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Qusay M Ali Hassan
College of eduction for Pure sciences

Hamza Bakr
University of Basrah

Hasan Sultan
University of Basrah

Raed M Hassan
University of Basrah

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QUSAY M. A. HASSAN, H. BAKR, H. A. SULTAN, RAED M. HASSAN & C. A. EMSHARY
Department of Physics, College of Education for Pure Sciences, University of Basrah Governorate, Iraq

ABSTRACT

The investigation of nonlinear optical characteristics of SAE 70 oil, by using self - diffraction techniques and Z-scan technique, using continuous wave (CW), visible laser beam is presented. Multiple diffraction rings were observed, when a beam propagates through this oil. A large thermal-induced nonlinear refractive index, up to 2.498×10^{-7} cm^2/W was obtained from SAE 70 oil, under 473 nm continuous wave (CW), laser irradiation. The nonlinear absorption of SAE 70 oil was obtained from open aperture, z-scan technique. Optical limiting performance of SAE 70 oil was investigated under irradiation, by a CW laser beam using transmission measurement, through the sample which indicates that this material is a potential candidate, for optical limiting applications in low power CW regime.

KEYWORDS: Nonlinear Optics, Nonlinear Refractive Index, Z-Scan Technique, Optical Limiting

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1. INTRODUCTION

Rapid technological advancements in optics have placed greater demand, on the development of nonlinear optical materials, with prominent applications in optical limiting and all optical switching [1-3]. So many materials have been tested for this goal viz., dense atomic vapors [4], nematic liquid crystals [5], solids [6], liquids [7] in vegetable oils [8]. In this article, we have presented the results of experimental investigations of the nonlinear properties of ASE 70 oil, owe to the severe shortages of the use of such materials, in optical applications. The multiple diffraction rings [9] have been used, to investigate the nonlinearities in these materials. Z-scan technique [10] is another technique that has also been used, for the same goal.

In the diffraction ring technique, the number of rings generally depends on the, on-axis nonlinear phase shift suffered by the laser beam, during the passage through the medium sample. When a Gaussian beam passes through a nonlinear medium, a concentric ring intensity distribution tends to form in the far field. This phenomenon has aroused wide interest among researchers, since Callen et al [11] observed first the far field annular intensity distribution, of a He-Ne laser beam passing through the nonlinear liquid CS_2, in 1967. By counting the number of rings that appear in each pattern, one can simply determine the nonlinear refractive index. The phase shift depends on an optical intensity, magnitude and saturation value, of the nonlinear refractive index, sample thickness, etc. Z-scan technique, based on the spatial distortion of a laser beam passed through the medium sample, is widely used in material characterization, because of its simplicity, high sensitivity and well-elaborated theory. The Z-scan method, exploits the self-focusing and refocusing phenomena, in nonlinear optical materials. In this method, the nonlinear sample is exposed through the focal plane of a tightly focused Gaussian laser beam and the change in the far-field intensity pattern is monitored. For a pure refractive nonlinearity, the light field induces an intensity- dependent nonlinear phase, as a consequence of the transverse Gaussian intensity profile; the sample presents a lens-like behavior. The induce self-phase modulation, has the tendency of defocusing or recollimating the incident beam, depending on its Z position, with respect to the focal plane. By monitoring the transmittance change through a small circular aperture, placed in the far-field position, one is able to determine the nonlinear refractive index. Both techniques can be conducted simultaneously, using the same apparatus, at low input cw laser beam powers.

2. EXPERIMENTAL

2.1 Sample and UV-Visible Spectroscopic Results

The SAE 70, used in the experiment's absorption, has been characterized at room temperature, in the range (350-900) nm using a double UV-visible spectrophotometer type, 6800 UV-visible Jenway, England. Figure 1, shows the spectral absorbance (A) of SAE 70 oil, in a glass cell of 1 mm thickness, where the absorption coefficient (α) at a laser beam wavelength of 473 nm is calculated, using the formula $\alpha = 2.303A/L$ (A is the absorbance and L is the cell thickness) which is found to be $\alpha = 21.14\ cm^{-1}$.

