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Nonlinear characterization and optical switching of Acid red 27 dye

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Nonlinear characterization and optical switching of Acid red 27 dye

Amenah Jamal Jawad[1] Qussay Mohammed Salman[2] Jassim Mohammed Jassim [3]

[1,2,3] Collage of science for women / University of Babylon/Iraq

Email: amenah.jawad@student.uobabylon.edu.iq

Abstract:

In this paper the linear and nonlinear optical properties(n_2, β), also switching behavior of Acid Red 27 by Z-scan technique is used to study the nonlinear absorption and nonlinear refraction behavior of the organic dye Acid Red of laser at 532 nm with 5.26 mW , Where the value of the nonlinear absorption coefficient of the highest concentration 10^{-4} is $1.558*10^{-3}$(cm/W) and the value of the nonlinear refractive index was of the highest concentration 10^{-4} is $8.362*10^{-7}$ (cm^2/W)and .The results show the behavior of Acid Red 27 is saturable also the dye have negative refractive index (self -defocusing)for all concentration studied according to the nonlinear results the behavior of optical switch have been studied by using laser at 532 nm as a pump and 632.8 nm as a prop ,where it is observed that the amplitude of prop laser decreases with increasing modulation frequency. The effect of intensity and concentration on the number of diffraction rings was also studied, the results show the number of ring increased with increasing intensity of laser and concentration of dye.

Keywords :Nonlinear optical properties; Z-scan; Optical switch; Diffraction ring.

1-Introduction

In the latest years, nonlinear optics plays an important role in the technology of photonics. Searching nonlinear materials with large nonlinear optical properties has increased because of their applications in integrated optics such as optical modulation optical information, optical data storage, optical power limiting, fluorescence excitation microscopy and imaging.[1]

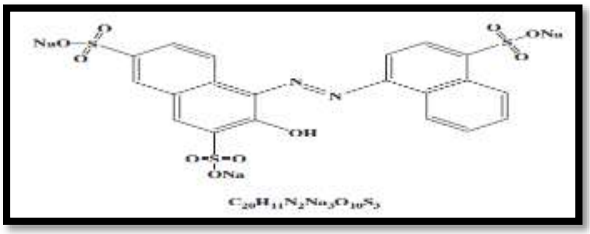
Nonlinear optics is study of phenomena that occur as a consequence of the modification of the optical properties of a material system by the existence of light. in most cases, only laser light is sufficiently intense to modify the optical properties of a material system. The start of the field of nonlinear optics is often taken to be the discovery of second-harmonic generation by Franken *et al.* (1961), shortly after the demonstration of the first working laser by (Maiman in 1960) Nonlinear optical phenomena are “nonlinear” in the sense that they occur when the response of a material system to an applied optical field depends in a nonlinear manner on the strength of the optical field[2][3]. Nonlinear optics is a study of high-intensity light in nonlinear materials, whose polarization density is not linearly dependent on the light’s electric field. The field emerged after (Mainman) invented the first laser in 1960[4][5] methods of nonlinear parameter measurement mainly include the Z –scan method[6][7].

One of the practical applications of nonlinear optics is the optical switch Third-order nonlinear optical materials of various kinds are being extensively investigated to achieve ultrafast all optical switching for future high-speed optical communications.

To accomplish interaction efficiently between two different lights, it is desirable that the employed nonlinear optical medium possess high nonlinearity, high power density, and a sufficiently long interaction length[8], In recent years the nonlinear optical properties of the z-scan method have been studied for many different materials and used in modern applications such as optical switch (communication and computing) and optical limiting. [9,10,11,12,]. A switch is the basic building block of information processing systems. The key element in an all-optical switch is a nonlinear optical material. Current interest has focused on novel materials that exhibit an efficient nonlinear optical response and provide advantages of small size and weight, high intrinsic speed, low propagation delay and power decadence and the ability to tailor properties for device applications[13], Since the application of the optical switch depends mainly on the linear and nonlinear properties of the material, therefore, there is a study on the Acid Red 27 dye, Conducted it each of the researcher (G. Balaji1, A. Ramalingam, D. Balasubramanian, and K. Mohanraj)[1] have studied about linear and nonlinear properties of the Acid Red 27 dye by using Z-scan technique and Nd-YAG laser 532 nm with 50 mw and the extent of their use in the applications of the optical limiting where they calculated the nonlinear properties of the dye , In this paper we will focus on the organic dye Acid red 27 and use it as an optical switch.

