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Study of The Nonlinear Properties of Methyl Red

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Abstract:

Nonlinear refractive index, n_2, of methyl red is estimated at the visible (532nm) laser beam via the generation of diffraction ring patterns. As high value as $5x10^{-7}cm^2/W$ for n_2 is obtained. Nonsymmetries in the diffraction ring patterns in the y-direction are noticed as a result of convection currents in the vertical direction.

Keywords: Diffraction ring patterns, Nonlinear refractive index, Methyl red, Convection currents.

1.Introduction:

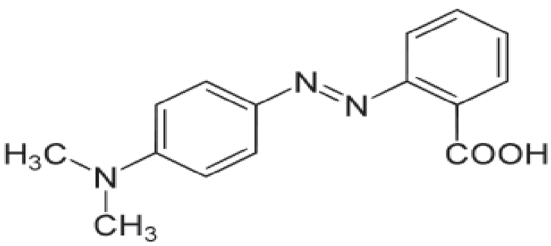
As a continuous laser beam with Gaussian profile propagates through a medium having nonlinear refractive index, number of effects occurs in the spatial dimensions. These effects are self-focusing, self defocusing, self phase modulation(SPM) [1-3] to name a few. Self-defocusing and (SPM) leads to the generation of diffraction ring patterns via which the nonlinear refraction index of so many materials have been calculated [4-6]. Nonlinear refractive indexes, n_2, of methyl orange, methyl red and methyl blue were measured [7-9] using the z-scan technique [10], excited with number of laser beam wavelengths viz., 473 nm,532nm and 635nm. Obtained n_2 values ranged from 10^{-14} cm^2/W to $10^{-7}cm^2/W$.

In this article the results of an experiment conducted on methyl red dissolved in Dimethylsulfoxide (DMSO.) using a cw low-power visible laser beam (532 nm) having Gaussian intensity distribution were diffraction ring patterns generated in the far field. Refractive nonlinear index, n_2, is calculated at 532 nm wavelength.

2. Experimental:

2.1 Molecular structure and formula of methyl red:

Fig. (1) Shows the molecular structure and molecular formula of methyl red



$C_{15}H_{15}N_3O_2$

Fig. (1): Molecular structure and molecular formula of methyl red

2.2 UV-visible spectroscopic study:

Fig. (2) represents the linear absorption spectrum of methyl red dissolved in DMSO the range 300-900 nm at room temperature where a jenway-England-6800 uv-visible spectrophotometer was used. Using Fig. (2) and the equation (1) [11]

α=2.303 A/d………………………………… (1)

the absorption coefficient,α, is calculated. A and d are the methyl- red absorption and thickness respectively .For d=1 mm, α= 55.9 cm^{-1}

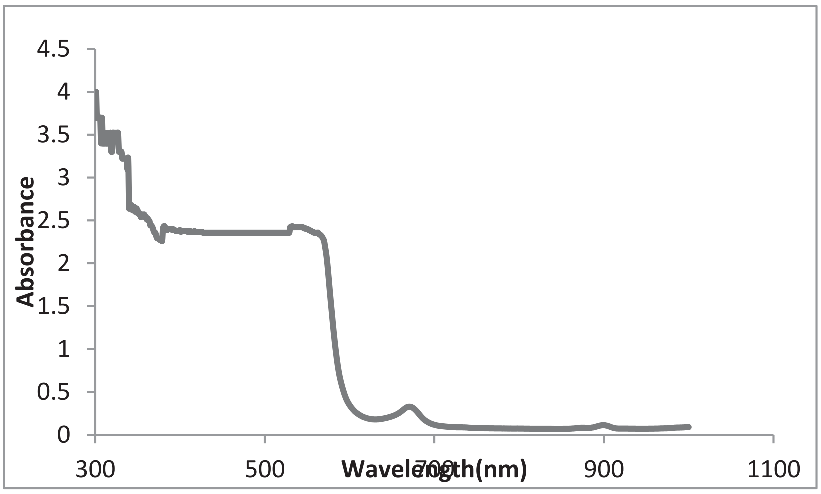


Fig. (2): Absorbance spectrum vs. wavelength for methyl red

2.3 Experimental set-up:

To obtain the diffraction ring patterns the experimental set-up shown in Fig.(3) was used. It comprises a cw low power laser beam obtained from a solid state laser (SDL) emitting light at 532 nm with Gaussian intensity distribution. A glass sample cell of 1mm thickness was used together with a glass 5 cm focal length glass lens to focus the laser beam on the sample cell and a 30*30 cm semi-transparent screen 70 cm away from the sample cell. A power meter (type SDL-PM-002) was used to measure the input power and a digital camera (DSC-T99-8700-82-25 mm) was used to register the diffraction ring patterns.

