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# Optical Limiting Properties of Liquid Crystals Doped by $CuCl_2$ Nanoparticles

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**Abstract:** We have investigated optical limiting properties of liquid crystal doped by ($CuCl_2$) nanoparticles in ethanol solvent with different concentrations (2, 4 and 6)$\times 10^{-5}$ M. The measurements were performed by Z-scan technique using Continuous Wave (CW) diode solid state laser at (457 nm) wavelength and (84 mW) power. The sample shows very good optical limiting behavior arising from nonlinear refraction. The results showed that the threshold of optical capacity reduction was inversely proportional to concentration which meant that optical selection characteristics were better with increasing concentrations, the result implied that all samples prepared can be used as a potential medium for various optoelectronic applications including that in optical limiting.

**Key words:** Liquid crystals, non-linear optical properties, optical limiting, ($CuCl_2$), (CW), optical capacity

## INTRODUCTION

The propelled look into in nonlinear optics rely upon the advancement of new materials with strong nonlinear optical impacts. Recently, utilizing of nanomaterial's is a one of the most productive factors in new ways to deal with the nonlinear optics field. Also, liquid crystals are extremely welcoming to different materials which are mixed to nanoparticles or imbedded into different materials confinements exceptionally well (Abdulazeez *et al*., 2017). This makes an open door for the development of a new universe of composite materials, for example, liquid crystalline nanomaterial's. Composite materials consisting of liquid crystals doped with nanoparticles materials have indeed attracted much scientific and technological interest mainly because the incorporation of nanomaterials enhances the optical properties of the liquid crystal itself (Dunmur and Sluckin, 2010).

Optical limiting with organic materials or gadgets with transmission that abatements with light level is called optical limiters and has applications in eye and sensor assurance. In a perfect world, an optical limiter should display direct transmittance at low incident light fluencies, yet become dark at high incident light flounce. To improve the application feasibility of the conjugated organic NLO materials in optical limiter gadgets an aggregate exertion from physicists, scientific experts and material researchers is at present in advancement to comprehend the principle relationship between optical limiting with many of effective parameters, for example, atomic structure (Yannopapas *et al*., 2012). The greater part of the investigations are centered around clarifying that the vast atomic number and the little atomic size may improve the optical limiting properties of organic mixes. Some are centered around the impact of the conjugation length and the donor acceptor quality on the optical limiting properties of organic NLO materials. However, little consideration has been paid to the impact of the ethanol dissolvable (Nooraldeen *et al*., 2009).

Abdulazeez *et al*. (2016) considered the nonlinear optical properties of nematic liquid crystal material at various concentrations utilizing Z-scan technique. Tests are performed utilizing Ceaseless Wave (CW) diode soild state laser at (473 nm) wavelength and (20 mW) power. In this research six concentrations were set up for (Di-Cinnamylidene Benzidine) (Abdulazeez *et al*., 2016).

Z. Fryad and P. Patil studied the nonlinear refractive index and nonlinear absorbtion coefficient of {(1Z)-[4-(Dimethylamino)phenyl]methylene} 4- nitrobenzocarboxy hydrazone mono-hydrate (DMPM4NBCHM) solution utilizing Z-scan technique with a Contineous Wave (CW) argonion laser. The outcomes demonstrate that this kind of organic material has a high nonlinear absorption and nonlinear optical properties will be explained detail in the following:

**Sample preparation:** Di-cinnamylidene benzidine was prepared by mixing (1.84 g; 0.01 mol) of benzidine dissolved in 10 mL of absolute ethanol with 2.64 g; 0.02 mol of cinnamaldehyde dissolved in 10 mL of absolute ethanol then three drops of glacial acetic acid were added to the prepared mixture and left under reflux for 2 h, producing yellowish solid product. A sample of selected metal salt (0.001 mol) was placed in a (50 mL) round

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bottom flask with absolute ethanol (10 mL). A solution of selected ligand (di-cinnamylidene benzidine) (0.001 mol) dissolved in absolute ethanol (10 mL) was then added. The reactants ratio was (1:1). The mixture was left under reflux for 1 h, producing colored solid product. The solid product formed was separated by filtration, purified by recrystallization from ethanol, washed with ethanol and then dried (Abdulazeez and Ban, 2016).

