Determination of thermo-optic, nonlinear absorption and nonlinear refraction coefficients in the thermal regime of L-tryptophan using closed aperture CW Z-scan technique

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Abstract : *The closed aperture (CA) continuous wave (CW) Z-scan of aromatic amino acid L-tryptophan was performed with red diode laser to investigate the variation of on axis nonlinear phase shift* $\Delta\Phi_0$ *with the change of optical field strength. In the studied range of incident optical fluence* (I_0) *varying from* $150\ MW/m^2$ *to* $290\ MW/m^2$, $\Delta\Phi_0$ *was found to vary nonlinearly. This nonlinear variation is explained by considering the effects of both linear and nonlinear absorptions of radiation on the thermo-optical refractive index. Using the quadratic fitting of* $\Delta\Phi_0$ *with* I_0 *we have found the thermo-optic coefficient of refractive index dn/dT, thermal coefficient of nonlinear refractive index* n_2^T *and the nonlinear absorption coefficient* β *in the observed power regime.*

Keywords *: CW Z-scan, thermo-optic coefficient, nonlinear absorption, thermal coefficient of nonlinear refractive index*

1. Introduction

- Z-scan is a widely used technique since 1989.
  Used to determine third order nonlinear parameters, such as, the coefficient of refractive index (n_2) and nonlinear absorption coefficient (β).
- *Single beam continuous wave (CW) closed aperture (CA) Z-scan implemented.*
- Thermal lensing in presence of both ***linear*** and ***nonlinear absorption*** considered (Palfalvi et. Al)
- **Quantities determined** :
  - Thermo-optic coefficient of refractive index dn/dT
  - Thermal nonlinear refraction coefficient n_2^T
  - Nonlinear absorption coefficient β
- Fluence range : $150\ MW/m^2$ to $290\ MW/m^2$
- Material : L-tryptophan ($C_{11}H_{12}N_2O_2$) aqueous solution.

- The sample in a cuvette is translated along the axis of a focused Gaussian beam and the transmitted beam is analyzed at a far field position (Fig. 1).

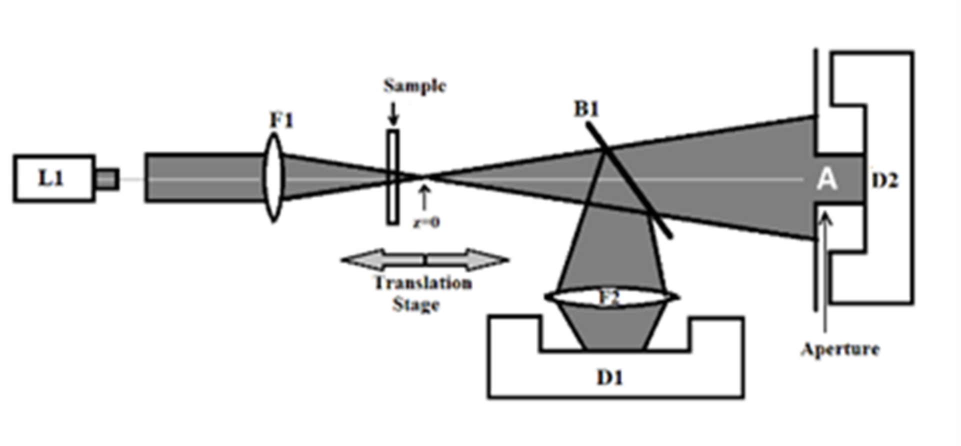

Fig. 1. Schematics of Z-scan setup

- D1 measures the open aperture optical power and D2 measures closed aperture optical power.
- The power transmitted through the closed aperture is a valley followed by a peak in case of positive nonlinear medium and a peak followed by valley in case of negative medium (Fig. 2.)

