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A Quantitative Study of the Laser-Induced Ring Pattern and optical limiting From 4-Chloro-3-methoxynitrobenzene solution

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Abstract:

The optical limiting performance of 4-Chloro-3-methoxynitrobenzene is described in solution state. The measurements were performed using a 100mW solid state cw laser at 473 nm. Parameters of optical limiting properties such as the threshold and saturated values can be engineered by modifying the parameters of the set-up and the concentration of the sample. Also this study observed and studied diffraction rings generated in 4-Chloro-3-methoxynitrobenzene using same cw laser. The number of rings increases almost exponentially with increasing concentration of the samples. The refractive index change, Δn, and effective nonlinear refractive index ,$n_{R2}R$, are found to be 10^{-5} and 10^{-9} cmP^2P/Watt, respectively. The effective nonlinear refractive index, nR_2R, was determined based on the observed number of rings. The threshold values of the sample at 14, 18 and 20 mM concentration are 7.1, 6.55 and 6.34 mW respectively. This large nonlinearity is attributed to a thermal effect. The present studies suggest that sample is a potential candidate for optical device applications such as optical limiters.

Keywords: optical limiting; Self-diffraction; refractive index change; organic dye

Introduction

Self-induced index changes in optical media have been investigated extensively in the past in connection with Q- switching and mode locking of lasers and self-focusing or defocusing of laser beams. The mechanisms behind self- induced changes fall into two categories. In the first category, there are several non-resonant mechanisms which have been studied quite extensively in the past in connection with self-focusing. In the second category, we have near-resonant effects, the most important of which is associated with the saturation of a more-or-less homogenously broadened absorption line [1]. For various reasons the diffraction pattern in the shape of concentric rings was studied, viz, strong self-defocusing effect and foure-wave mixing in bacteriorhodopsin films [2] absorbing solution [3], optical multistability in nematic liquid crystal [4], organically modified sol-gel materials [5], mercury dithizonate [6], femtosecond Bessel

beams [7], self-focusing spatial beams [8] and bulk ceramic and thin film PLZT [9].
It is well-known that intense laser beam can easily
damage delicate optical instruments, especially
the human eye, and consequently the field of optical limiting has invested much effort into the research of materials and processes in an attempt to afford some measure of protection from such beams. The need for materials to protect optical sensors from intense laser is not only limited to the military, but also is rather a growing problem that can only escalate [10
systems that permit transmission of ambient light levels but which strongly attenuate high intensity, potentially damaging light such as focused laser beams. Previous researches on optical limiting materials focused on nonlinear, organic [11-20] and semiconductor materials [21]. Since it was found that organic materials have large nonlinearity and ultra-fast response time, the research on optical limiting organic materials is of great importance. Nonlinear absorptive organic dyes are among the most widely studied optical limiting materials. Recently, Palanisamy *et al*. studied the third-order nonlinear optical response of a triphenylme-thane dye (Acid blue 7) using the Z-scan technique with a continuous wave He Ne laser radiation at 633 nm [22].

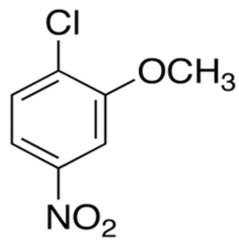
The optical limiting can be caused by several different mechanisms such as reverse saturable absorption (RSA), two photon absorption, nonlinear refraction, and optical induced scattering [23]. Under cw illumination, the form of optical nonlinearity exhibited by materials is predominantly refractive rather than absorptive [24-27] and suitable schemes based on nonlinear refraction have to be exploited for obtaining the limiting action. Certain materials such as liquid crystals, porphyrins, organics such as azobenzene, etc. are known to be optically nonlinear under cw laser illumination [28-30]. The refractive indices of these materials depend on the input intensity, resulting in either focusing or defocusing effects on the incident laser beams. The defocusing effect under CW laser irradiation, usually associated with nonlinearity of thermo-optic origin, can be used for the design of an optical limiting device.

In the present work we present experimental evidences of observing diffraction pattern in 4-Chloro-3-methoxynitrobenzene with the calculation of the refractive index change, Δn , effective nonlinear refractive index n_2 .The optical limiting property of this sample has been studied, as well.

1.EXPERIMENTAL RESULT

1.1 Optical limiting effect

The limiting effect of the 4-Chloro-3-methoxy- nitrobenzene dye solvent in DMSO was studied by using a 100 mW solid state CW laser at 473nm. 4-Chloro-3-methoxynitrobenzene (molec- ular weight = 187.58) and DMSO were purchased from Aldrich Chemical Company and were used without any purification. The chemical structure and molecular formula of 4-Chloro-3-methoxy- nitrobenzene are shown in Fig.1.The experimental setup for the demonstration of optical limiting is shown in Fig.2.



