Linear and Nonlinear optical properties of dichromate gelatin

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Abstract

The linear and nonlinear optical properties represented by nonlinear refractive index and nonlinear absorption coefficient were determined using a highly sensitive method known as Z-scan technique. Z-scan experiment was performed using Nd-YAG (1064 nm) and Nd-YVO4 laser in two parts (532 nm). The first part has been done using a closed aperture placed in front of the detector to measure the nonlinear refractive index at two wavelengths. The second part was done using an open aperture to measure the nonlinear absorption coefficient at two wavelengths.

الخلاصه

تم ايجاد الخواص ألبصريه الخطيه واللاخطيه لمادة دايكرومات الجلاتين مثل معامل الانكسار اللاخطي ومعامل الامتصاص اللاخطي باستخدام طريقه حديثه وذات حساسيه عاليه تعرف بتقنيه المسح على المحور الثالث وتم استخدام ليزر الحالة الصلبة نديميوم ياك بطول موجي (1064 nm) ونديميوم ياك مضاعف التردد بطول موجي(532 nm) وعلى جزئيين الجزء الاول تم بوضع ثقب ضيق امام الكاشف لدراسة معامل الانكسار اللاخطي للطولين الموجيين والجزء الثاني برفع الفتحه لغرض دراسة معامل الامتصاص اللاخطي عند نفس الطولين الموجيين.

Introduction

The study for new materials for optical limiters and optical photonics devices spreading over alary area of were studies on nonlinear materials become major research area[1]. The characterization of the nonlinear optical properties of materials has a great relevance to the possibilities of practical application for optical limiting and optical devices[2]. To achieve this goal it is necessity to find the materials which have large nonlinearities refractive index and small absorption coefficients linear and nonlinear [3].The Z-scan measurement technique is a simple experimental procedure that gives information on the optical nonlinearities of materials. The technique originally formulated is performed via sending an axially symmetric Gaussian beam through a converging lens, then through a sample of material placed near the beam waist, and finally through an aperture placed in front of a detector in the far field. T he sample is moved to one side of the beam waist, the detected power increases to a peak as the sample is moved to the other side of the waist , the detected power decreases to a valley. The

difference in power from the peak to the valley has been shown to be proportional to the nonlinear index of refraction [4,5]. Z-scan technique is one of the simplest and effective tools for measuring the third order of nonlinear optics such as nonlinear refraction coefficient and absorption[6]. It has been widely used in material characterization .in this method , the nonlinear sample is scanned along the propagation path of a focus Gaussian laser beam [7].It can provide not only the magnitudes of real and imaginary parts of nonlinear susceptibility ,but also simultaneously can clarify the sign of the real part [8]. This technique is a method which can rapidly measure both nonlinear absorption and nonlinear refraction in solid, liquids and liquid solutions [9. The main optical properties involved in the light –matter interaction are absorption .It is defined by the absorption coefficient, and refraction and is defined by refractive index [10]. These two parameters were depending on the electric field intensity of laser light .When the material is irradiated, the energy of the absorbed photons makes it possible for the transition from the ground state to the excited state, and this represented a linear absorption[11].

Experimental

Sample preparation

A simple method of preparing a hardened gelatin film is the following: A 1% solution of gelatin evenly over a glass plate, and the excess solution is allowed to run off the plate. After the film is dry (4 hours) soaking in 1% aqueous solution of ammonium dichromate for 3 min at room temperature .The film is then allowed to dry slowly. It used after (4 hours).

