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NONLINEARITIES OF A BRAKE FLUID USING LOW VISIBLE LASER BEAM

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Abstract

A number of diffraction rings were observed when a continuous wave laser light beam from a solid laser passed through the brake fluid. The effect of incident intensity on number and size of diffraction rings are reported. The nonlinear refractive index at the wavelength of 473 nm by diffraction rings and Z-scan techniques are determined. The results obtained from self-diffraction rings and Z-scan method are compared. The results showed that the brake fluid has large nonlinear refractive index. The optical limiting properties of the brake fluid were investigated. The optical limiting mechanism for sample is given.

Key words: Spatial self-phase modulation, Diffraction ring pattern, Z-scan, Nonlinear refractive index.
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1. Introduction

The search for obtaining new materials to be used in different applications viz., all optical switches, optical computing, optical data storage, optical communications, optical phase conjugation, optical limiting, all optical processing, etc. [1-28] is an going matter. These materials have to have high nonlinear refractive indexes and responds in short times. The present authors have published recently series of papers studying the nonlinearities of vegetable oils [29,30] and metal oils [31,32]. The most simple and accurate methods used to evaluate the change in refractive index and nonlinear refractive indexes of different materials are the diffraction ring patterns [33-,34] and the Z-scan [35,36]. In this work the results of experiments conducted on a brake fluid concerning the evaluation of the change in refractive index of this material and its nonlinear refractive index using the diffraction ring pattern technique and the Z-scan's using visible low power single transvers, TEM_{00}, mode laser beam at 473 nm. The transmission technique was used to measure the optical limiting response at the same wavelength.

2. Experimental

2.1 UV-visible spectroscopy to measure absorption coefficient,α

To obtain the linear absorption coefficient,α, of the brake fluid type Dexron-VI obtained from ACDelco at room temperature the absorbance, A, of the brake fluid in a quartz 1 mm thickness cell using a Jenway-England-6800 UV- visible spectrophotometer is measured. The result of the variation of absorbance, A, against wavelength in the 350- 900 nm range is shown in Fig.(1). With the aid of Fig.(1) and the following relation [37]

$$\alpha = 2.303\frac{A}{L} \tag{1}$$

Where L is the sample cell thickness (= 1 mm) so that α = 34.31 cm^{-1}.

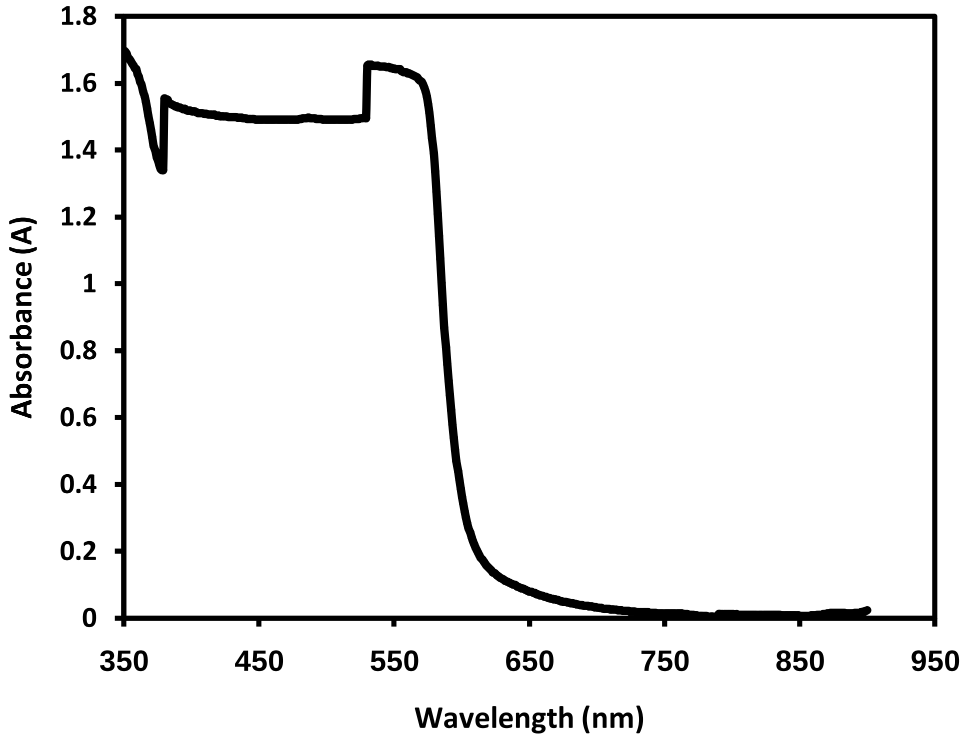

Fig.1. UV – visible absorption spectra for brake fluid.