$C_7H_6ClNO_3$

Fig.1. The chemical structure and molecular formula of 4-Chloro-3-methoxy- nitrobenzene

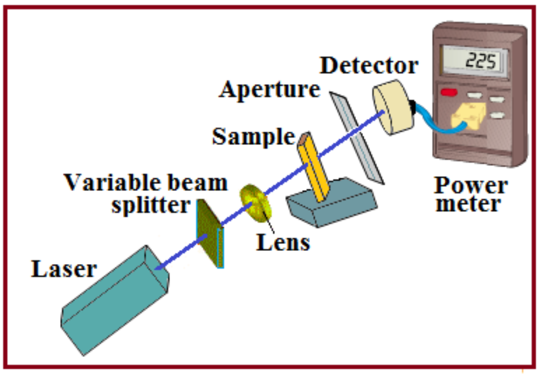


Fig.2. Experimental setup for an optical limiting effect.

The laser beam was focused normally into the sample by a positive lens with a focal length of +5 cm. In the case of the sample solution, a 1 mm quartz cell was used to contain the solution of 4-Chloro-3-methoxynitrobenzene. The sample could be moved back and forth along the direction of the optical axis in order to change the position of the focal point of the lens with respect to the sample. A variable beam splitter (VBS) was used to vary the input power. An aperture of variable diameter was used to control the cross-section of the beam leaving of the sample. The beam is then made to fall on the photo detector (PD). The input laser intensity is varied systematically and the corresponding output intensity values were measured by the photo detector that was connected to a power meter (Field Max II-To+OP). The dependence of optical limiting on the sample concentration was studied for different sample concentrations as shown in Fig.3. In this experiment the sample was placed behind the focal point of the lens and the aperture size was set to be 5 mm in diameter.

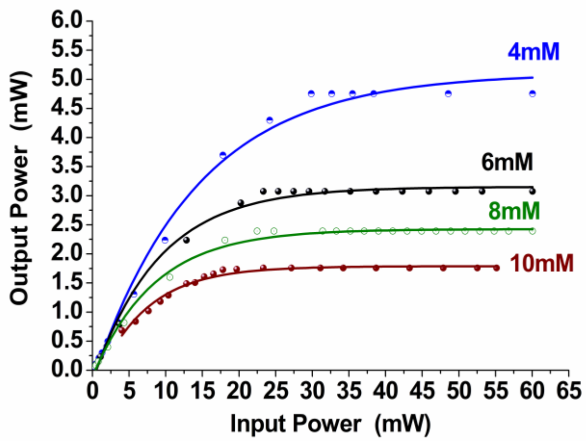


Fig.3. Optical limiting of sample with different concentrations.

The output power rises initially with an increase in input power for all the sample concentration, but after a certain threshold value the sample concentration it starts defocusing the beam, resulting in a greater part of the beam cross-section to be cut off by the aperture. Thus the transmittance recorded by the photo-detector remains reasonably constant showing a plateau region and saturated at a point defined as the limiting amplitude. i.e., the maximum output intensity, showing obvious limiting property. The saturated output value at which limiting occurs for the sample solution are shown in Fig.4 for different concentrations. It can be seen from Fig. 4 that the saturated output value decreases with the increase of concentration.

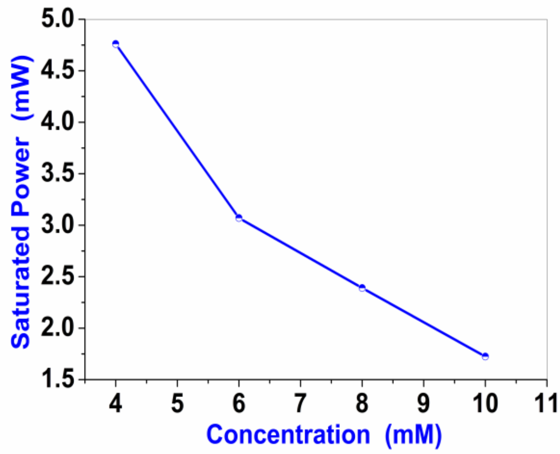


Fig.4. Concentration dependence of saturated output value.