**Z-scan technique:** The Z-scan experiments will be explain detail in the following paragraph:

**Z-scan theory:** The Z-scan technique is an exceptionally prominent and delicate single beam method for measuring the nonlinearity of optical materials. The Z-scan technique includes two test set-ups: a-with a little aperture (closed aperture) b-with no gap (open aperture), keeping in mind the end goal to determine the nonlinear refraction index ($n_2$) and absorption coefficient ($\beta$) (Nadafan *et al.*, 2015).

The mathematical relationships for nonlinear materials at high intensity of absorption and nonlinear refraction is given by Gomez *et al.* (2003):

$$\alpha = \alpha_0 + \beta I \quad (1)$$

Where:

$\alpha$ = The linear absorption coefficient
$\beta$ = The nonlinear absorption coefficient related to the intensity

The coefficients n and $\alpha$ are related to the intensity of laser (Patil *et al.*, 2016).

$$n = n_0 + n_2 I \quad (2)$$

Where:

$n_0$ = The linear refractive index
$n_2$ = The nonlinear refractive index

The nonlinear optical properties can be investigated by Z-scan technique at which it can be used to determine the nonlinear refractive index when closed-aperture geometry is used and nonlinear absorption coefficient with open aperture. The nonlinear refractive index is calculated from the peak to valley difference of the normalized transmittance by the following Eq. 3 (Patil *et al.*, 2016):

$$n_2 = \frac{\Delta\Phi_0}{I_0 L_{eff} k} \quad (3)$$

Where:

$k = 2\pi/\lambda$ = Wave number
$\lambda$ = The beam wavelength
$I_0$ = The intensity at the focal spot
$\Delta\Phi_0$ = The nonlinear phase shift

$$\Delta T_{p\text{-}v} = 0.406\,|\Delta\Phi| \quad (4)$$

$\Delta T_{p\text{-}v}$ the difference between the normalized peak and valley transmittances, $L_{eff}$ is the effective length of the sample, determined from (Gomez *et al.*, 2003):

$$L_{eff} = \frac{\left(1-\exp^{-\alpha_0 L}\right)}{\alpha_0} \quad (5)$$

Where:

L = The sample length
$\alpha_0$ = Which is given as (Patil *et al.*, 2016)

$$\alpha_0 = \frac{\mathrm{Ln}\left(\frac{1}{T}\right)}{t} \quad (6)$$

Where:

t = The thickness of sample and
T = The transmittance

The linear refractive index ($n_0$) obtained from equation (Boyd, 2008):

$$n_0 = \frac{1}{T} + \left[\left(\frac{1}{T^2} - 1\right)\right]^{\frac{1}{2}} \quad (7)$$

The intensity at the focal spot is given by Boyd (2008):

$$I_0 = \frac{2P_{peak}}{\pi\omega_0^2} \quad (8)$$

Is defined as the peak intensity within the sample at the focus, where $\omega_0$ is the beam radius at the focal point. The coefficients of nonlinear absorption ($\beta$) can be easily calculated by using following Eq. 1:

$$\beta = \frac{2\sqrt{2}T(z)}{I_0 L_{eff}} \quad (9)$$

where, T(z): the minimum value of normalized transmittance at the focal point where (z = 0).

**Z-scan set up:** The experimental setup of used Z-scan technique is shown schematically in Fig. 1. The measurements were performed by using Continuous Wave (CW) diode solid state laser at (457 nm) wavelength and (84 mW) power (Milanchian *et al.*, 2016).

