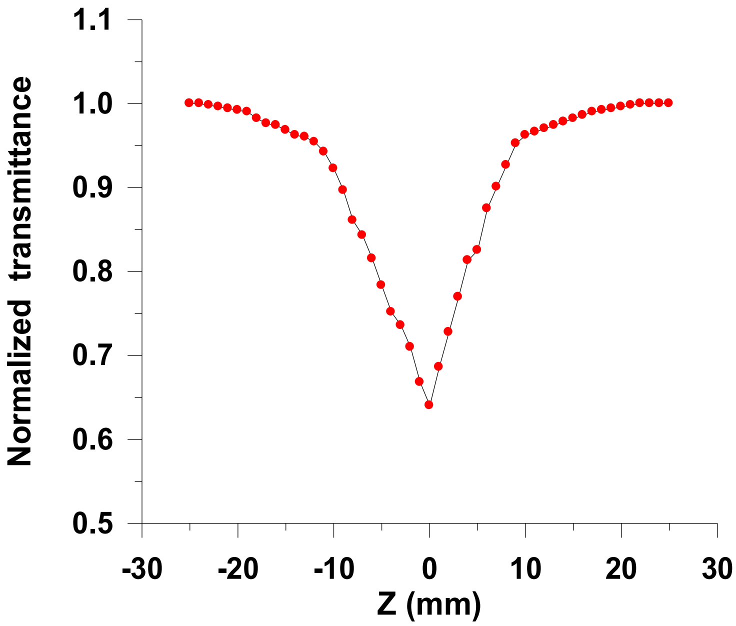


Fig. 5. Open aperture Z-scan data for congo red dye when the concentration of the solution is 0.05 mM at 1 mm thickness.

A method [10] to obtain a purely effective n2 is to divide the closed aperture transmittance by the corresponding open aperture scans. The data obtained in this way purely reflects the effects of the nonlinear refraction. The ratio of Figs 4 and 5 scans is shown in Fig. 6. The sign and magnitude of n_2 is determined from the relative position of the peak and the valley with z.

Generally the measurements of the Normalized transmittance versus sample position, for the cases of closed and open aperture, allow determination of the nonlinear refractive index, n_2, and the reversible saturation absorption (RSA) nonlinear coefficient, β [17]. Here, since the closed aperture transmittance is affected by the nonlinear refraction and absorption, the determination of n_2 is less straightforward from the closed aperture scans. Therefore, it is necessary to separate the effect of nonlinear refraction from that of the nonlinear absorption. A simple and approximate method to obtain purely effective n_2 is to divide the closed aperture transmittance by the corresponding open aperture scans.

ISSN-1994-697X

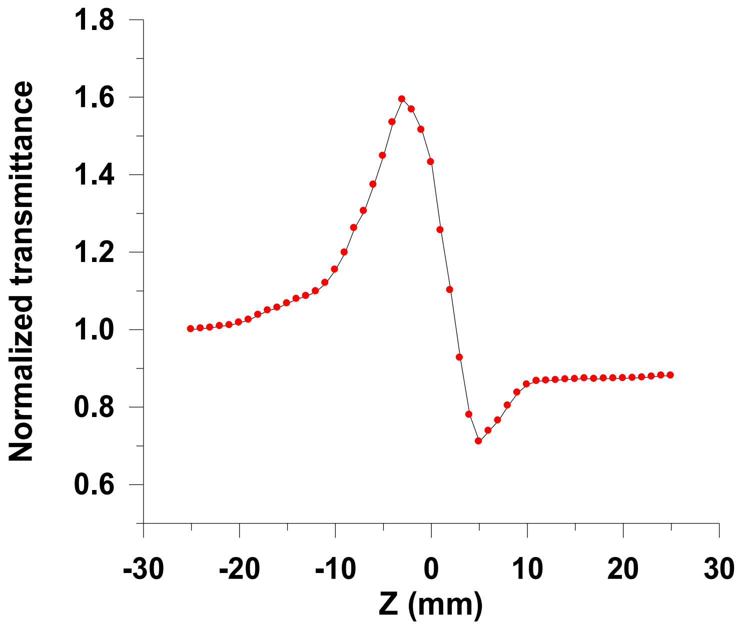


Fig. 6. Close aperture division Open aperture Z-scan data for congo red dye when the concentration of the solution is 0.05 mM at 1 mm thickness.