Z-scan measurement

The Z-scan is a simple and popular experimental technique to measure the intensity dependent third order nonlinear susceptibility of the materials. It allows the simultaneous measurement of both the nonlinear refractive index and the nonlinear absorption coefficient in this method ,the sample is translated in the Z-direction along the axis of focused Gaussian beam from the two cases of wavelength case I: 532 nm and case II: 1064 nm . The far field intensity is measured as a function of the sample position. The schematic diagram of Z-scan technique is shown in figure (1). By properly monitoring the transmittance change through small aperture at the far field position (closed aperture) [figure(1)]. By moving the sample through the focus and without placing an aperture at the detector (open aperture) as shown in figure (2). Two techniques have been used to measure the nonlinear optical properties of dichromate gelatin, closed- aperture used to measure the nonlinear refractive index and open- aperture used to measure the nonlinear absorption coefficient. Each technique applied on two case of wavelength case I: 532 nm and case II: 1064 nm

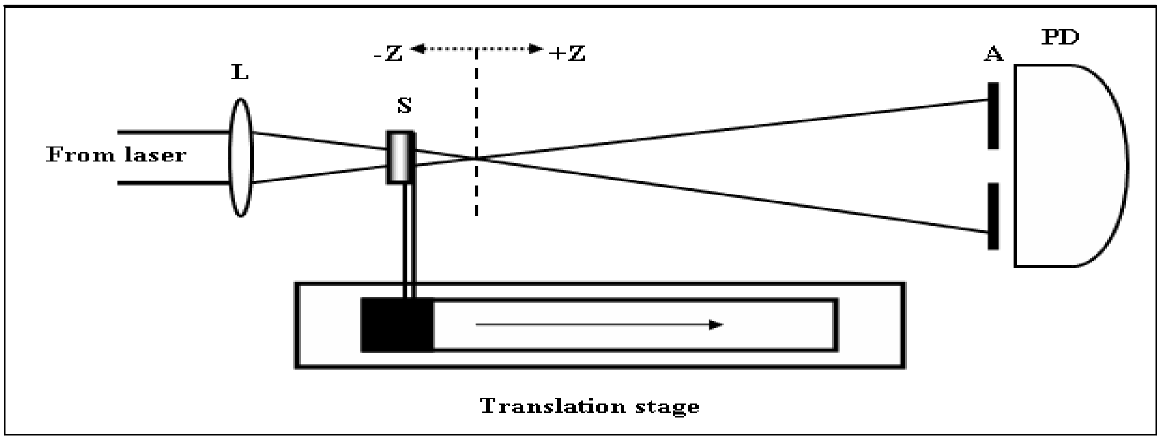


Figure (1) A schematic diagram of closed- aperture Z- scan
L,Lens; S, sample;A,aperture;D,detector.

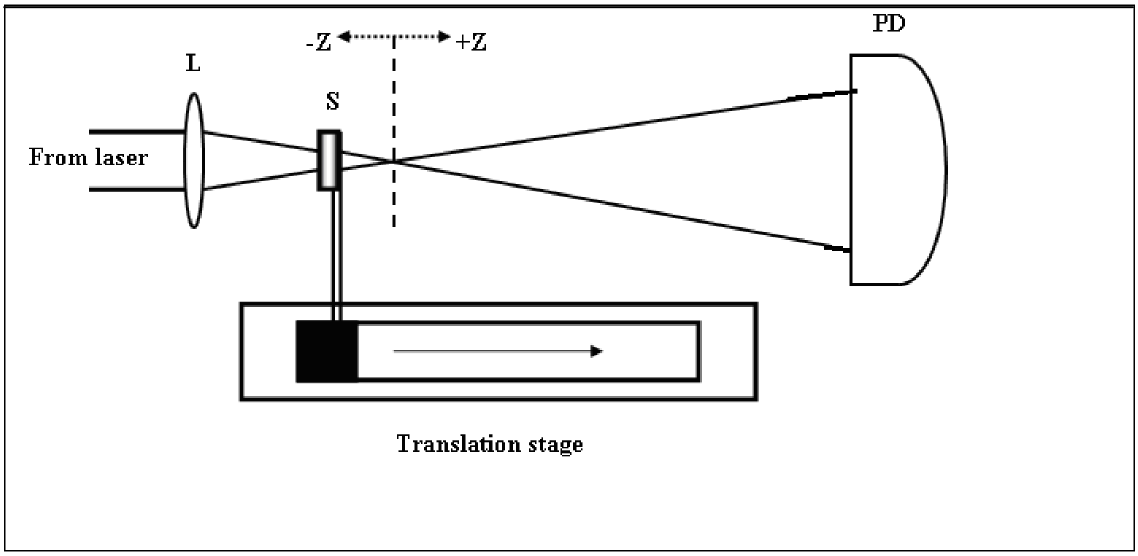


Figure (2) A schematic diagram of open - aperture Z- scan.