2- Materials and Experimental

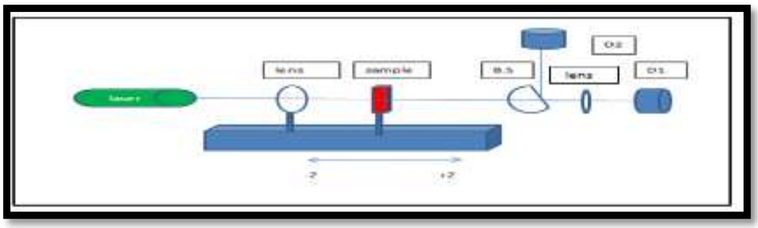
The dye , Acid red 27 which Sigma Aldrich was chosen for this study . the chemical structure of the organic dye Acid red 27 is shown in figure (1). Where methanol was used as a solvent for this dye .Methanol was chosen because it gives best solvent for the dye .



Fig(1):Chemical structure of Acid red 27.

The dye was prepared and dissolved in methanol at different concentrations(10^{-5} M,$2*10^{-5}$ M,$7*10^{-5}$ M,10^{-4}M) and an absorption spectrum was taken for AcidRed27 dye by using UV-VIS spectrophotometer(CECIL CE 7200(ENGLAND)) it has Spectral range from(900-200 nm) ,The studied of linear properties include absorption spectrum the linear properties of the dye were calculated(α_0, $\Delta\lambda$)

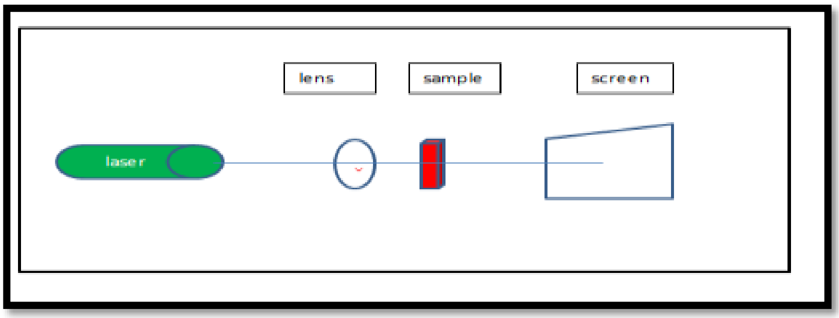
In this study have been studied by using Z-scan, equipped by Mahfanavar (ZSCAN VER-8), which consists of parts and optical elements as shown in figure (2), the nonlinear properties of the dye were calculated(n_2,β,Δn).



Fig(2):Experimental set up for Z-scan.

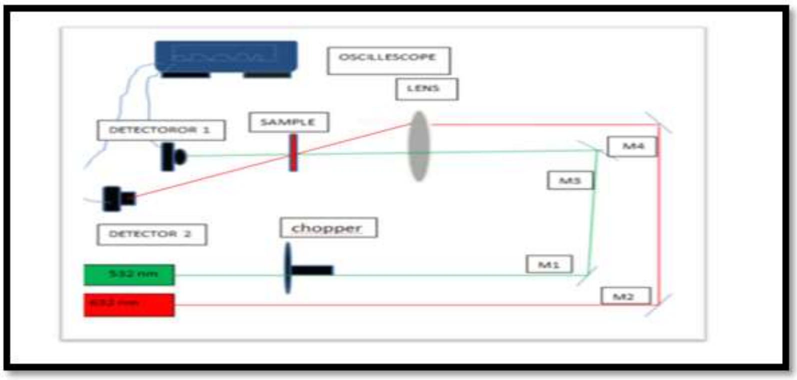
For study nonlinear properties The Nd-Yvon laser with a wavelength of 1064 nm second harmonic generation 532 nm, lens with 8.5 cm focal length so we can obtain intensity about 760 W/cm^2 ,cell which chosen used in this study was made of quarts with thickness 0.1 mm , And two detectors one of them (D2) with pinhole to read the data of close aperture and the other(D1) to read the data of open aperture and both of them are collected with oscilloscope ,lens to collected the beam from the sample before detector (D1) ,power meters made in japan (mobiken) .