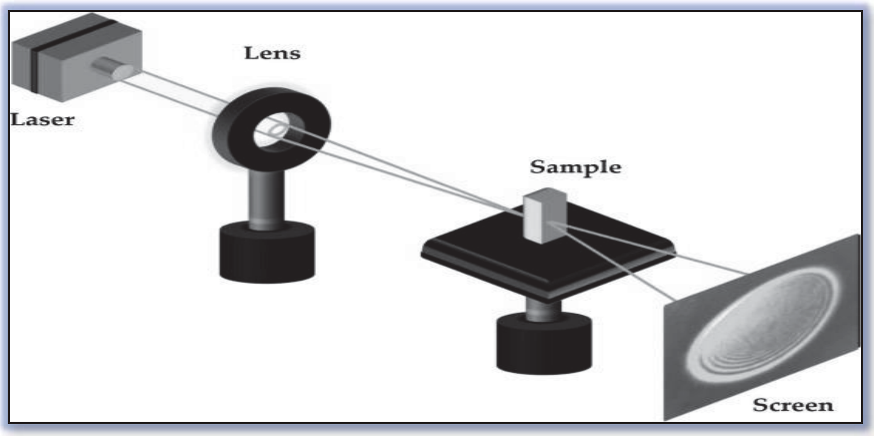


Fig. (3): Experimental setup for the generation of diffraction ring patterns

3. Results and discussion:

Fig.(4) shows diffraction ring patterns obtained in methyl red where it can be seen that(1) each diffraction ring pattern area increases monotonically with the increase of input power,(2) the number of rings per each pattern increases with the increase of input power,(3) it can be seen that each pattern loses symmetry in the y-direction, with the increase of input power, compare to the x-direction i.e. the diameter of each ring in the x-direction increases in a ratio greater than those in the y-direction.

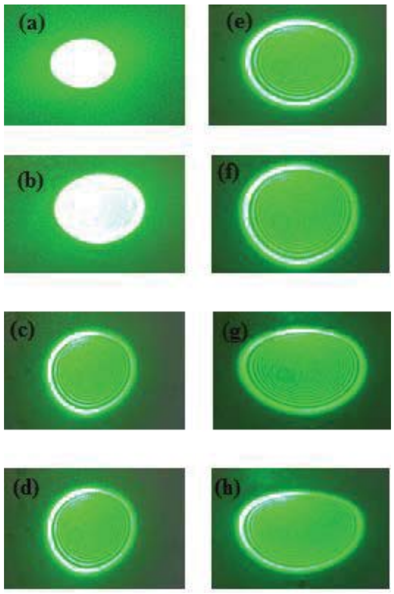


Fig. (4): Diffraction ring patterns in methyl red at input power (mW):(a) 9, (b) 18, (c) 34, (d) 56, (e) 70, (f) 86, (g) 94, (h) 102

The first two observations are explained as follows: As the input power increased so does the the amount of power absorbed by the methyl-red hence more heat is generated locally which leads to changes in the refractive index of the methyl-red based on the equation

$n=n_0+\Delta n$

$n=n_0+n_2I$…………………………………………… (2)

n is the sample refractive index in the presence of laser beam ,n_0 is the linear (back-ground)refractive index ,Δn is the total change in refractive index, n_2 is nonlinear refractive index and I is the input intensity. Since the area of diffraction ring patterns increases with increase of input power, self-defocusing occur i.e more heat is generated locally in the shape of Gaussian distribution so that the methyl-red mimics locally a concave(negative) lens that act to increase the area of each ring pattern as input power increased. The third observation is explained as follows: As the input power is low, conduction of the heat in the horizontal(x) direction equals the convection of heat in the vertical(y) direction so that each ring pattern appeared symmetric. As input power increased more heat is generated and the conduction current in the x-direction is no longer equals the convection current in the y-direction so that each ring pattern loses symmetry as can be seen in Fig. (4).

4-Estimation of the nonlinear refractive index of methyl-red:

when a diffraction ring appeared it means that the phase of the laser beam has change by (2π) radians as it traversed the nonlinear medium. For N rings to appear the total phase(ϕ) change equals $2\pi N$ i.e

$\phi=2N\pi$ .... (3)

For a medium of thickness, d, the phase change,ϕ,can be written as

$\phi=k\Delta$ ………………………………………………… (4)

K is the beam wave vector=$2\pi/\lambda$, λ is the laser beam wavelength and total path length,Δ

Δ=dΔn ……………………………………………… (5)
Δn is the total change in refractive index of the sample, so that
Δn=n_2I ……………………………………………… (6)
and [12]
Δn=Nλ/d ………………………………………… (7)
λ=532 nm, d=0.1 cm, N=15,I=2P/$\pi\omega^2$(P is the laser beam input power,ω is the laser beam spot size falling on the sample =1.22 fλ/ω_0',f is the lens focal length =5 cm ,ω_0' is the laser beam spot size falling on the lens =ω_0 $[1+(z/z_0)^2]^{1/2}$,ω_0 is the laser beam spot size as it leaves the laser output coupler=0.15 cm) so that
Δn= 7.98x10^{-3}
n_2 =5 x 10^{-7} cm^2/W
the nonlinear refractive index of methyl-red solution can be compared well with those of number of representative materials: Curcumin 5.825x10^{-7} cm^2/W, Dimethoxy curcumin 4.16x 10^{-7} cm^2/w, Chlorocurcumin 2.838x10^{-7} cm^2/W [14], Cobalt Phthalocyanine 7.79x$10^{-9}$$cm^2$/W [15], Rose, Linseed and Chamomile (0.3,0.43,1.43) x10^{-6} cm^2/W [6], 10W30, 1.62x10^{-7} cm^2/W [4], etc.

Conclusions:

The illumination of methyl-red with visible,532nm, cw low power laser beam have led to the generation of multiple diffraction ring patterns. These patterns show direct dependence in number of rings and areas of each pattern on the input power of the laser beam. Based on the number of rings obtaind, the nonlinear refractive index of methyl-red has been obtained. As the input power of the laser beam increased the diffraction ring patterns lose symmetries in the y-direction due to convection currents.

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