Results and discussion

Linear 0ptical properties

The optical transmission measurement of dichromate gelatin was analyzed using UV-VIS spectrophotometer. Figure (3) shows the transmission spectrum of dichromate gelatin (DCG)

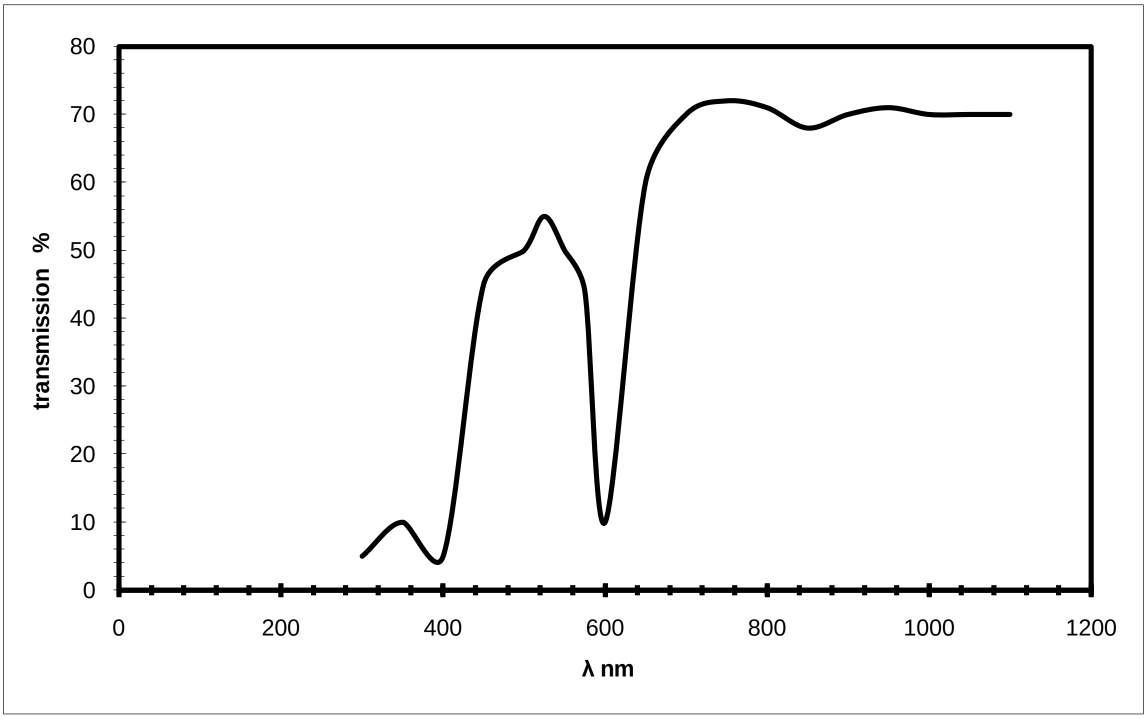


Figure (3) UV – VIS transmission spectrum of (DCG)

The linear absorption coefficient of DCG was determined for both wave lengths using the formulae[9].

$$\alpha_0 = \frac{1}{d}\ln(\frac{1}{T}) \quad \text{...........(1)}$$

where d is the thickness of sample and T is the transmittance, and the extinction coefficient is obtained interns of the absorption coefficient ,

$$K = \frac{\lambda\alpha}{4\pi} \quad \text{................(2)}$$

The reflectance in terms of absorption coefficient is derived

$$R = \frac{1 \pm \sqrt{1 - \exp(-\alpha.d) + \exp(\alpha.d)}}{1 + \exp(-\alpha.d)} \quad \text{...............(3)}$$

And the linear refractive index is given by

$$n = \frac{-(R+1) \pm \sqrt{\left(-3R^2 + 10R - 3\right)}}{2\left(R-1\right)} \quad \text{..................(4)}$$

The measurement details and the results show in table 1

Table 1 measurement details and the results of linear optical properties by the Z- scan.