To study the effect of intensity on the number of rings and the effect of concentration on the number of rings, we used the setup is shown in figure(3) laser (532 nm), a lens with a focal length 8.5 cm, and a cell containing the dye with a thickness 0.1 mm and screen.



Fig(3):Experimental set up for spatial self- phase modulation (SSPM).

Fig (4) illustrated an experimental set up which was used for the measurements of the optical switch, where a quartz cell with a width of 1 cm was used as a container for the dye, and a laser with a wavelength 532 nm as controlling laser (pump laser) , laser 632 nm were use as signal laser (prop laser), detectors were used to read the intensity of controlling laser (532 nm), and signal laser (632 nm)they are linked to a oscilloscope , To modulate the beam the chopper has been used in front of 532 nm as Fig (4) .



Fig(4): Experimental setup for optical switch

3- Result and Discussion

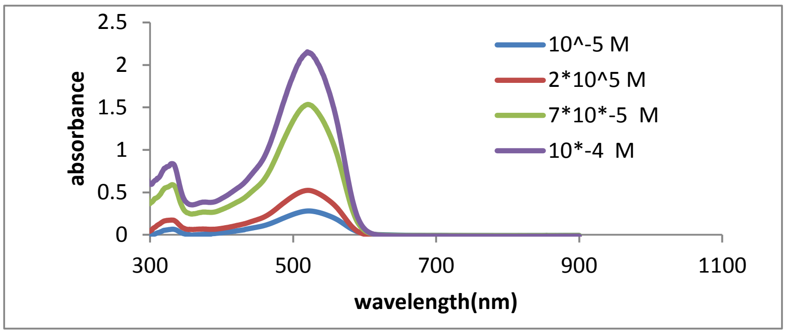
3-1 Linear and Nonlinear measurements

1 – Linear measurements

Figure (5) shows the absorption spectra of a dye Acid Red 27 which dissolved in methanol for different concentration .the linear absorption coefficient is calculated by using formula (1):-

$$\alpha o = 2.303\, A/t \qquad (1)$$

Where absorbance (A),thickness of cell (t).fig (5) shows that the absorbance increases with increasing concentration, because the number of molecules increases with increasing concentration.



Fig(5):UV-VIS absorption spectra of Acid red 27 dye in methanol for different concentrations.

In table (1) the linear optical properties α_0 ,$\Delta\lambda$,λ_{max}) are calculated ,The study showed that with increasing concentration, the absorption coefficient and the refractive index increase, while the band width is not change for all concentrations.

Table(1):Linear optical parameters of Acid Red 27 dye in methanol for different concentrations.

