OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 7, No. 1-2, January - February 2013, p. 26 - 29

Third order nonlinear optical properties of sulforhodamine B dye by Z-Scan Technique

S. KUMARESAN[a], M. BASHEER AHAMED[b,*]
[a]*Department of Physics, GKM College of Engineering &Technology,Chennai-63, India*
[b]*Department of Physics, BS Abdur Rahman University, Chennai-600 048, India*

The third order nonlinear properties of sulforhodamine B dye were studied by using Z-scan technique. The pulsed Nd: YAG laser of wavelength 532 nm is used as a source of excitation. The experimental results have been investigated from closed and open aperture curve graph. The closed aperture curve showed that negative nonlinearity and open aperture curve was saturation absorption of the sample. The nonlinear refractive index n_2, nonlinear absorption coefficient β and real and imaginary parts of third order nonlinear optical susceptibility χ^3 are measured for different concentrations of dye in ethanol. This shows that the dye has potential application in nonlinear optics.

(Received October 3, 2012; accepted; February 20, 2013)

Keywords: Z-scan, Sulforhodamine B, NLO properties

1. Introduction

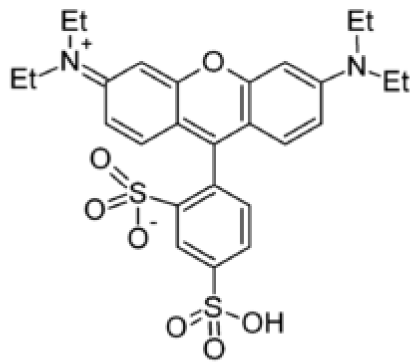
In recent years, the third order nonlinear optical (NLO) materials have been applied widely in many important technologies including optical recording, optical limiting for sensor protection, photonic switching, optical signal processing and optical limiting. The Z-scan method is a simple and effective technique for determining nonlinear properties of organic dye. This method is very useful to measure the sign and magnitude of real and imaginary part of third order nonlinear optical susceptibility. The dye sulforhodamine B is chosen for this experimental work because its absorption spectra wavelength is 555 nm. Nonlinear refractive index n_2, nonlinear absorption co-efficient β and third order nonlinear optical susceptibilities χ^3 were measured.

The nonlinear refractive index is calculated from closed aperture curve peak and valley signal difference. Saturation absorption can be determined in the open aperture curve, where the transmitted beam is collected and detected. The third order nonlinear optical susceptibility was calculated in the order of 10^{-6}esu [1-5].

2. Procedure

2.1 Materials and methods

The dye sulforhodamine B was purchased Sigma Aldrich, India. It was weighed and dissolved in ethanol at various concentrations 1mM, 1.1mM, and 1.2 mM respectively. The nonlinear optical properties of the sample were studied by using pulsed Nd: YAG laser at 532 nm. The organic structure of sulforhodamine B dye is as shown in Fig. 1.



$C_{27}H_{30}N_2O_7S_2$

Fig. 1. Chemical structure and Molecular formula of sulforhodamine B.

2.2 Absorption spectra

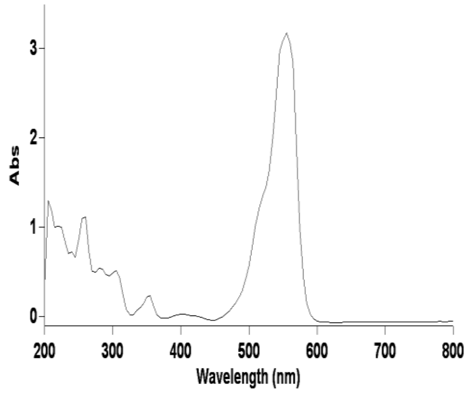


Fig. 2. UV-VIS absorption spectra of dye sulforhodamine B in ethanol.

The spectral property of the dye sulforhodamine B in liquid medium of concentration 0.01 mM was studied by using a UV-VIS spectrophotometer (VARIAN COMPANY). The absorption was in the range of 300 to 600nm, as shown in the Fig. 2. The spectral absorption peak wavelength (λ_a) was calculated to be 555 nm. The spectral parameters such as molar extinction co efficient $\varepsilon(\lambda) = 4.09\times10^{4}$Lmol^{-1}cm^{-1}, oscillator strength(f) = 1.59×10^{-24}Lmol^{-1}cm^{-2}and band width ($\Delta\gamma_{1/2}$) = 9×10^{3}cm^{-1}were calculated at 555 nm [6].