λ nm	Thickness (mm)	α_o (cm)$^{-1}$	K	R	n
532	12	0.544	23.04x10-7	1.676	1.504
1064	12	0.299	25.32x10-7	1.363	1.325

Table 1 portrays the experimental details and the result of the DCG.It is clear that the reflectance and the extinction coefficient depend upon the absorption coefficient. The high transmission low absorbance, low reflectance and low refractive index of DCG in the UV.VIS region makes the material a prominent one for anti reflection coating in solar thermal devices and nonlinear optical applications. The low extinction value show the semiconducting nature of the material. Thus linear optical properties of DCG confirm the material suitability for nonlinear optical and semiconducting application

Nonlinear optical properties:-

The nonlinear refractive index and nonlinear absorption coefficient of DCG were measured by the Z-scan techniques. Two techniques have been used to measure the nonlinear optical properties of DCG, closed- aperture used to measure the nonlinear refractive index and open- aperture used to measure the nonlinear absorption coefficient. Each technique applied on two cases of wavelength case I 532 nm and case II 1064 nm.

index Nonlinear refractive:-

In order to investigate the nonlinear refractive index there were two cases chosen at 532 nm (50 mW power) and at 1064 nm (80 mW power). In case I figure (4) shows the closed- aperture Z-scan curves, at 532 nm which represents the normalized transmittance as a function of position

