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Diffraction Ring Patterns And Z-Scan Measurements Of The Nonlinear Refraction Index Of 5W20 Oil

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Abstract:
Nonlinear properties of 5W20 oil have been investigated using the diffraction ring pattern and Z-scan techniques. The nonlinear refractive index was measured by the use of a solid state laser in the CW regime at wavelength 473 nm. Experimental results show that such a sample has a large, negative, nonlinear refractive index ($n_2 = 4.22 \times 10^{-7}$ cm^2/W). The optical power limiting performances for 5W20 oil have been investigated. These results proved that 5W20 oil has significant nonlinear properties and it could be used for photonic and nonlinear optical devices.

***Keywords*: Self-phase modulation, Diffraction ring pattern, Z-scan technique.**

1. Introduction

The race for obtaining new materials with fast response time and large nonlinear refractive index is an ongoing matter for the last thirty years [1-6]. These materials have been extensively used in all optical applications such as high density optical data storage, optical phase conjugation, all optical switches and optical limiting devices [7-10]. Vegetable oils are the new comer to be used for the same proposes owe to the new work of Sultan et al. [11] and Hassan et al. [12]. Very little attention have been paid to oils [13,14]. These oils shows large nonlinear refractive index in the visible region viz. oils in the 660 nm wavelength [13] and SAE 70 oil in the 473 nm wavelength. In this work the results of two experiments on 5W20 oil viz. diffraction ring and Z-scan is presented to estimate its nonlinear refractive index. The experiments were performed using a continuous wave (CW) solid state laser (SDL) emitting light at wavelength of 473 nm.

2. Experimental

2.1 sample and uv-visible spectroscopic results

The absorption property of the 5W20 oil used in the experiment which was characterized at room temperature in the (350-900) nm range using a double UV-visible spectrophotometer type 6800 Jeneway, England. The absorbance (A) of 5W20 oil in a glass cell, 1 mm thick against wavelength is shown in Fig.(1). The absorption coefficient ,α, is calculated using Fig.(1) and the relation [15]

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

where d is the samples thickness, so that α = 17.29 cm^{-1} , at λ=473 nm.

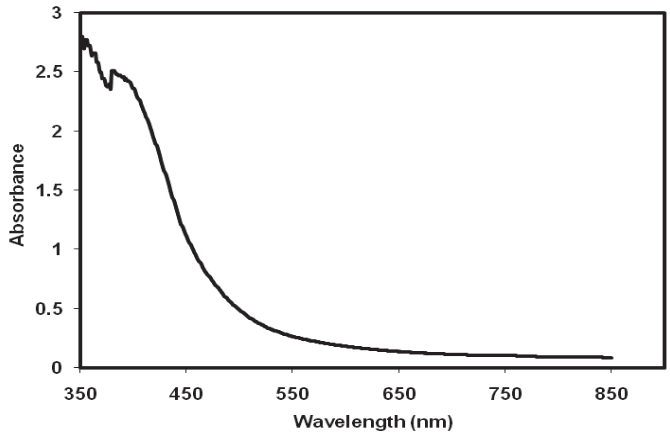

Fig.(1): UV-vis absorption spectrum of 5W20 oil.

2.2 Experimental set up

The experimental set up used to obtain the diffraction ring pattern is shown in Fig.(2) where a solid state laser emitting single transverse mode, CW, 473 nm, beam with variable power (0 - 66 mW) was used as irradiation source. The laser beam was focused using a 50 mm focal length glass lens onto a 1 mm glass cell containing the 5W20 oil sample, resulting ring patterns was examined on a 30 x 30 cm semitransparent screen 70 cm away from the sample cell.

The Z-scan experiment was conducted using the same set up of diffraction pattern except fixing the sample cell onto a movable stage and the screen was replaced by a power meter covered with a narrow (2 mm) circular aperture to measure to the power transmitted from the sample.

The optical limiting responses was performed via measuring the transmitted power from the sample against input power. Also the optical limiting experiment was carried out using the same set up of diffraction pattern except that the screen was replaced by a power meter.