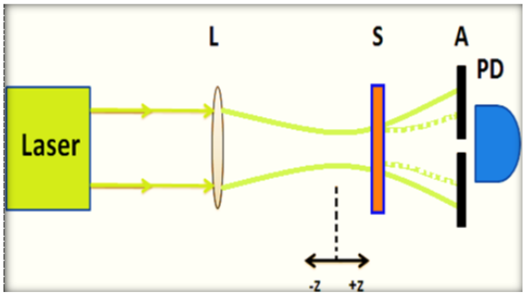


Fig. 1: Schematic diagram of the experimental arrangement for close aperture Z-scan setup (Milanchian *et al*., 2016)

## RESULTS AND DISCUSSION

The linear and nonlinear optical properties will be explain detail in the following paragraph:

**Linear optical properties:** The linear absorption of Di-cinnamylidene benzidine by $CuCl_2$ nanoparticles in ethanol solvent with different concentrations (2, 4 and 6)×$10^{-5}$ M recorded for wavelengths 190-700 nm were tested using UV-VIS spectrophotometer model (Aquarius 7000, Optima, Japan) at room temperature as shown in Fig. 2. The present outcomes demonstrate that the absorption peak for (Di-cinnamylidene benzidine) of various concentrations of Di-cinnamylidene benzidine in ethanol solvent were moved toward the more long wavelengths with diminishing concentrations. This move get because of diminishing number of molecules per volume unit at low concentrations, we notes absorption expanding with increasing concentrations.

The linear absorption coefficient ($\alpha_o$) and linear refractive index ($n_o$) of (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles, obtained from Eq. 6 and 7, respectively (Nadafan *et al*., 2015) . The values of ($\alpha_o$) and ($n_o$) are decreased with decreasing the concentrations of solutions as listed in Table 1.

**Nonlinear optical properties:** The nonlinear properties of (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles in ethanol solvent with different concentrations (2, 4 and 6)×$10^{-5}$M were measured by the Z-scan technique. The nonlinear refractive index ($n_2$) by closed-aperture Z-scan measurements and nonlinear absorption coefficient (β) by open-aperture Z-scan. The measurements were done at (457 nm), (84 mW). Figure 3 show closed-aperture Z-Scan at different concentrations of (Di-cinnamylidene benzidine doped by $CuCl_2$ nanoparticles) in ethanol solvent, the nonlinear effect region is extended from (-3-3) mm. The peak followed by

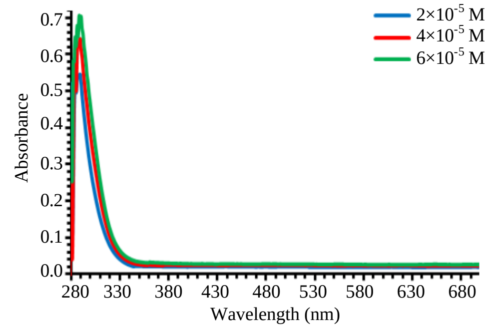


Fig. 2: Absorption spectra of (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles in ethanol solvent at different concentrations

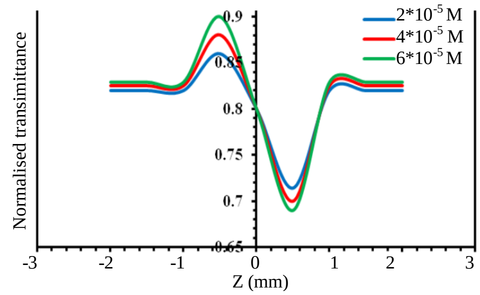


Fig. 3: Closed-aperture Z-scan data for different concentrations of (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles

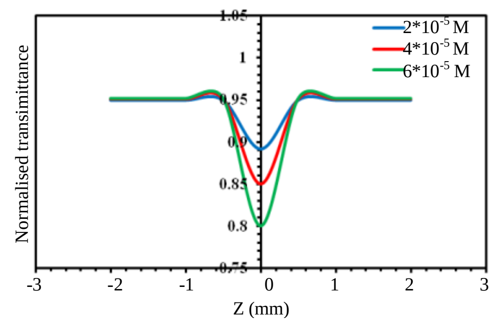


Fig. 4: Open-aperture Z-scan data for different concentrations of (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles

a valley transmittance curve obtained from the closed aperture Z-scan data indicates that the sign of the refraction nonlinearity is negative ($n_2$<0) leading to self-defocusing lensing in the sample.