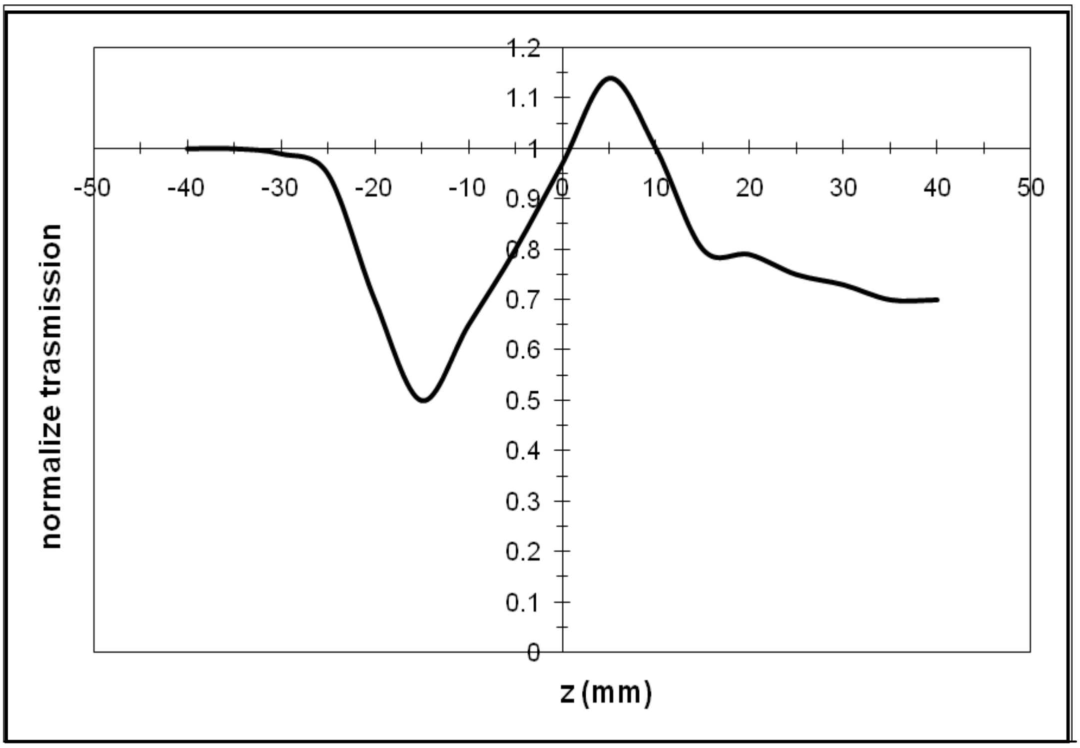
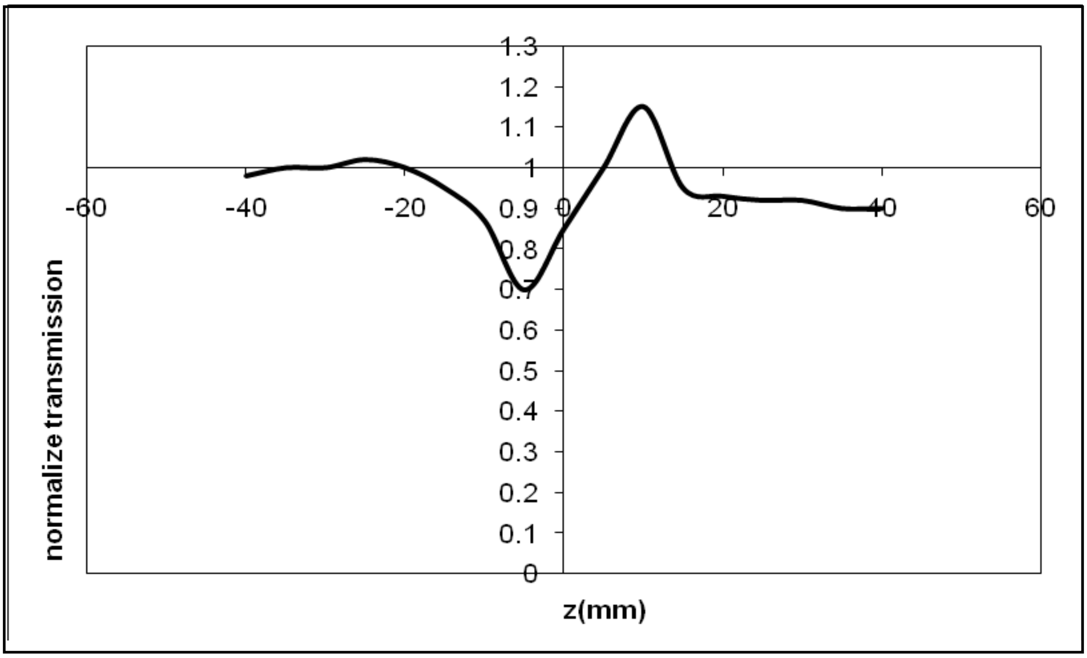


Figure (4) normalized transmittance versus position at 532 nm

In case II the closed- aperture Z-scan curves determined at 1064 nm as in the figure (5)



Figure(5) normalized transmittance versus position at 1064 nm

From the figure (4) and (5), the normalized transmittance started with low change (linear) at different positions from the far field of the sample position (-Z) with respect to the focal plan at Z=0. At the near field the transmittance begins to decrease until it reaches the minimum value (Tv) at approximately Z=-15 mm in case I and Z=- 5 mm in case II. After the focal plane, the normalized transmittance begins to increase until it reaches the maximum value (Tp) at approximately Z=5 mm in case I and Z=10 mm in case II. The normalized transmittance begins to decrease toward a low change behavior at the far field of the sample position +Z, the closed-aperture Z-scan measures the transmittance of a sample, as it passes through the focal plan. The behavior of Z-scan curves was in good aggrement with that obtained by Sheik-Bahae et al. [12] .As a results, the closed-aperture Z-scan measures the change in transmittance of a beam, as the sample passes through the focal plane, the divergence of the beam is unaffected by the sample and the detector measures no net change in transmittance. As it leaves the focal plane, the sample will focus the diverging beam. In the far field, this decreases beam divergence and is measured as an increase in power through the aperture. The sample nonlinearity was calculated from the difference between the heights (peak) and the lowest value (valley transmission (ΔT_{P-V}) is written in terms of on axis phase shift at the focus as[9].