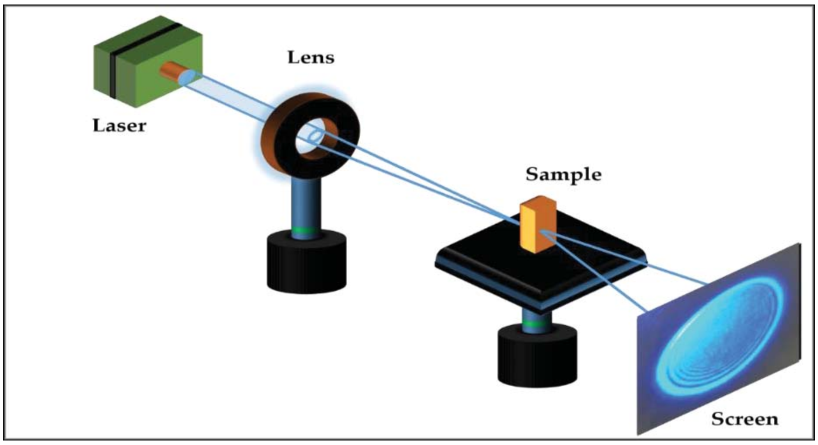

Fig.(2): Experimental set-up for generation of diffraction ring patterns.

3. Results and discussion

3.1 Diffraction ring

Fig.(3) shows diffraction patterns at input power (mW): 5, 20, 36, 51 and 65 where it can be seen that the number of rings of any ring pattern and the size of each pattern increases with increasing input power. Fig. (4) shows the variation of the diameter of the outer- most ring in each pattern against input power at λ=473 nm. It can be seen from the Fig.(4) that the diameter of the outer- most ring increases with increasing input power.

3.2 Estimation of the nonlinear refractive index due to ring patterns

The radius of the laser beam falling on the sample, ω, can be obtained using the relation [16]

$$\omega = \frac{1.22\, f\lambda}{\pi\omega_o} \qquad (2)$$

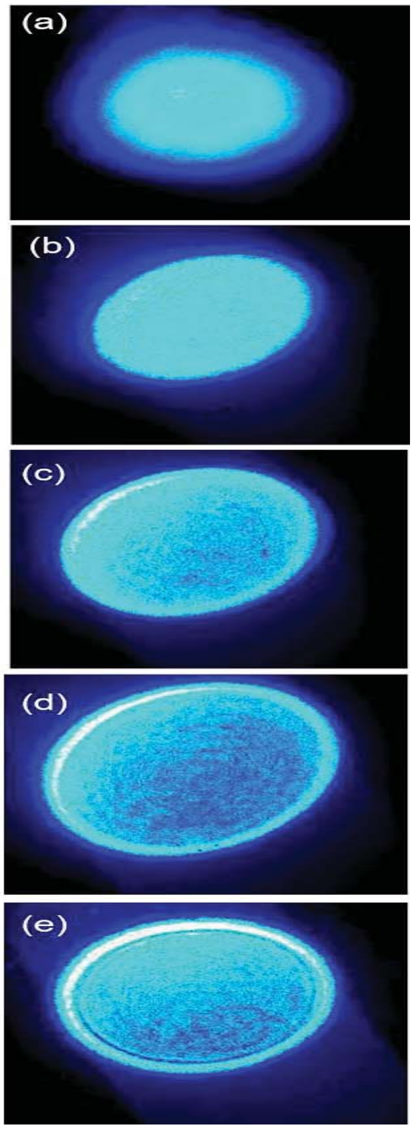

Fig.(3): Images of the far field diffraction rings at input laser power passing through the sample cell of (a) 5 mW, (b) 20 mW, (c) 36 mW, (d) 51 mW (c) 65 mW.