To investigate the nonlinear absorption coefficient, Fig. 4 shows open-aperture Z-scan of di-cinnamylidene benzidine doped by $CuCl_2$ nanoparticles, at (457 nm), (84 mW), the nonlinear parameters are calculated as tabulated in Table 1 from this table, we show that the

Table 1: The nonlinear optical parameters at different concentrations of di-cinnamylidene benzidine doped by $CuCl_2$ nanoparticles

| $C \times 10^{-5}$ Mol/L | T | $\alpha$ ($cm^{-1}$) | $n_\circ$ | $\Delta T_{pv}$ | $\Delta_{\phi\circ}$ | $n_2 \times 10^{-11}$ ($cm^2$/mW) | T(z) | $\beta \times 10^3$ (cm/mW) |
|---|---|---|---|---|---|---|---|---|
| 2 | 0.95059 | 0.0506 | 1.37853 | 0.14 | 0.3448 | 3.08 | 0.892 | 3.09 |
| 4 | 0.94418 | 0.0574 | 1.40801 | 0.18 | 0.4433 | 3.96 | 0.850 | 2. 95 |
| 6 | 0.93595 | 0.0661 | 1.44464 | 0.21 | 0.5172 | 4.62 | 0.800 | 2.77 |

Table 2: The optical limiting response of di-cinnamylidene benzidine doped by $CuCl_2$ nanoparticles at different concentrations in ethanol solvent

| Concentration | Limiting threshold | Limiting amplitude |
|---|---|---|
| $6 \times 10^{-5}$ | 84 | 7 |
| $4 \times 10^{-5}$ | 88 | 8 |
| $2 \times 10^{-5}$ | 90 | 9 |

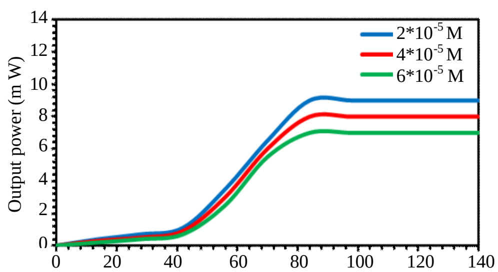


Fig. 5: The optical limiting response for (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles at different concentration

values of non-linear parameter ($n_2$) are decreased with decreasing the concentrations and the nonlinear coefficient ($\beta$) increase when the concentrations and linear parameters ($\alpha$) decrease.

**Optical limiting behavior:** Optical limiting happens when the optical transmission of a material the security of sensors and human eyes from the intense laser radiation. The optical power limiting property saturates with increasing laser intensity a property that is attractive for (Di-cinnamylidene benzidine) doped by $CuCl_2$ nanoparticles is measured with a similar laser utilized in Z-scan technique. Also a varying beam splitter was utilized to vary the input power. Figure 5 give the optical limiting attributes at room temperature for all the samples. The sample indicate great optical limiting conduct emerging from nonlinear refraction.

The out power rises at first with the expansion in input control, yet, after a specific limit threshold value, the sample begin defocusing the beam resulting about a larger part of the beam cross-section being cut off by the aperture. Thus, the transmittance recorded by the photodetector remained sensibly steady demonstrating a plateau district. From the threshold intensity for optical limiting for each sample, the optical power limiting is contrarily relative to the concentrations as appeared in Table 2 that is mean the properties of the optical limiting be better with increasing the concentrations.

## CONCLUSION

By utilizing Gaussian beam from (CW) pulsed laser at (457 nm), we investigated the nonlinear optical properties of (Di-Cinnamylidene Benzidine) in ethanol solvent doped with ($CuCl_2$) nanoparticles materials at various concentrations. The relation between the nonlinear refractive index and the nonlinear phase shift is a straight increasing relation. In closed aperture the peak-valley arrangement revealed a negative nonlinear refraction which is ascribed to de-focusing process for solution while in open aperture absorption phenomena were showed two photon absorption of solution. All the sample of pure and doped liquid crystal have a good optical limiting behavior. So, it very well may be accessible for the applications utilized in taking care of the laser output to ensure human eye and the sensors.

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