$$\Delta T_{p-v} = 0.406\left|\Delta\Phi_0\right| \quad \ldots\ldots\ldots\ldots\ldots(5)$$

The nonlinear refractive index is given by

$$n = \frac{\Delta\Phi}{KIL_{eff}} \quad \ldots\ldots\ldots\ldots\ldots\ldots(6)$$

where $K = 2\pi/\lambda$,I is intensity of th laser beam at the focus (Z = 0),

$L_{eff} = \frac{1-\exp(-\alpha L)}{\alpha}$, L_{eff} :the effective length of the sample, L: is the sample length , α : linear absorption coefficient

Nonlinear absorption coefficient:

The nonlinear absorption coefficient B of the samples was determined by performing the open aperture Z- scan . figure (6)shows the open- aperture case I Z- scan curves , which represents the normalized transmission as function of position Z

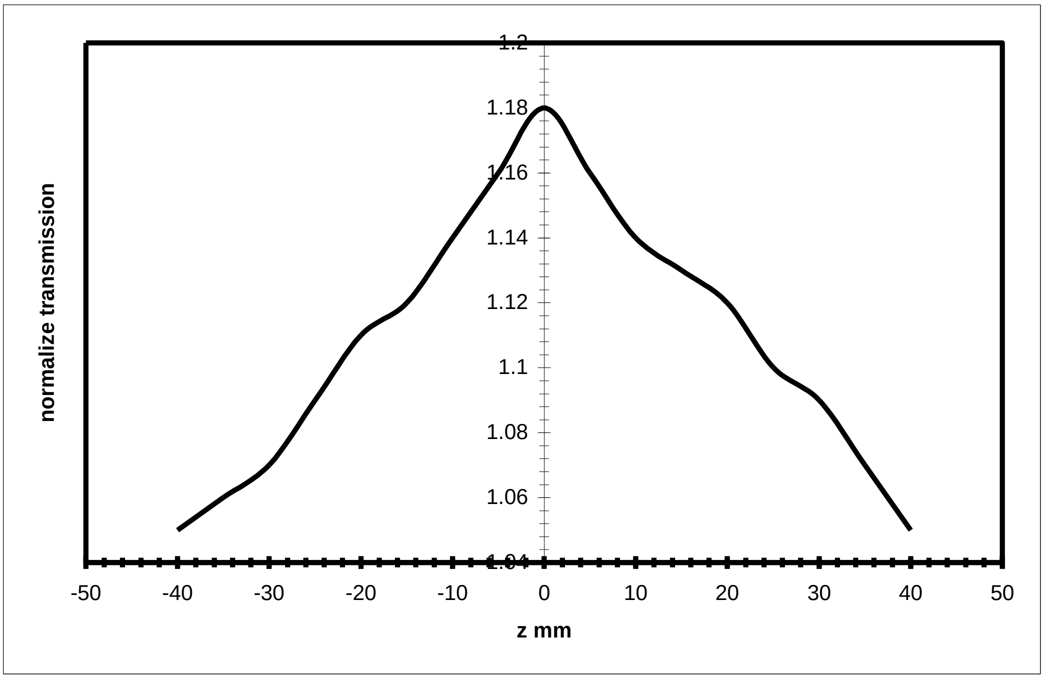


Figure (6) normalized transmittance versus position at 532 nm

In case II the open aperture Z-scan curves at 1064 nm. show in figure (7)