4. Optical limiting

By optical limiting measurement the critical power of laser beam at which the nonlinearity starts to affect the transmission can be measured. For this experiment the sample is put near the focal plane of the lens and the input power is changed. The input power is measured by power meter. In Fig. 7 the output power of laser beam is plotted as a function of incident power for (0.05 mM) concentration of sample .

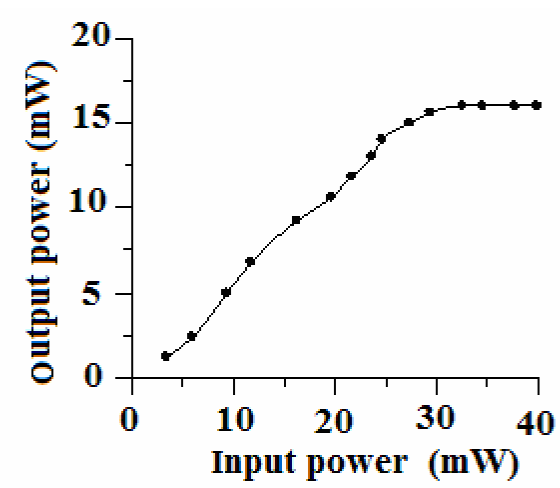


Fig.7. The nonlinear transmission behavior of congo red dye of 0.05 mM concentration (1mm thickness).

The input power is in the range of (0–40) mW. As is shown clearly for incident beam power of above 25 mW, the transmission becomes nonlinear. At low incident power up to 25 mW, the output power varies linearly with a ratio of 0.73 (threshold value) for 0.05 mM concentration of congo red dye solution. At

ISSN-1994-697X

incident power above 26 mW the output power tends to be constant, because its nonlinear absorption coefficient increases with increase in the incident irradiance. Generally in liquids, where the thermal expansion is large, high absorbance of the nonlinear material at the corresponding wavelength leads to increase in the temperature and density of the sample. Heating due to laser absorption is the responsible mechanism for changing the absorption coefficient and optical limiting effect [18-20]. Results confirm that congo red dye solution is a good candidate for optical limiting at 532 nm cw lasers.

Conclusion

The Z-scan measurement indicates that the sample exhibited large nonlinear optical properties, n_2, β and Δn values was found to be 4.14 ×10-8cm2/W, 1.99×10-3cm /W and 2.25 ×10-4 , respectively. The optical nonlinearity of the dye may be due to laser heating induced nonlinear effect. A laser beam, while passing through an absorbing media, induces temperature and density gradients that change the refractive index profile. This intensity-induced localized change in the refractive index results in a lensing effect on the optical beam. Thus the sample with many attracting linear and nonlinear optical properties is suitable candidate for optoelectronic applications. Based on nonlinear refraction the sample be haved as good optical limiters at low incident power up to 25mWatt, indicating this sample find potential applications in optical limiting and signal processing applications.

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ISSN-1994-697X

الخواص البصرية اللاخطية وتأثير الحد البصري في صبغة الكونغو الحمراء تحت تأثير ليزر مستمر

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الخلاصـــــة:

تمت دراسة الخواص البصريه اللاخطيه لصبغة الكونغو الحمراء المذابه في رباعي هيدرو الفوران بأستخدام تقنيات مختلفه وقد جرت التجارب بأستخدام حزمة دايود ليزر بطول موجي ٥٣٢ نانومتر وقدرة ٤٠ ملي واط وقد لوحظ ظهور الصفات اللاخطيه في صبغة الكونغو الحمراء ..إن خواص الحد البصري قد تحققت بواسطة قياس نفاذية العينه وإن معامل الامتصاص الخطي قد حُسب بواسطة تقنية المسح البصري بأتجاه المحور Z للفتحة المفتوحه بينما معامل الانكسار اللاخطي حسب بتقنية المسح البصري بأتجاه المحور Z للفتحة المغلقه ووجدت قيم هذه المعاملا ت هي 1.99×10^{-3} سنتمتر / واط , 4.14×10^{-8} سنتمتر مربع /واط على التوالي . بينما تشير النتائج الى ان صبغة الكونغو الحمراء هو مرشح محتمل لتطبيقات الحد البصري ذو الطاقه المنخفضه. ان سلوك الحد البصري لصبغة الازو المذابه يُمكن مُلاحظتهُ ايضا .