Concentration(M)	λ_{max}(nm)	$\Delta\lambda$(nm)	α_0(cm^{-1})
10^-5	521	100	0.647037062
2*10^-5	521	100	1.205440866
7*10^-5	521	100	3.536795402
10^-4	521	100	4.962739306

2- Nonlinear measurements

There are several methods of nonlinear parameter measurement mainly include the Z-scan, four wave mixing (FWM), interferometry and spatial self-phase modulation (SSPM). (8),in this articles was used Z-scan method to determine both nonlinear refractive index(n_2)and nonlinear absorption coefficient (β). The Z-scan experiment was applied by using laser 532 nm, focused by lens (8.5 cm)focal length on the medium with 760 (W/cm^2) nm. The laser beam waist at the focus was measured to be (20 μm). the beam converges or divergence depending upon the property of the material this phenomena is mention to as self-focusing or self-defocusing. The transmission of the beam through an sample is measured using photo detector to calculate nonlinear parameters (n_2,β), The nonlinear absorption coefficient can been given (β) [1]:-

$$\beta = 2\sqrt{2}/ I_0 L_{eff} \quad (2)$$

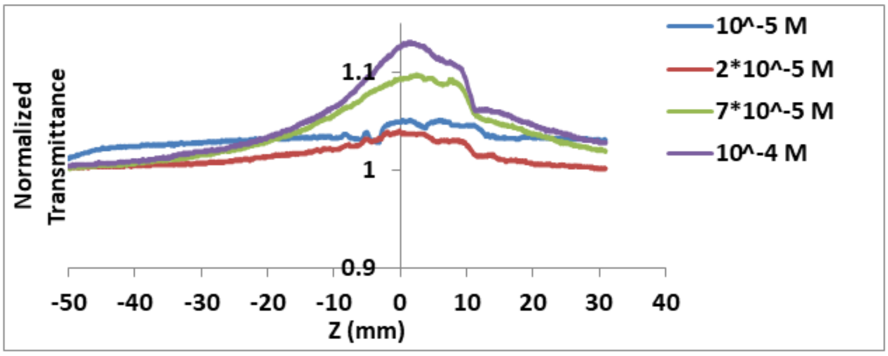
Where(I_0)incident intensity,(L_{eff}) Effective thickness which can be given by[1] :-

$$L_{eff}=(1-e^{-\alpha 0t})/\alpha_0$$

The nonlinear refractive coefficient can been given (n_2)[1]:- (3)

$$n_2 =\lambda \, \Delta \, T_{P-V} / 0.812\pi(1-S)^{0.25} L_{eff} \, I_0 \quad (4)$$

Where (n_2) the nonlinear refraction coefficient, (ΔT_{P-V}) the difference between peak to Valery of the transmittance. Where different concentrations of the dye were studied (10^{-4},$7*10^{-5}$,$2*10^{-5}$,10^{-5} M) Where it was found that there is no nonlinear absorption coefficient and nonlinear refraction coefficient at low concentrations($2*10^{-5}$,10^{-5} M)as shown in fig (5) where illustrated the open aperture Z-scan curve of dye (Acid Red 27) at four concentration ,the results indicated that the dye exhibited saturable absorption with negative absorption coefficient(β) It also demonstrates increased transmission by increasing the concentration at focusing Z=0 .



Fig(6):Open aperture Z-scan experimental data of Acid Red 27 dye in methanol for different concentrations .

Fig (6) illustrated the close aperture Z-scan curve of dye (Acid Red 27) at four concentration ,the results indicated that the dye exhibited self –defocusing with negative refractive index coefficient(n_2) It also demonstrates increased transmission by increasing the concentration at focusing Z=0 .