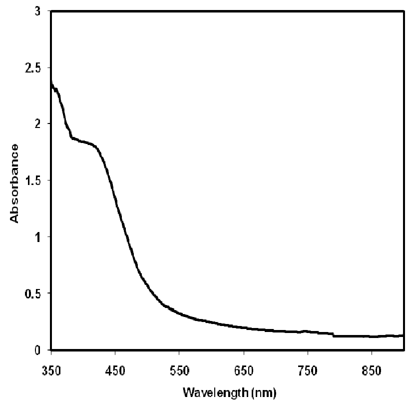

Figure 1: Spectral Absorbance of SAE 70 Oil

2.2 Experimental Set Up for Diffraction Ring Patterns

The experimental arrangement, shown in Figure 2, comprised SAE oil 70, in a glass cell, 1mm thick, and a conventional solid state laser (SDL-473-050T) emitting continuous wave visible (473nm) laser beam of, 1.5mm spot size, (at $1/e^2$ of the maximum intensity) operating on the lowest TEM_{00}, fundamental Gaussian mode. A 50 mm focal length glass positive lens was used to focus the laser beam, on the sample cell. The laser output power was measured using a power multi-range meter (type SDL-PM-002), while a digital camera (type 50ny DSC-T99-8700-82-25 mm) was used to record the ring patterns. A 30x30 cm semitransparent screen was used, to measure each ring pattern.

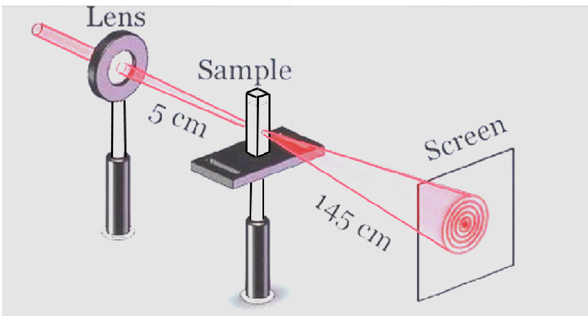

Figure 2: Experimental Set-Up for Diffraction Rings Technique

2.3 Z-Scan Technique

The conventional Z-scan scheme was used in this study. Light from a CW solid state laser SDL (λ = 473 nm), propagating in the z direction, was focused onto a narrow aperture with the same lens, used the section 2.2. The intensity at the focus point was calculated to be, 2.5 kW/cm^2. The sample was moved back or forth along the z axis, near the beam waist of the laser. The far field transmitted intensity, of the laser beam was measured as a function of the sample position, using a photo detector fed to the digital power meters (Field Max II-To+OP-2 Vis Sensor) and placed behind the sample. As the sample moved along the z axis, passing through the focal point of the lens, near the beam waist. Self-focusing or self-defocusing, modifies the wave front of the beam and thereby changes the detected intensity of the emerging beam. An aperture of 2.5 mm in radius was placed in front of the detector, to assist in the measurement of the self-defocusing effect. In this experiment, measurements were made at room temperature.

2.4 Optical Limiting

The optical limiting setup was similar to that used for the above measurements and the same laser was used as, for the Z-scan experimental set-up, except that the cell containing the nonlinear medium was placed, just after the focal point.

3. RESULTS AND DISCUSSIONS

3.1 Diffraction Ring Patterns Measurement

Using the blue 473nm laser beam, with variable output power falling on the sample cell, the diffraction ring pattern appeared post irradiation instantaneously, as it can be seen in Figure 3, where it can be seen that, number of rings in each pattern in SAE 70 oil, increases with the increase of input power.