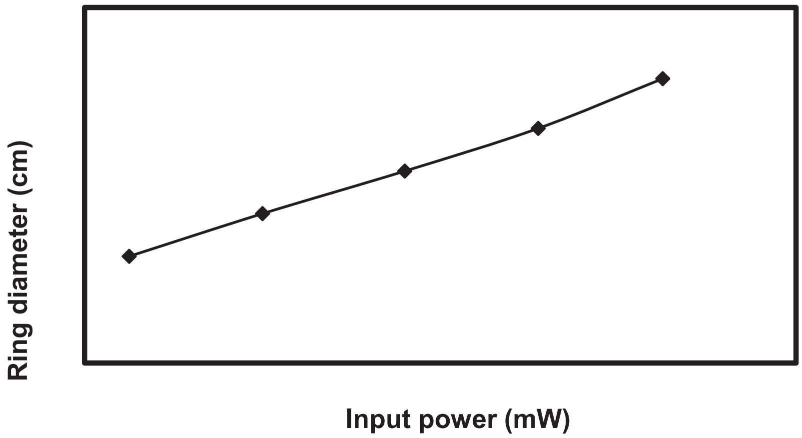

Fig. (4): Diameter of outer-most rings for 5W20 oils against input power respectively at λ=473 nm.

ω_o is the beam radius as it leaves the laser output coupler (=0.15 cm), f is the lens focal length and λ is the laser beam wavelength (=473 nm) so that ω = 19.235 μm. The laser beam intensity falling on the sample can be obtained using the relation
P is the input power falling on the sample so that the maximum input intensity is 11190 W/cm^2. The

$$I = \frac{2P}{\pi\omega^2} \quad (3)$$

total change in the refractive index of the medium, Δn, and the nonlinear refractive index, n_2, can be calculated using the relations [17]

$$\Delta n = \frac{N\lambda}{d} \quad (4)$$

$$n_2 = \frac{\Delta n}{I} \quad (5)$$

N is the total number of rings per each diffraction ring pattern and d is the sample cell thickness. For N = 10, λ=473 nm, d = 0.1 cm , I = 11190 W/cm^2 , Δn = 0.00473 and n_2 = 4.22x10^{-7} cm^2/W.

3.3 Z-scan

To obtain the nonlinear refractive index , the closed aperture Z-scan experiment was carried out by translating the sample cell in the z-direction between (-z) passing through z = 0 and (+ z), and measuring the transmitted intensity, the result of which is shown in Fig. (5).

3.4 Estimation of nonlinear refractive index due to Z-scan

The data are analyzed on the basis of thermal variation of the refractive index as the predominant mechanism of nonlinearity in the case of low power CW laser excitation. Such a thermally induced effect has been reported in solutions of many absorptive materials [18,19]. Thermal lensing occurs as the energy absorbed from a Gaussian laser beam produces heating of an absorbing medium about the beam axis. A radially dependent temperature distribution is created which in turn produces a refractive index change.

For input power of 20 mW (intensity $I = 3443$ W/cm^2) and difference between transmittances at peak and valley, $\Delta T_{p-v} = 0.1957$ and d = 0.1 cm, the nonlinear refractive index, n_2, was calculated using the relation [20]
So that n_2 equals to 0.42 x 10^{-8} cm^2/W.

$$n_2 = \frac{\Delta T_{p-v} \lambda}{4\pi d\ I} \qquad (6)$$

The obtained results ensured that self-defocusing nonlinearity is the main cause of the diffraction ring pattern with negative nonlinear refractive index (peak followed by valley Z-scan shown in Fig.(5)).The self-defocusing effect is due to the local variation of the refractive index with temperature.