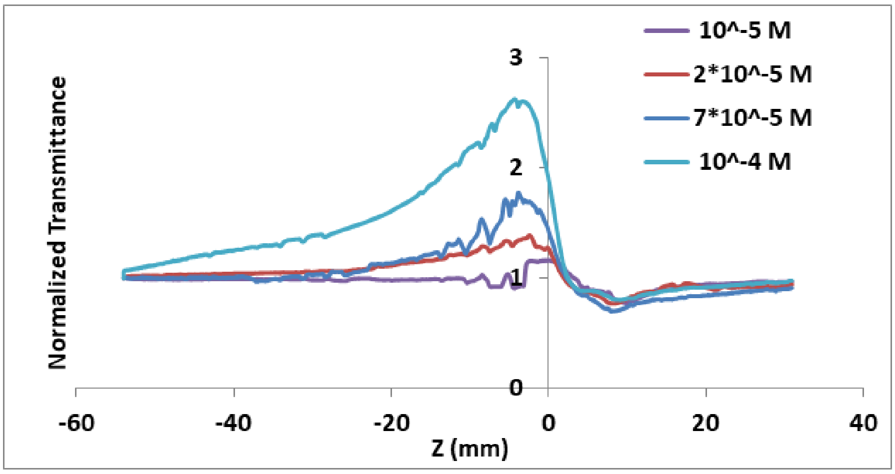


Fig (7):Close aperture Z-scan experimental data of Acid Red 27 dye in Methanol at different concentration.

From table(2) its clearly observed that the nonlinear optical parameters(n_2 , β , Δn, L_{eff}) are increase with increasing concentration.

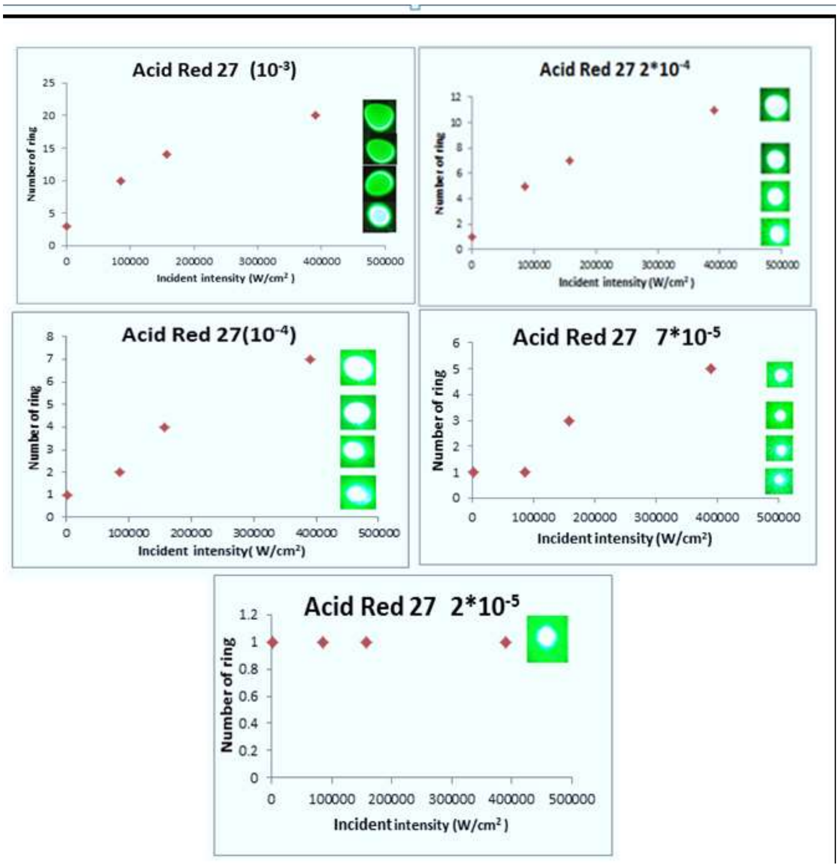
Table(2) Nonlinear optical parameters of Acid Red 27 for different concentrations by using Z-scan technique.

Concentration(M)	L_{eff} (cm)	β(cm/W)	$n_2(cm^2/w)$	Δn
10^-5	0.096833	-0.0000384	-1.739*10^-7	-0.0001321
2*10^-5	0.094207	-0.00007891	-2.940*10^-7	-0.0002234
7*10^-5	0.084228	-0.0006892	-2.3406*10^-7	-0.0002223
10^-4	0.078828	-0.00155814	-8.362*10*-7	-0.0006355