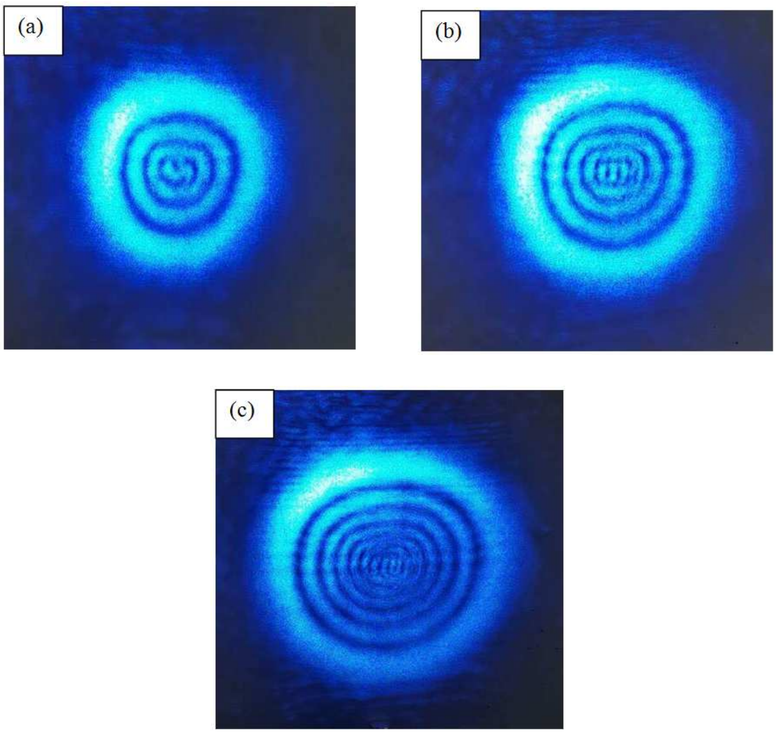

Figure 3: Images of the Instantaneous Rings Patterns at (a) 44 Mw (b) 54 Mw (c) 66 Mw Laser Beam Passing Through SAE 70 Oil

3.2 Estimation of Nonlinear Refractive Index

The laser beam, leaving the positive glass cell and falling on the sample cell having a spot size, ω, which was calculated using the formula, $\omega = 1.22\ f\lambda/\ \omega_o$ [12], f is the lens focal length, λ is the laser beam wavelength and ω_0 is the laser beam spot size, that leaves the laser output coupler. For f = 50 mm, λ = 473 nm and ω_o = 1.5 mm, ω = 19.235 µm. The input intensity of each power input, was calculated using the formula, $I=2P/\pi\omega^2$ so that, the input intensities, for the power input of 44 mW, 54 mW and 66 mW are, 7573 W/cm^2, 9297 W/cm^2 , 11359 W/cm^2 respectively. For each ring that appeared in every ring pattern the phase shift suffered by the laser beam, as it traverse the sample cell, is equal to 2π. So that, for N number of rings, the total change in refractive index, Δn, can be calculated using the formula

$$\Delta n=N\lambda/L$$

[4] Where λ and L were defined earlier so that, Δn is equal respectively to, 1,419x10^{-3} , 1.892x10^{-3} , 2.838x10^{-3} , for N = 3,4,6.

The nonlinear refractive index, n_2, can be calculated using the formula

$$\Delta n = n_2 I$$

[13], I is the laser input intensity, so that n_2 equals, respectively to 1.87x10^{-7} cm^2/w, 2.035x10^{-9} cm^2/w, 2.498x10^{-9} cm^2/w.

3.3 Z-Scan

The open-aperture Z-scan (i.e. in the absence of the aperture in front of the detector), was performed, to measure the magnitude of the nonlinear absorption coefficient, of the SAE 70 oil. Figure 4a, shows the open aperture obtained data from Z-scan, for SAE 70 oil. The curve exhibits a normalized transmittance valley, indicating the presence of induced nonlinear absorption, in the sample.

The nonlinear absorption coefficient, β, was estimated from the original valley value (ΔT), at the experimental open aperture Z-scan curve [10] as,

$$\beta = \frac{2\sqrt{2}\Delta T}{I_o L_{eff}} \tag{1}$$

Where ΔT is the one-valley transmittance value, in the open aperture Z-scan curve, $L_{eff} = [1-\exp(-\alpha L)]/\alpha$ is the effective thickness of the sample. α and L have the same definitions, introduced earlier.

The closed aperture Z-scan curve of SAE 70 oil is shown in Figure 4b. The peak followed by a valley-normalized transmittance features, obtained from the closed aperture Z-scan data, indicates that the sign of the refraction nonlinearity is negative, i.e. self-defocusing [18]. The self-defocusing effect is due to the local variation of the refractive index with temperature. As the material has a negative refractive index, it results in defocusing nature of the material, which is an essential property, for the application, in the protection of optical sensor, such as night vision devices.