2.2 Experimental set-up

The experimental set-up shown in Fig.(2) to obtain diffraction ring pattern (then Z-scan with minor modifications) comprised a cw visible laser beam obtained from a solid laser device (type SPC T50) emitting single mode-TEM_{00}- laser beam, a glass lens of 5 cm focal length is used to focus the laser beam onto the sample glass 1 mm thickness cell, and a 30 x 30 cm semitransparent, 75 cm away from the sample cell, screen, to cast the ring patterns.

The Z-scan technique was carried out using the same set-up shown in Fig.(2) except that the sample cell was fixed on a translational stage to sweep the sample cell across the focal point of the glass cell from position –z to +z while the screen was replaced with a detector covered with 2 mm diameter circular aperture to achieve the closed-aperture type of the Z-scan technique.

The same experimental set-up for the Z-scan was used to study the optical limiting properties of sample, except fixing the sample position behind the focus. These properties have been studied by changing input power and measuring the output power.

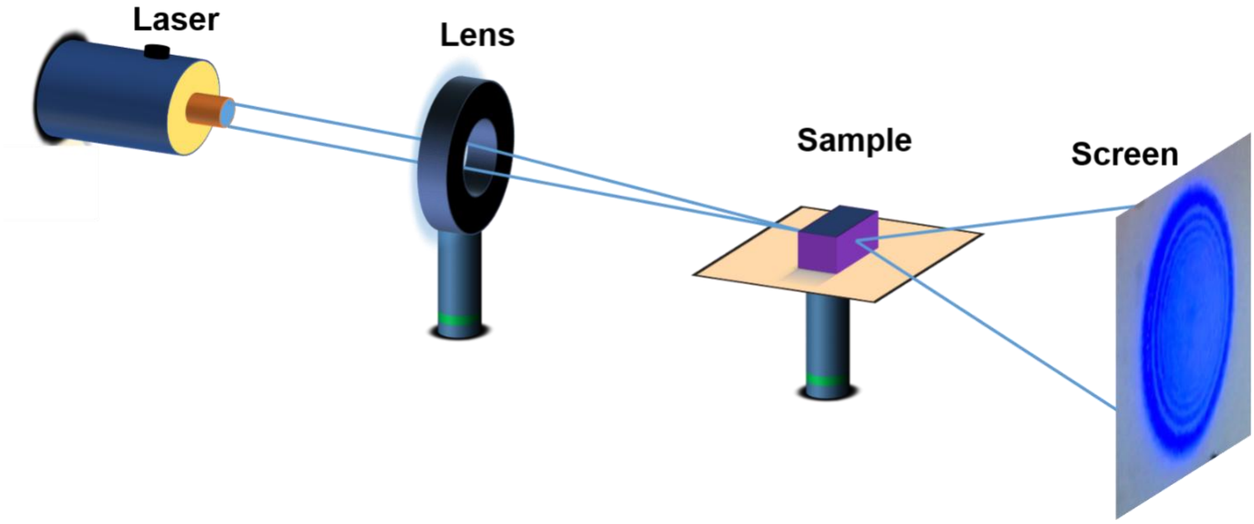

Fig. (2): Experimental set-up for generation of diffraction ring patterns in the brake fluid.

3.1 Diffraction ring pattern

The obtained diffraction ring patterns against input power at λ=473 nm are shown in Fig.(3). Three features can be obtained from Fig.(3) (1) the number of rings in each pattern increases with the increase of input power (2) the area of each pattern increase with the increase of input power (3) the outermost rings in each pattern are the most intense compare to the inner ones and (4) patterns lose symmetry which is obtained at low input power as the input power increased i.e., the rings diameters in the horizontal diameter increase in more ratio than those in the vertical direction as a result of convection current occurring in the vertical direction compared to conduction current in the horizontal direction.

3.2 Z-scan

The closed Z-scan technique is a method used to study the nonlinear optical properties of materials. The open and closed aperture Z-scan measurements were carried out at 0.86 kW/cm^2 incident intensity. The results were obtained as follows: in the case of the open aperture Z-scan a horizontal straight line resulted indicating that the brake fluid does not have a nonlinear absorption coefficient, but in the situation of closed aperture Z-scan obtained the result is shown in Fig. (4). According to the obtained curve, it is observed that a transmittance peak, followed by a transmittance valley, indicates that the sample possesses a negative nonlinear refractive index (i.e. self-defocusing).