2.3 Z-Scan technique

A pulsed Nd: YAG Laser (QUANTA RAY: Model Lab–170-10) of wavelength 532 nm is used as the excitation source for the Z-scan technique. The laser of Gaussian beam profile was focused by a convex lens of focal length 10 cm to produce beam waist (ω_0)of 105.6 µm.

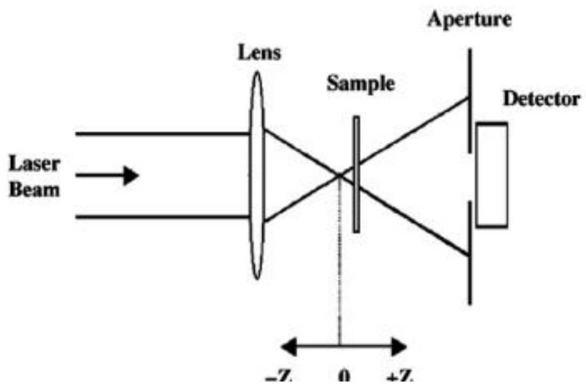


Fig.3 Experimental setup for Z-scan Instrument

The peak intensity of the incident laser beam was I_0=10.1kW/cm^2. The schematic diagram of the experimental setup used is shown in Fig. 3. A 1mm wide optical cell containing the dye dissolved in solvent was translated across the focal region along the axial direction which is the direction of the propagation of laser beam. The transmission of the beam was through an aperture placed in the far field was measured using detector and the output power was recorded by the digital power meter (EPM 2000, Coherent MolectronUSA make). For an open aperture Z-scan, a lens was used to collect the entire laser beam transmitted through the sample with the aperture replaced [7, 14].

3. Results and discussion

The third order nonlinear refractive index n_2 and the nonlinear absorption coefficient β, of the sulforhodamine B dye in ethanol at various concentrations for the incident intensity $I_{0=}$ 10.1 kW/cm^{-2} were evaluated by the measurements of Z-scan. The saturation absorption for the dye in solvent are shown by the open Z-scan curve (S=1) in (Fig. 4). S is the aperture linear transmittance is given by

$$S = 1–\exp(2r_a^{2}\omega_a^{2}) \qquad (1)$$

With r_a, ω_a indicates the aperture radius and the radius of the laser spot before the aperture. The open aperture Z-scan curves for the sulforhodamine B dye as shown in Fig. 4. The open aperture transmittance curve is symmetric with respect to the focus and the transmittance is calculated at the focus point indicating intensity dependent absorption effect. The Z-scan curve closed aperture as shown in Fig. 5. The peak to valley configuration of the curve suggests that the refractive index change is negative exhibiting a self-defocusing effect. This shows that the dye has a large negative nonlinear refraction [8].

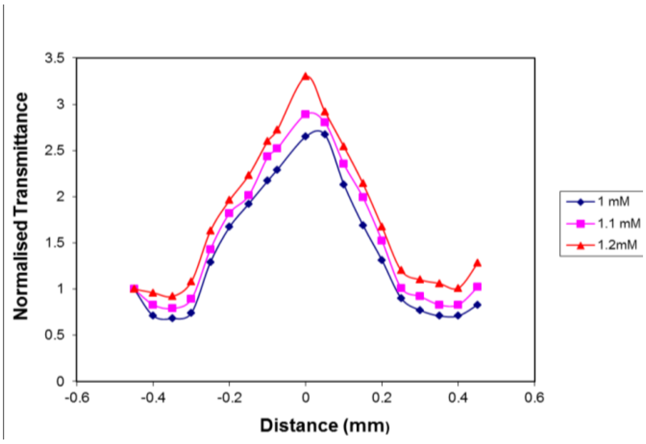


Fig. 4. Open Z-Scan curve for dye in solvent at various concentrations.