Generally, the measurements of the normalized transmittance versus sample position, for the cases of closed and open aperture, allows the use, in the determination of the nonlinear refractive index, n_2, and the saturation absorption coefficient, β. 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 scan. 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 data, by the corresponding open aperture scans. Figure 4c, represents such plot, obtained from the samples, i.e., the ratio of closed aperture to the open aperture Z-scans. The data obtained in this way, purely reflects the effects of nonlinear refraction.

The on-axis phase shift, $|\Delta\phi_o|$, at the focus, is related to the difference in the peak-valley transmissions, ΔT_{p-v} as,

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

Where $S=1-\exp(-2r_a^2/\omega_a^2)$, is the aperture linear transmittance, with r_a denoting the aperture radius and ω_a denoting the beam radius at the aperture, in the linear regime. The nonlinear refractive index, n_2, is then given by,

$$n_2 = \frac{\Delta\phi_o \lambda}{2\pi L_{eff} I_O} \tag{3}$$

Where I_o is the incident beam intensity.

The nonlinear absorption coefficient, β, (cm/W) and nonlinear refractive index, n_2, (cm^2/W) for SAE 70 oil were calculated from the open and closed aperture normalized transmittances in Figures.4a and c respectively, their values are 8.76 x 10^{-4} cm/W and 1.85 x 10^{-8} cm^2/W respectively.

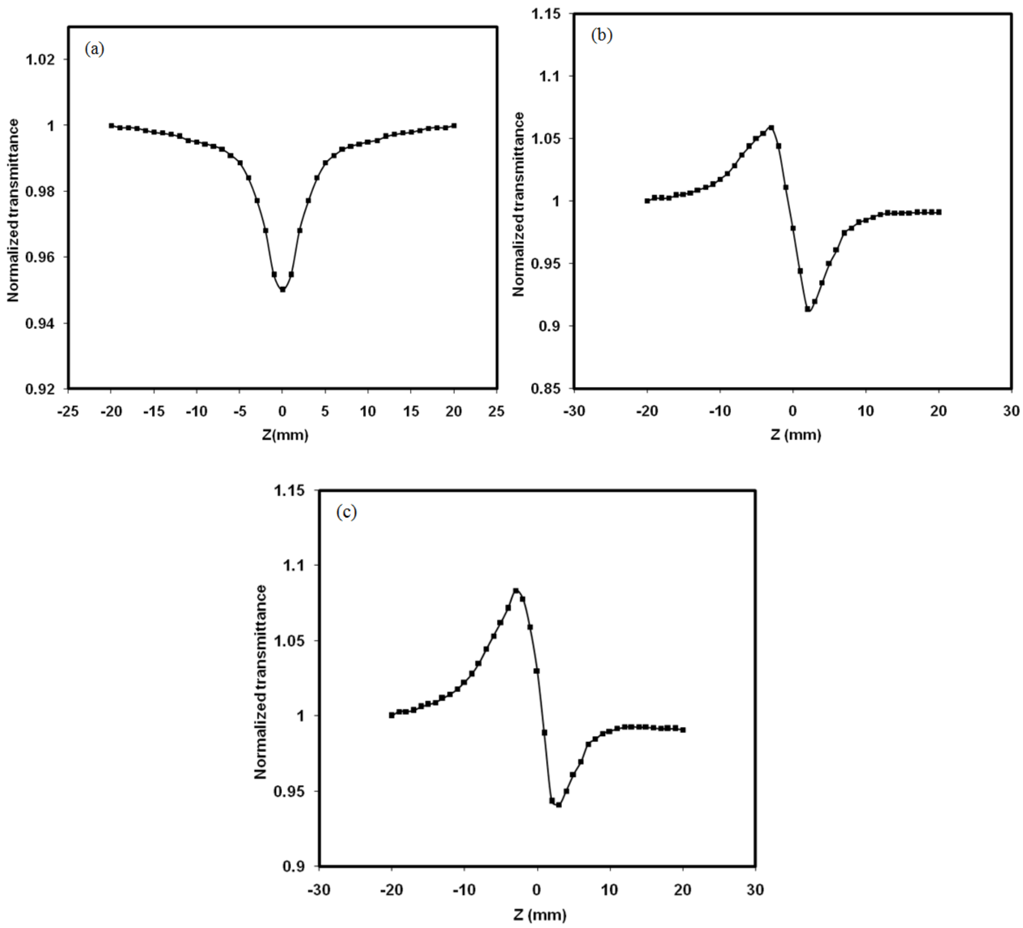

Figure 4: Z-Scan Data of SAE 70 Oil (a) Open Aperture Scan (b) Closed Aperture Scan and (c) the Division of B by A