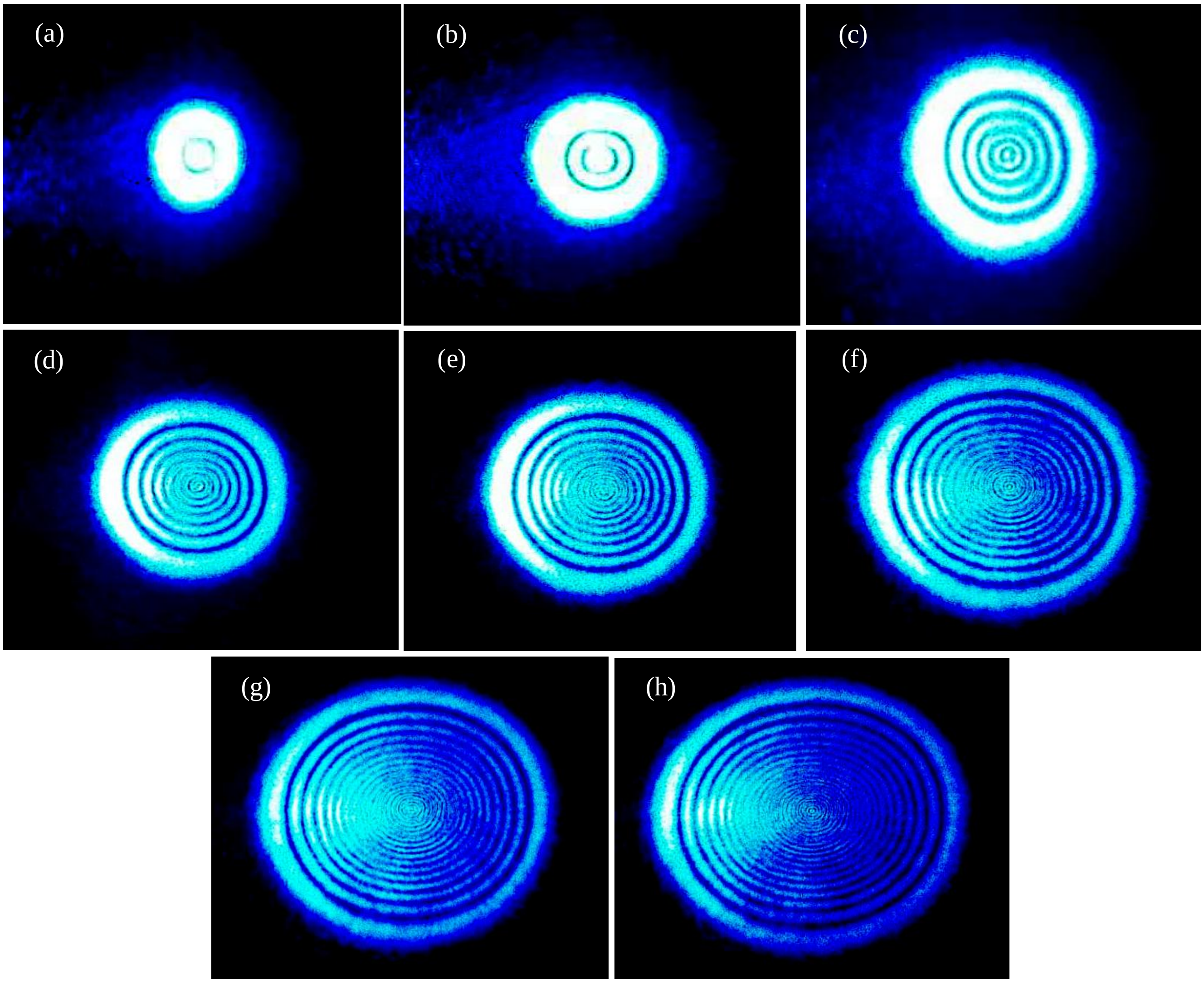

Fig.3. Photographs of the far-field intensity distributions of diffraction ring patterns in the brake fluid against input power of (mW): a:14, b:18, c:26, d:33, e:41, f:49, g:64, h:66.