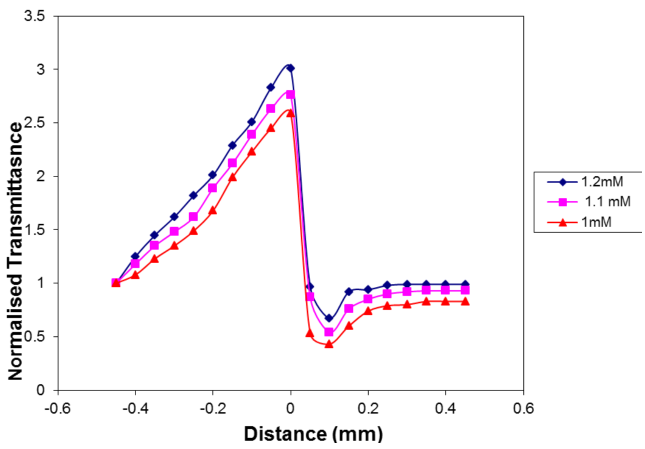


Fig. 5. Closed Z scan curve for dye in solvent at various concentrations.

The measurable quantity $\Delta T_{(p-v)}$ can be defined as the difference between the normalized peak and valley transmittances, Tp-Tv. The variation of this quantity [9] as a function of $|\Delta\phi_0|$ is given by

$$\Delta T_{p-v}=0.406(1-S)^{0.25}|\Delta\phi_0| \qquad (2)$$

where, $\Delta\phi o$ is the on-axis phase shift at the focus. The on-axis phase shift is related to the third order nonlinear refractive index (n_2) by,

$$|\Delta\phi_0| = kn_2 L_{eff} I_0 \quad (3)$$

Where I_0 is the intensity of the laser beam at focus Z= 0, k is the wave number ($k = 2\pi / \lambda$), λ is the wavelength of the light used, $L_{eff} = (1-e^{-\alpha L})$ is the effective thickness of the sample, L is the sample length, α is the linear absorption coefficient.

Table 1. Nonlinear parameters of sulforhodamine B dye in solvent.

Concentration	$\Delta T_{(P-V)}$	$n_2 x10^{-8}$ cm^2/w	β x 10^{-4} cm/w	$\Delta n x10^{-4}$	$\lvert\chi^3\rvert x10^{-6}$ (esu)
1 mM	2.16	-12.39	-2.06	-12.5	3.79
1.1 mM	2.22	-12.74	-2.24	-12.8	3.97
1.2 mM	2.34	-13.41	-2.56	-13.5	4.31

If we collect all the energy transmitted by the sample (open aperture Z-scan), the measurement is sensitive to nonlinear absorption only. If an aperture is placed in front of the detector (closed aperture Z-scan), the measurement is sensitive to both nonlinear absorption and nonlinear refraction [1].

$$\beta = 2 \sqrt{} 2\Delta T/ I_o L_{eff} \quad (4)$$

The imaginary parts of the third order nonlinear optical susceptibility (χ^3) is estimated using the value of the nonlinear absorption coefficient β obtained from the open aperture Z- scan data (Fig. 4). Where, ΔT is the normalized transmittance of the sample when at the position of Z. Experimentally determined nonlinear refractive index n_2 and nonlinear absorption coefficient β can be used in find the real and imaginary part of the third-order nonlinear optical susceptibility (χ^3)[10-13] according to the following relations,

$$\operatorname{Re}\chi^3 = 10^{-4}\frac{\varepsilon_o c^2 n^2}{\pi} n_2 \quad (5)$$

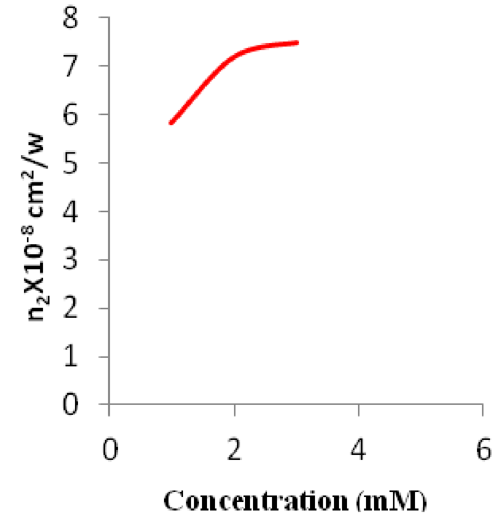
$$I_m\chi^3 = 10^{-2}\frac{\varepsilon_o c^2 n^2 \lambda}{4\pi^2}\beta \quad (6)$$

where ε_0 is the vacuum permittivity and c is the light velocity in vacuum.

The absolute value of the third order nonlinear optical susceptibility (χ^3) is given by the relation.

$$\chi^3 = \left\{[\operatorname{Re}\chi^3]^2 + [\operatorname{Im}\chi^3]^2\right\}^{1/2} \quad (7)$$

The experiment was repeated for various concentrations of the dye sulforhodamine B to obtain the nonlinear parameters. The experimentally determined values of ΔT_{p-v}, $n_{2,}$ $_{\beta,}\Delta n$ and χ^3 are given in Table (1).