3-2 Optical switch Measurements

3-2-1 Effect of laser intensity

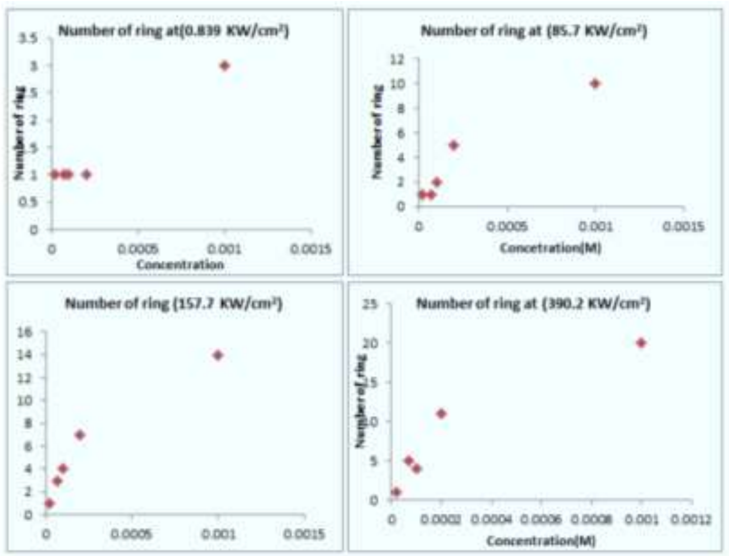
The effect of laser intensity on the number of diffraction rings has been by using set up shown in the fig (3), the result shown that the number of rings increasing with intensity for give concentration(10^{-3},$2*10^{-4}$,10^{-4},$7*10^{-5}$,$2*10^{-5}$ M) the maximum number of ring(20) was obtain at intensity (390.22 KW/cm ^{2}) with concentration (10^{-3} M) After that, may be that the rings begin to fold, deforming the orderly shape of the laser beam, and this occurs due to arugula unstable of thermal distribution inside the sample. It's clearly from figure (7) that in general the ring increase with increasing the intensity of laser , The figure shows at concentration $2*10^{-5}$ the constant number of rings at different intensities due to the absence of nonlinear properties to it.



Fig(8):Illustrate the change in the number of rings with the change of intensity at 532 nm.

3-2-2 Effect of concentration of dye

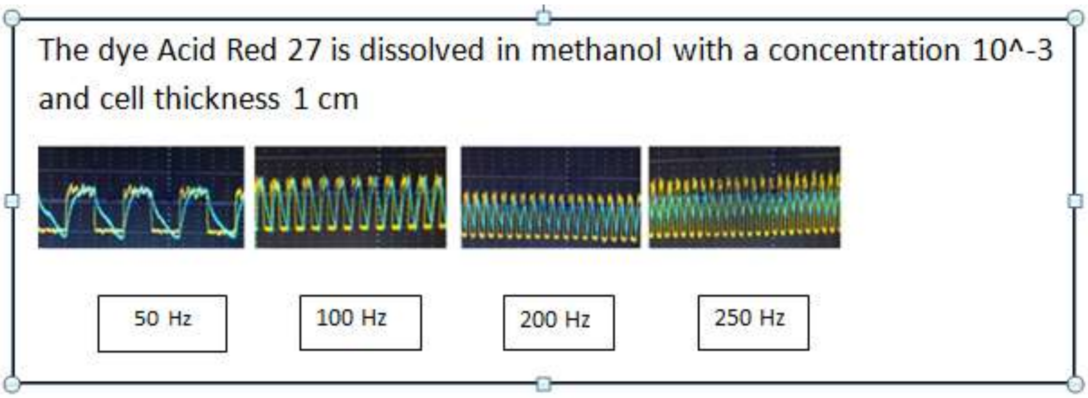
Fig (8) it's clearly that the number of diffraction rings increase with increasing the concentration for five concentration(10^{-3},$2*10^{-4}$,10^{-4},$7*10^{-5}$,$2*10^{-5}$ M).