3.3 Estimation of total change in refractive index, Δn, and nonlinear refractive index, n_2:

The appearance of single diffraction ring is a manifestation of a change of 2π radians in phase of the laser beam as it traverses the nonlinear, brake fluid, medium. For N rings the total change in phase, ϕ, equals [33]

$$\phi = 2\pi N \qquad (2)$$

For a beam to traverse a sample of thickness L the total change in phase, ϕ, equals to

$$\phi = k\Delta \qquad (3)$$

Where $k=2\pi/\lambda$ is the propagation vector and Δ is the optical path length that is written as:

$$\Delta = L\Delta n \tag{4}$$

Δn is the total change in refractive index of the sample [($n=n_o\pm\Delta n$), n is the sample refractive index in the present of laser beam and n_o is the linear refractive index]. From equations (3-4) [33]

$$\Delta n = \frac{N\lambda}{L} \tag{5}$$

And

$$n_2 = \frac{\Delta n}{I} \tag{6}$$

I is the incident light intensity i.e.

$$I = \frac{2P}{\pi\omega^2} \tag{7}$$

P is the incident laser power and ω is the laser beam radius at the entrance of the sample cell and is related to the laser beam radius, ω_o, as it leaves the laser output coupler by [38]

$$\omega = \frac{1.22\, f\lambda}{\omega_o} \tag{8}$$

For L= 0.1 cm, λ=473 nm, ω_o=1.5 mm, N=17, P_{in}= 66 mW, I= 11362 W/cm^2, Δn and n_2 values are 8.04 x 10^{-3} and 7 x 10^{-7} cm^2/W respectively.

3.4 Estimation of the nonlinear refractive index using the closed aperture Z-scan

In order to test the possibility of using the thermal lens model (TLM) of Z-scan presented by Cuppo et al. [39] the separation, ΔZ_{p-v}, between the transmittances at peak and valley in the z direction should be written as:

$$\Delta Z_{p-v} \approx 2\, Z_R \tag{9}$$

In present work Z_R the Rayleigh length equal to 2.46 mm, and by applying Eq. 9 the calculated value of ΔZ

$_{p\text{-}v}$ is approximately equal to 4.92 mm. From Fig.(4), the $\Delta Z_{p\text{-}v}$ is equal to 5 and it is approximately equal to the value calculated from Eq. 9, so that the thermal lens model of Z-scan introduced by Cuppo et al. [39] can be applied, also this proves that the nonlinearity shown by the brake fluid is of thermal origin. In accordance with this theory, the nonlinear refractive index is given by the following formula [40]

Where $\Delta T_{p\text{-}v}$ is the difference between the transmittances at peak and valley. Using Eq. 10 and Fig.(4) the value of nonlinear refractive index of brake fluid is calculated and found to be 0.95 x10^{-7} cm^2/W.