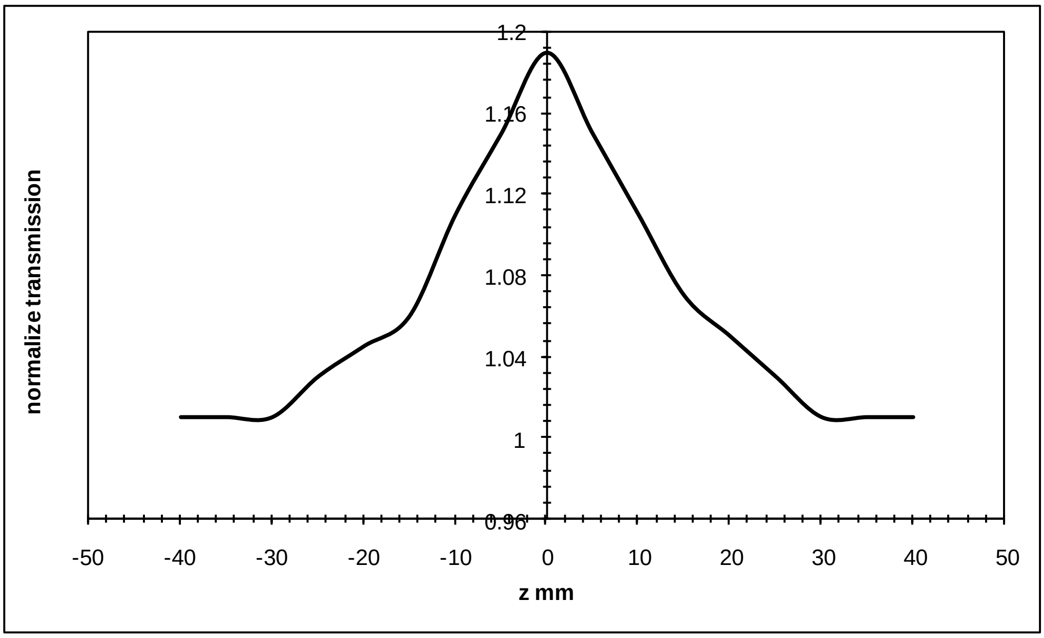


Figure (7) normalized transmittance versus position at 1064 nm

From figure (6)&(7) the behavior of transmittance curves starts linearly at different distances from the far field of the sample position (-Z). The near fold the transmittance curve begins to increase until it reaches the maximum value (Tmax) at the focal print, where (Z=0 mm), afterwards, the transmittance begins to decrease toward the linear behavior at the far field of the sample position (+Z), from the open aperture Z-scan data, the nonlinear absorption coefficient is estimated as

$$\beta = \frac{2\sqrt{2}}{IL_{eef}} \Delta T \quad \text{.................(7)}$$

Where ΔT is the one peak value at the open aperture Z-scan curve.

Table (2) shows values of nonlinear refractive index nonlinear phase shift, effective length and nonlinear absorption coefficient both wave length 532 nm and 1064 nm

Table 2 measurement details and the results of nonlinear optical properties by the Z- scan.

λ nm	$\Delta\Phi_o$ rad	L_{eff} (cm)	β(cm/watt)	n_2 cm^2/watt
532	1.576	0.88	0.0187	0.445×10^{-7}
1064	1.108	0.929	0.00718	0.235×10^{-7}

Conclusion

There are a variety of methods and techniques to determine the nonlinear optical response each with its own weakness and advantages.In general, it is advisable to use as many complementary techniques as possible over a broad spectral range in order to unambiguously determine the active nonlinearities. Z-scan is one of the simpler experimental methods to employ. Despite the wide range of available methods, it is rare that any single experiment will completely determine the physical processes behind the nonlinear response of given material. A single measurement of the nonlinear response of a material, at a single wavelength. The high transmission, low reflectance of DCG in the UV-VIS region make the material a prominent one for antireflection coating in solar thermal devices.

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