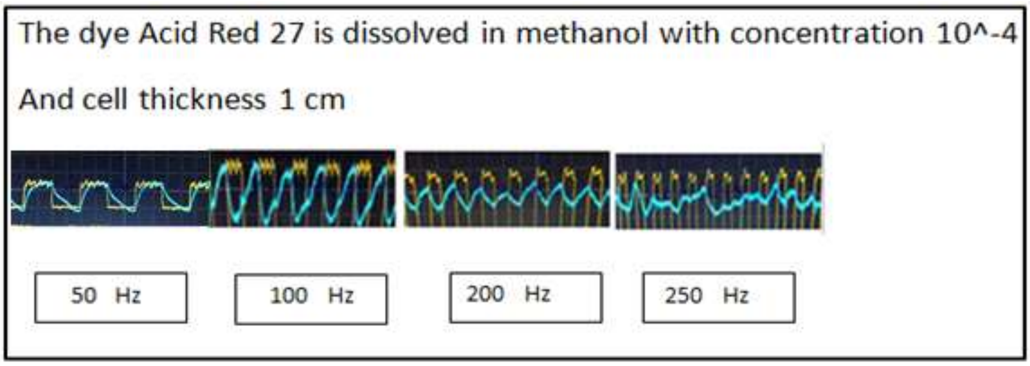
Fig(8):Illustrate the change in the number of rings with the change of concentration.

3-2-3 Modulation of Light

In the process of light modulation most of the materials used depend on the non-linear behavior of these materials such as thermal effect, concentration effect, saturated absorption, reverse saturated absorption. Where the interaction takes place between the two beams of the controlling laser beam and the signal and the effect a occur when two beams meet at the same point or a very small angle in The free space, Acid Red 27 was chosen for its ability to apply light using the experimental setup shown in figure (4), where the sample was placed in the area where these two rays meet, in which the intensity of the controlling laser is the greatest possible due to its focus using the lens, as this intensity must be higher than The threshold limit (which generates the nonlinear response in the material) according to that the wavelength of 532 nm was chosen for this beam because this dye has a high response to it, which in turn affects the response of the signals generated and transmitted through it. The wavelength of the laser beam was also chosen. The signal 632 nm has a low intensity without a threshold limit. Which (does not generate a nonlinear response within the material) then both the frequency effect of the controlling laser beam was chosen and the dye concentration on the susceptibility and response of this dye to the process of modulation where different frequencies of the beam of the controlling laser beam were generated using the mechanical optical chopper. The figure (9) and figure (10) respectively show the relationship between the controlling laser signal and the laser signal by the frequency effect and the dye concentration.



Fig(9):Show the effect of frequency on the controlling laser and signal laser ,the dye with concentration(10^{-3}).



Fig(10): Show the effect of frequency on the controlling laser and signal laser, the dye with concentration (10^{-4}).

From fig(9),(10) We note that the intensity of the beam of the controlling laser led to a change in the beam of the signal laser beam, and this indicates that this intensity led to a change in the phase of the beam of the beam of the signal laser, which led to a change in its intensity, It is noticed that there is a change in the value of the signal in the case of ON to its value in the case of OFF with an increase, It observed that the amplitude is decreasing with frequency compare with amplitude of pumping beam.

Conclusion

Linear optical properties (α_0,$\Delta\lambda$,λ_{max}) ,Nonlinear refractive index, nonlinear absorption and optical switching behavior of Acid Red 27 has been studied by using Z-scan technique with laser 532 nm. The linear absorption coefficient increases with increasing concentration, saturable absorption and self-defocusing behavior is observed for the nonlinear absorption and negative nonlinear refractive index of the dye solution that is mainly due to nonlinear refractive index for the dye and this one of the mechanisms to achieve an application optical switching, the optical switch have been studied by using controlling laser 532 nm, signal laser 632 nm .The effect of intensity and concentration on the number of diffraction rings was also studied by using laser 532 nm . It was observed that the number of diffraction rings increased with increasing intensity and concentration, also noted that the amplitude of prop laser decreases with increasing modulation frequency .

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