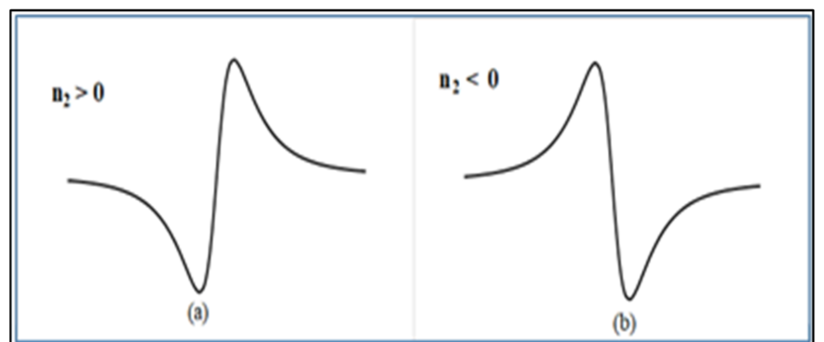

Fig. 2. Z-scan plot for (a) positive nonlinearity and (b) negative nonlinearity

- The transmittance through the aperture is given by

$$T = 1 + \frac{4\Delta\Phi_0 x}{(1+x^2)(9+x^2)} \qquad (1)$$

- Where $x = z/z_0$, z_0 being the Raleigh range of the focused beam. The on-axis phase shift depends is

$$\Delta\Phi_0 = k\Delta n L_{eff} \qquad (2)$$

- Where $k = \frac{2\pi}{\lambda}$ is the wavenumber and $L_{eff} = (1 - e^{-\alpha L})/\alpha$ is the effective path length of the medium.
- The shift in refractive index from linear is given by

$$\Delta n = n_2 + n_2^T I_0 \qquad (3)$$

- where, n_2 is the intensity independent refractive index and n_2^T is an intensity dependent nonlinear term given by

$$n_2^T = \frac{1}{4\kappa}\frac{dn}{dT}\left(\frac{\alpha}{2}\omega_i^2 + \frac{\beta P_i}{\pi}\right) \qquad (4)$$

- The nonlinear on axis phase shift is expressed as

$$\Delta\Phi_0 = kL\left(1 - \frac{\alpha L}{2}\right)n_2 + \frac{1}{2}\frac{k\omega_0^2 L(1-\frac{\alpha L}{2})}{4\kappa}\frac{dn}{dT}(\alpha I_0 + \beta I_0^2) \quad (7)$$

Here, optical fluence $I_0 = 2P_0/\pi\omega_0^2$.

- The solution of the above equation gives the values of dn/dT, n_2^T and β.

2. EXPERIMENTAL

- Stock solution (0.05 M) prepared with analar grade L-tryptophan ($C_{11}H_{12}N_2O_2$, 204.23 g/mol) at 25^0C.
- UV-Vis absorbance study with the Shimadzu UV-1800 spectrophotometer gives the linear absorption coefficient, α, at 661 nm.
- Tryptophan solution taken in a quartz cuvette with path length 2.8 mm.
- The sample cuvette moves a distance of 12 cm by a microcontroller controlled motorized stage and the closed aperture and open aperture data are collected every 10 micrometer interval.
- The data set is then normalized and then curve fitted to derive the phase shift value.
- Repeated for 16 different powers

3. RESULTS

A. UV-VIS spectroscopy result

- The absorbance (Fig. 3) at 661 nm gives $\alpha = 10.13\ m^{-1}$.

B. Z-scan Results

- Fig. 4 to Fig. 7 presents different aspects of Z-scan results
- Fig. 8. Shows the variation of Phase shifts with fluences
- Table 1 summarizes the results obtained from the experiment.
- Fig. 9 shows the Z-scan results of deionized water along with those of the tryptophan solution at three powers.