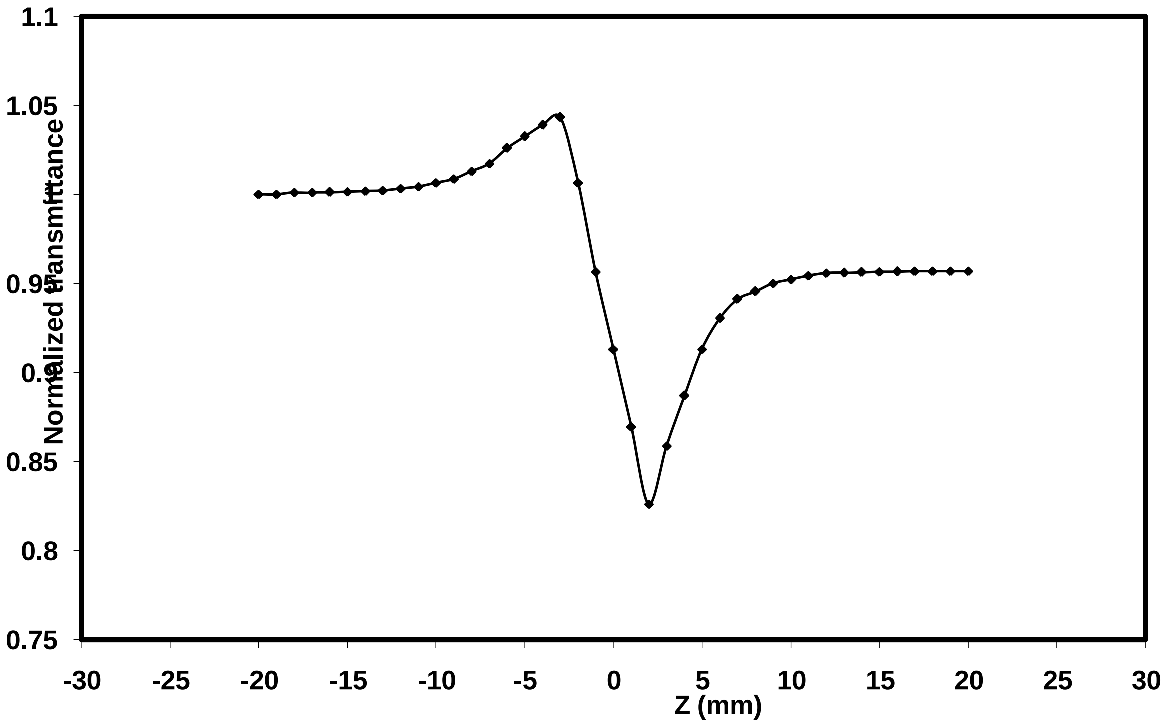

Fig.4. Closed aperture Z-scan data for the brake fluid

3.5 Optical limiting

The device optical limiter is used to protect the human eye and optical sensors against high intensities of laser beam. It has high transmittance at low intensity and low transmittance at high intensity. Fig. 5 illustrates the results of optical limiting experimental for brake fluid. In this Figure output power is plotted as a function of the input power. As it observed from the Fig. 5, the sample has the characteristics of the optical limiter. When the input power is low, the relation between the input power and output power is linear. But the sample shows nonlinear relationship response of the input power versus output power at high input powers.

There is a parameter that must be measured which determines the useability of the material as an optical limiter which is the threshold limiting. This is defined as the value of input power when the transmittance is reduced by half. Fig. 6 shows the transmittance through the brake fluid as a function of the input power. According to this curve it is found that the value of the threshold limiting for brake fluid is equal to 21 mW. The mechanism of optical limiting is nonlinear refraction (thermal effects). Since laser used emits cw laser beam , the sample will absorb energy, which causes it to be heated, and this lead to creating a thermal lens that causes self-defocusing to laser beam.

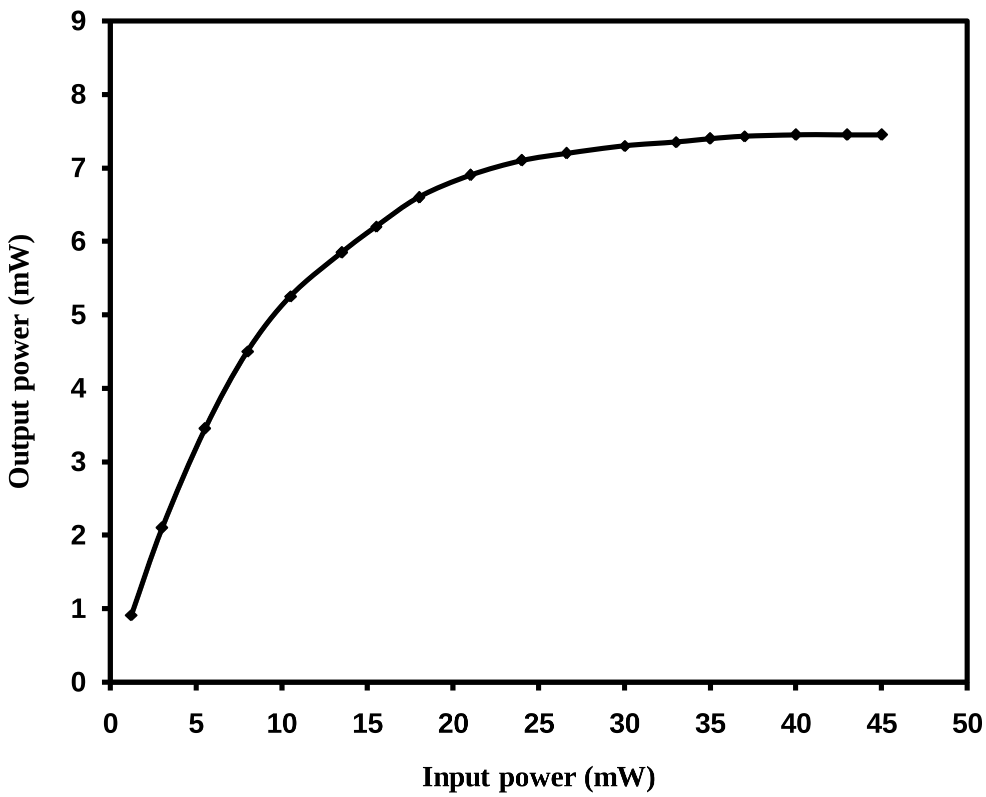

Fig.5. Variation of output power against input power of that brake fluid.