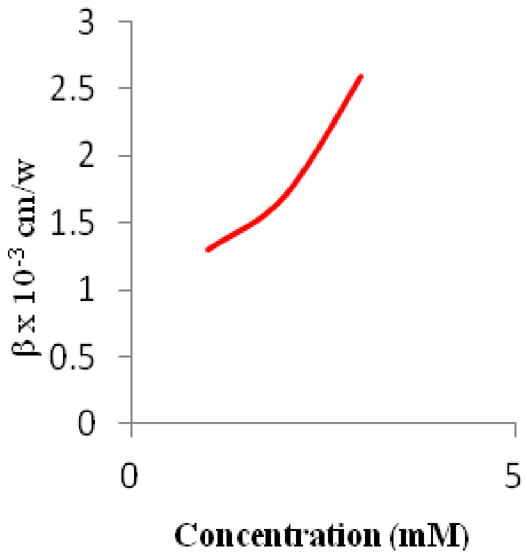


Fig. 6. Concentration dependence n_2,β of Sulforhodamine B dye in solvent.

The value of n_{2}, β and $\chi3$ increases as the concentration increases in this dye (Fig. 6). As the number of dye molecules increases when concentration increases more particles are thermally agitated resulting in an enhance effect.

A pulsed Nd: YAG laser beam passing through an absorbing media induces temperature and density gradient that change the refractive index profile. This intensity induced localized change in the refractive index results in a lensing effect on the optical beam [6, 9].

4. Conclusion

The z-scan results indicated that the nonlinear absorption is saturation absorption, while the nonlinear refraction leads to self-defocusing in this dye. The closed aperture curve showed that the dye has a negative nonlinear. These observations show that the dye has a large third order nonlinear susceptibility and quite encouraging for possible applications in nonlinear optical devices.

References

[1] M. A. Sheik Bahae, T. SaidWei, D. J. Hagan, E. W. Stryland, IEEE J. Quantum Electron. **26,** 760(1990).

[2] A. Costela, I. Garcia Marino, J. M. Figuera, F. Amat-Guerri, J. Barrosoand and R. Shastre, Opt. Commun. **130**, 44 (1996).

[3] G. Vinitha, A. Ramalingam, Spectrochem. Acta A **60,** 1160 (2008).

[4] S. Kaladevi, C. Vijayan, M. P. Kothiyal, Opt. Mater. **27**, 1606 (2004).

[5] S. Venugopalrao, N. K. M. N. Srinivas, D. N. Rao, L. Giribabu, B. G. Maiya, R. Philip, G. R. Kumar, Opt. Commun. **182,** 255 (2000).

[6] G. Sreekumar, B. ValsalaMilka, C. I. Muneera, K. Sathiyamoorthy, C. Vijayan, Opt. Mater. **30**, 311 (2007).

[7] R. K. Rekha, A. Ramalingam, AMJ. appl. Sci. **2**(2),285(2009).

[8] C. Gayathri, A. Ramalingam, Optik.**119**, 409 (2008).

[9] H. J. Ravindra, A. Johnkiran, K. Chandrasekaran, H. D. Shashikala, S. M. Dharmaprakash Appl. Phys. **88**, 105 (2007).

[10] S. J. Mathews, S. Chaitanya Kumar, L. Giribabu, S. Venugopal Rao, Mater. Lett. **61**, 4426 (2007).

[11] T. Cassano, R. F. Tommasi, F. Babudri, G. M. Farinola, F. Naso, Phys. **272**, 111 (2001).

[12] M. Rashidian, D. Dorranian, S. AhmadiDarani, S. Saghafi, M. Ghoranneviss, Optik. **120**, 1000 (2009).

[13] G. Mathew, C. I. Muneera, C. P. Singh, K. S. Bindra, S. M. Oak, Opt. Laser Technol. **40**, 373 (2008).

[14] T. H. Z. Hao, G. Hongmei, Zijun, Liu, S. Xiao, S. Li, Y. Zhai, S. You, Q. Wang, J. Qin, Chem. Phys. Lett. **451,**213 (2008).

[15] Q. M. Ali, P. K. Palanisamy, Optik. **116**, 515 (2005).

*Corresponding author: basheerahamed@bsauniv.ac.in