3.4 Optical Limiting

Optical limiters are devices that strongly attenuate optical beams, at high incident intensities while exhibiting high transmittance, at low intensities. An ideal optical limiter, is perfectly transparent at low intensities, up to a predetermined intensity level, above which, the transmitted intensity was clamped at a constant value. These materials have important applications, for the protection of the human eye and optical sensors, from intense irradiation fields. The optical limiting is obtained by varying the input power of the laser and measuring the output power by the sample, in the presence of an aperture. Figure 5 presents the optical limiting results of the SAE 70 oil. It is found that, the sample shows optical limiting effect. At low incident intensity, output from optical limiter varies linearly with the incident intensity, obeying the Beer's law. But at a high incident intensity, the output intensity of the sample tend to deviate linearity and a nonlinear relationship was observed, between the output and incident intensity; which is defined as the limiting threshold. With a further increase in the incident intensities, the output intensity reaches a plateau and is saturated.

Figure 6, shows the behavior of the transmitted light intensity, as a function of the incident intensity. In general, the optical limiting ability of a sample is evaluated in terms of a limiting threshold, which is defined as the incident input intensity/power, where the transmission reduces by 50 %. The optical limiting thresholds, for the sample is measured to be 21 mW.

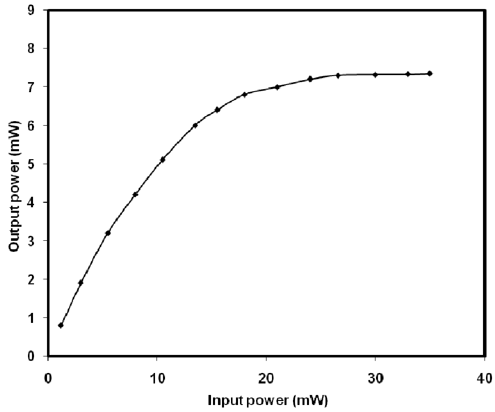

Figure 5: Optical Limiting of SAE 70 Oil

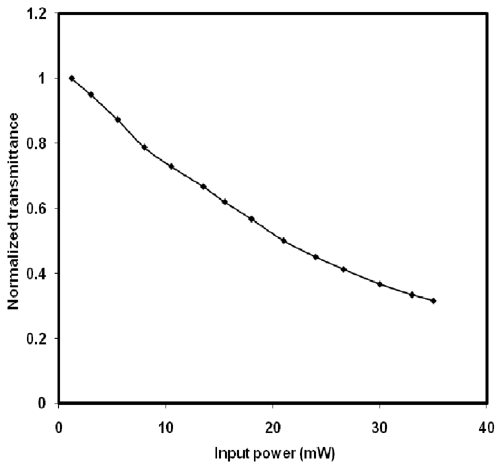

Figure 6: Normalized Transmission Curve of Optical Limiting for SAE 70 Oil

4. CONCLUSIONS

In the present work, we studied the nonlinear optical properties of SAE 70 oil, using self-diffraction and single beam Z-scan techniques. We have studied systematically, the generation and evolution of the far-field diffraction, of Gaussian beams, post propagation through a self-defocusing medium. It is found that, the number of rings observed in the far field, varies as a function of beam intensity. Both techniques and measurements, performed with CW laser light, revealed that, the nonlinear refractive index, in SAE 70 oil is in the range of 10^{-7} cm^2/W. The negative sign of nonlinear refraction, determines self-defocusing phenomena, for SAE 70 oil. The values of nonlinear absorption coefficient, β, are obtained in order of 10^{-4} cm/W. The optical limiting properties of SAE 70 oil were investigated and the results showed that, the oil show optical limiting effect.

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