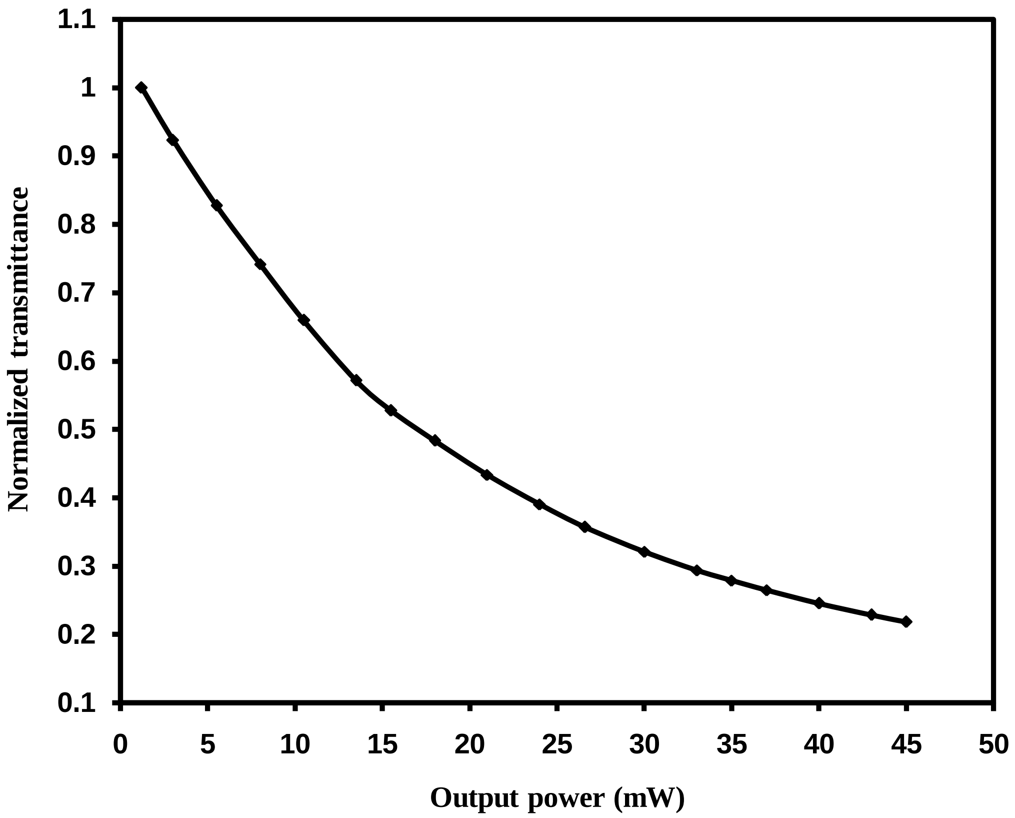

Fig.6. Variation of transmittance with input power of the brake fluid.

3.6 Discussion

The nonlinear refractive index value of brake fluid calculated by the diffraction ring patterns method is larger than the value calculated by the Z-scan method. This difference in the value is due to the level of intensity used in both cases. The intensity used in the diffraction method is 13th times that used in the Z-scan method. It is known, that the refractive index depends on the intensity, and this identical with the results obtained in section 3.1 of the diffraction ring pattern, where it is found that the number of rings increases with increasing the incident intensity, which leads to the increase of the refractive index. Therefore, the refractive index value calculated by diffraction is greater than the value calculated by the Z-scan method.

4. Conclusion

The nonlinear refractive index of brake fluid was measured using self-diffraction and Z-scan techniques. The generation of diffraction ring patterns of laser Gaussian beams post propagation through the brake fluid was studied. It is found that the number and area of diffraction rings increasing with increased incident intensity. The refractive index value of the brake fluid in order to 10^{-7} cm^2/W was obtained by diffraction method. From the Z-scan measurements it is observed that the brake fluid does not have nonlinear absorption coefficient, and showed self-defocusing nonlinearities. The nonlinearity shown by the sample is attributed to thermal nonlinearity. The optical limiting property of brake fluid is reported. The results show that the brake fluid has a good optical limiting behavior.

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