1.2. Nonlinear refractive index

The sample was positioned at or immediately behind the focal point of the lens. As the power was gradually increased, diffraction ring of patterns were observed on the screen. The maximum number of rings obtained (3) was for input power 72 mW. We can estimate the induced refractive index *n*, and the effective nonlinear refractive index, n_2, for the preceding data as follows. Because the laser beam used in the experiment has a Gaussian distribution, the φ, suffered by the beam while traversing the sample of thickness (L) can be written as:

$$\Delta\varphi = kL\Delta n \qquad (1)$$

where k - vector in vacuum

The relationship bet rings, N, can be written as [31]:

$$\Delta\varphi = 2\pi N \qquad (2)$$

The relationship between the total refractive index, *n*, and nonlinear part of the refractive index, n_2, can be written as follows [31]:

$$n = n_0 + \frac{n_2}{2} I \;\; , n = n_0 + \Delta n \qquad (3)$$

Where n_0 is the background refractive index, and I is the laser beam intensity.

Fig.5 shows diffraction rings pattern taken for samples with 14, 18 and 20 mM concentrations. We can see from the Fig.5 that number of self diffracted rings increases with increasing concentration of the samples. Also the threshold values of the sample with different concentrations for self-diffraction rings are unequal, the threshold values of the sample at 14, 18 and 20 mM concentration are 7.1, 6.55 and 6.34 mW respectively. The increases of the number of diffraction rings with increasing the concentration are due to the increase in aggregation of the sample molecules at the point of focus at higher concentrations. The diffusivity extends to a larger region thereby causing more interference to take place leading to an increased number of rings mentioned in Table, the number of rings ,N, observed were 3, 2, and 1, for the 4-Chloro-3-methoxynitrobenzene solutions respectively. Based on N, the parameters φ , Δn, and, n_2 were calculated and the values obtained are given in Table 1.

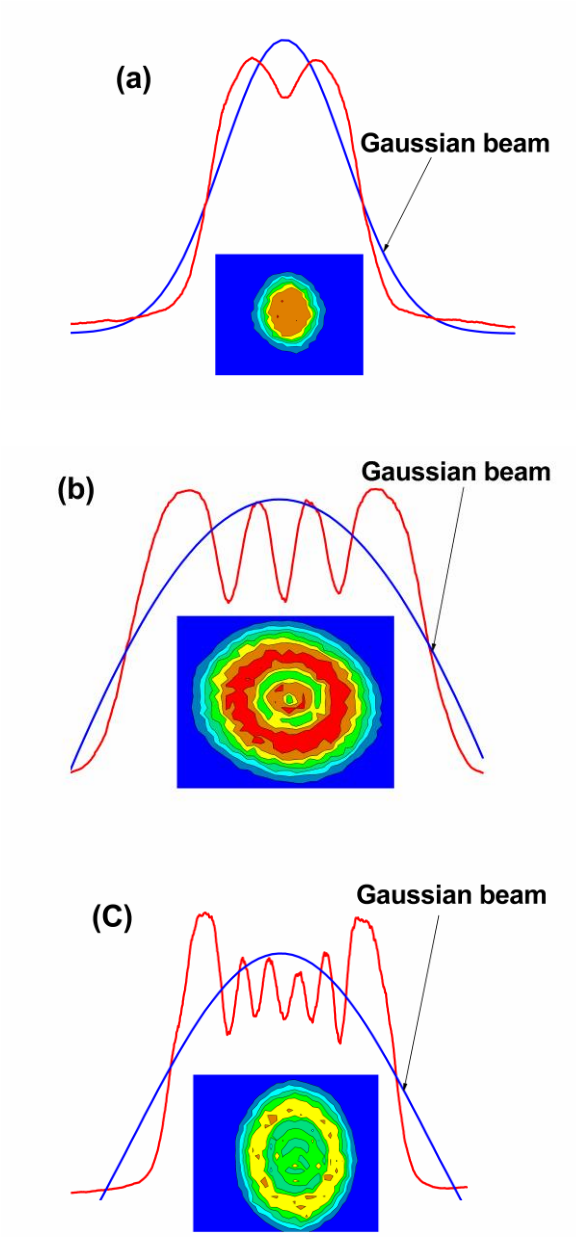


Fig. 5 . Self-diffraction patterns at three different concentrations: (a)14 mM,1 Ring (b)18 mM, 2 Ring and (c) 20 mM, 3 Ring.

Table 1. Nonlinear optical parameters for 4-Chloro -3-methoxynitrobenzene solutions determined by using the diffraction ring technique.