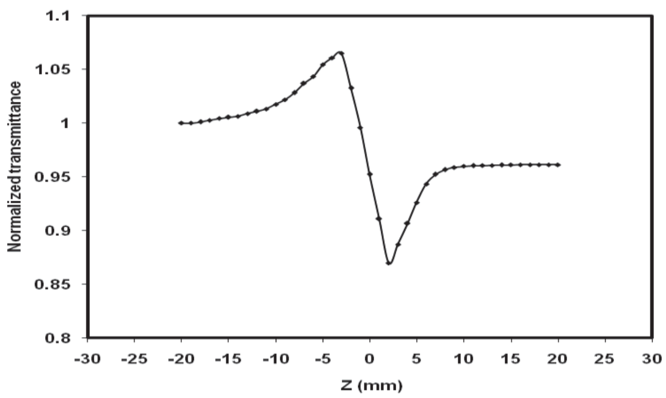

Fig. (5): Closed aperture Z-scan data for 5W20 oil**.**

3.5 Optical limiting

Optical limiting devices are currently of interest for protecting sensors and eyes against high laser intensity. An ideal limiter exhibits a linear transmission below threshold, and a constant transmission above threshold. In order to obtain the optimum optical limiting characteristics, the sample is fixed at the valley position of the Z-scan. Fig. (6) shows the limiting behavior measured at 473 nm wavelength for 5W20 oil. Optical limiting was obtained by varying the input power and by monitoring output power. It is found that the sample shows optical limiting effect. That is, the response of the 5W20 oil is linear to the input power at very low output power, obeying Beers Law, but at high input power, the output power reaches a plateau, with further increase of the input power, i.e., it is saturated at a point defined as the limiting amplitude, and a nonlinear relationship is observed between the output and input power.

Fig.(7) shows the normalized transmittance curve as a function of incident input power for the sample. The limiting threshold is defined as the incident laser power, at which the transmittance falls to 50% of the linear transmittance. The limiting threshold of the 5W20 oil was found to be 21 mW.

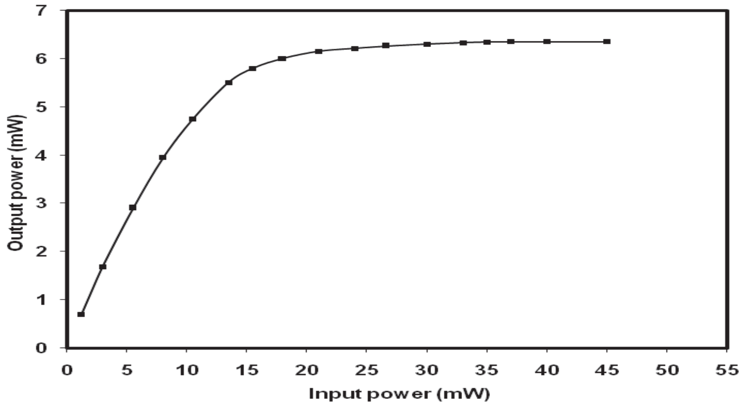

Fig.(6): Optical limiting property of 5W20 oil.

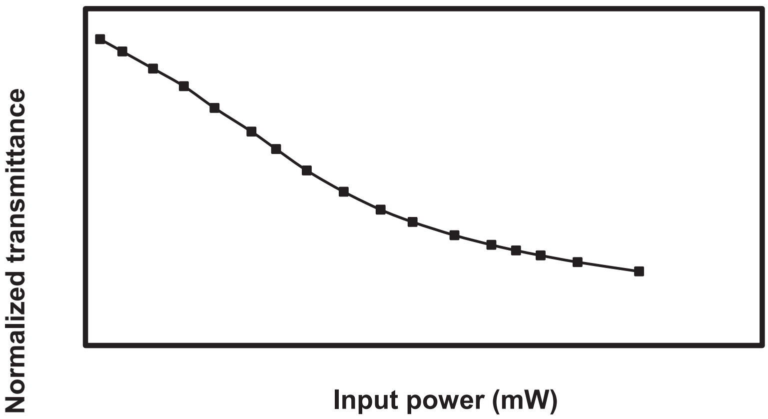

Fig.(7): Normalized transmission curve of optical limiting for 5W20 oil.

4. Conclusions

Self-diffraction rings or spatial self-phase modulation were observed in 5W20 oil under 473 nm continuous wave laser irradiation. It is found that the number of rings as well as diameter of the outer-most ring in each pattern obtained increases with increasing input power. We have measured the nonlinear refraction index coefficient n_2 for 5W20 oil using diffraction ring pattern and the Z-scan. The results indicate that the 5W20 oil exhibits self-defocusing nonlinearities. The large nonlinearity which shown by the sample is attributed to a thermal effect resulting from linear absorption. The optical limiting properties of 5W20 were studied. The sample show optical limiting action. The results obtained in this work shows that the studied material can be used as a stable optical limiter in various optical limiting devices for the eye or sensor protection.

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