Con. mM	Rings No.	n_2 x10^{-9} Cm^2/Watt	Δn x10^{-5}	φ
14	1	0.90	0.83	0.10
18	2	1.83	1.70	0.21
20	3	2.79	2.59	0.32

These profiles demonstrate that a bright diffraction ring gradually becomes thicker from inner to outer side, and the light energy is mainly concentrated inside the outermost ring. Such behaviour corresponds to that observed earlier for divergent Gaussian beams passing through self-defocusing media. Notice that, in general, self-defocusing media have a negative optical nonlinear birefringence Δn [32,33]. The number of rings depends on the concentration, that is, increasing the molecular values increases the number of rings for the same input power. This means that, in the investigated samples, thermal effects have a large contribution to the negative nonlinear refractive index. The heat released in the 4-Chloro-3-methoxynitrobenzene solution by the focused Gaussian laser beam causes a migration of the solutes in the different concentration (DMSO and organic dye molecules) from the hotter region to the colder one.

2- Conclusion

The optical limiting performances of 4-Chloro-3-methoxynitrobenzene solutions have been investigated at 4, 6, 8 and 10 mM concentra- tions, using cw laser beam at 473 nm wavelength. The results show that the optical limiting efficiency is concentration dependent. Excellent optical limiting performances with relatively good stability for 4-Chloro-3-methoxynitrobenzene soluteons have been observed until the incident input power approaches 25 mW without sample damaging. The limiting behavior observed in all samples is attributed mainly to nonlinear refraction. Since the samples were pumped with cw laser beam the arising nonlinearities are predominantly thermal in nature. Due to change in refractive index of the material self-focusing and self-defocusing can be observed in the material, leading to reduction of transmittance at far field (due to distortion of spatial profile of Gaussian beam). Reduced transmittance in the far field gives better optical limiting performance. The self-diffraction ring pattern formed in the far field using 4-Chloro-3-methoxynitrobenzene in the DMSO solvent with different concentrations under CW laser for incident intensity 9.314 kW/cm^2 .The Intensity of the outer rings is greater than the intensity of the internal one and with higher concentration value led to an increase negative nonlinear refractive index, in other words, the sample appears as a defocusing medi- um. The increase of the number of diffraction rings and the size of the outmost ring with increasing the concentration are due to the increase in aggregation of the dye molecules at the point of focus at higher concentrations. The diffusivity extends to a larger region thereby causing more interference to take place leading to an increased number of rings. Also the threshold values of the sample with different concentrations for self-diffraction rings are unequal, the threshold values of the sample at 14, 18 and 20 mM concentration are 7.1, 6.55 and 6.34 mW respectively.

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دراسة كمية أنماط حلقات الليزر المحتث والحد البصري لمحلول نترات البنزين 4-كلورو-3-ميثوكسي

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الخلاصة :

تم توضيح فعالية الحد البصري لحالة محلول مادة نترات البنزين 4-كلورو-3-ميثوكسي وقد أجريت القياسات بأستخدام قدرة مقدارها 100 ملي واط لليزر الحالة الصلبة ذي الموجة المستمرة عند الطول الموجي 473 نانومتر وان لمعلمات خواص الحد البصري مثل قيم العتبة والمشبعة ممكن تعديلها هندسيا بواسطة تعديل معلمات التركيب وتركيز العينة . وكذلك في هذه الدراسة شوهدت ودرست أنماط الحيود المتولدة في مادة نترات البنزين 4-كلورو-3-ميثوكسي باستخدام نفس الليزر ذي الموجة الموجهه . ان عدد الحلقات يزداد تقريبا أسيا مع زيادة القدرة وزيادة التركيز للعينة .فقد وجد ان قيمة التغيير في معامل الانكسار وقيمة معامل الانكسار المؤثر بحدود 10^{-5} و 10^{-9} سنتمتر مربع / الواط على التوالي حيث ان معامل الانكسار المؤثر تم حسابه على أساس عدد الحلقات الملاحظة . أن قيمة العتبة للعينة عند التركيز 18,14, 20 ملي مول بحدود 6.43 ,6.55 ,7.1 ملي واط على التوالي وان هذه القيمه الكبيره في اللاخطية تعزى الى التأثير الحراري . الدراسة الحالية تتوقع بأن العينة مرشح محتمل للتطبيقات الاجهزه البصرية التي تدخل في تطبيق الحد البصري .

الكلمات المفتاحية : الحد البصري , الحيود الذاتي , التغيير في معامل الانكسار , صبغة عضوية .