Table 1. Nonlinear optical parameters of L-tryptophan under CW irradiation.

dn/dT (K^{-1})	β (mW^{-1})	n_2^T (m^{2}W^{-1})
-10.271×10^{-5}	-2.298×10^{-08}	$-3.64 \times 10^{-14} \pm 7.74 \times 10^{-15}$

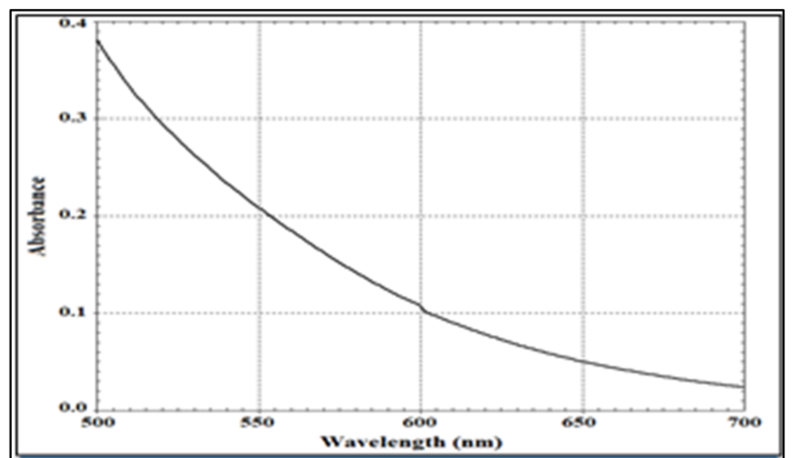

Fig. 3. UV-VIS absorption spectrum of 0.05M L-tryptophan solution

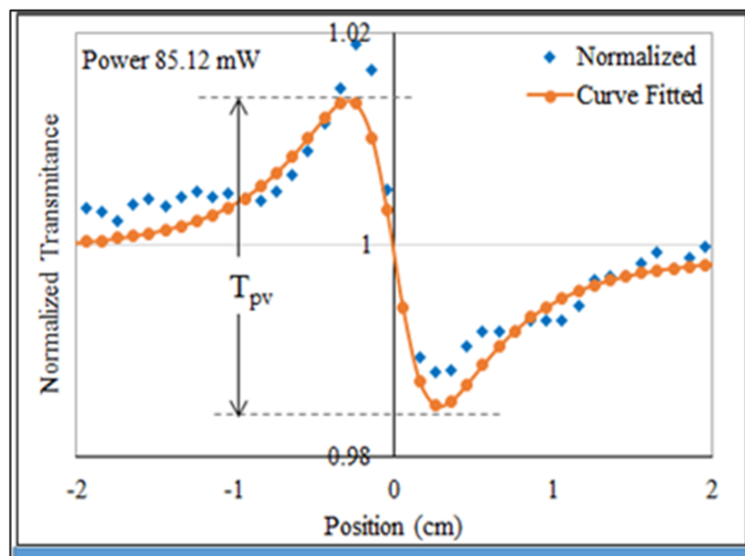

Fig. 4. Normalized and curve fitted Z-scan plot of L-tryptophan at 85.12 mW incident

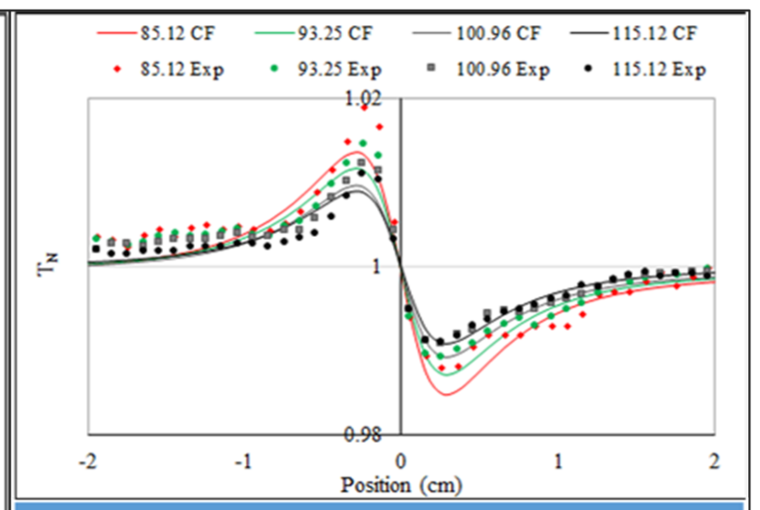

Fig. 5. Z-scan plot of L-tryptophan at five different powers varying from 85.1 mW to 115.1 mW

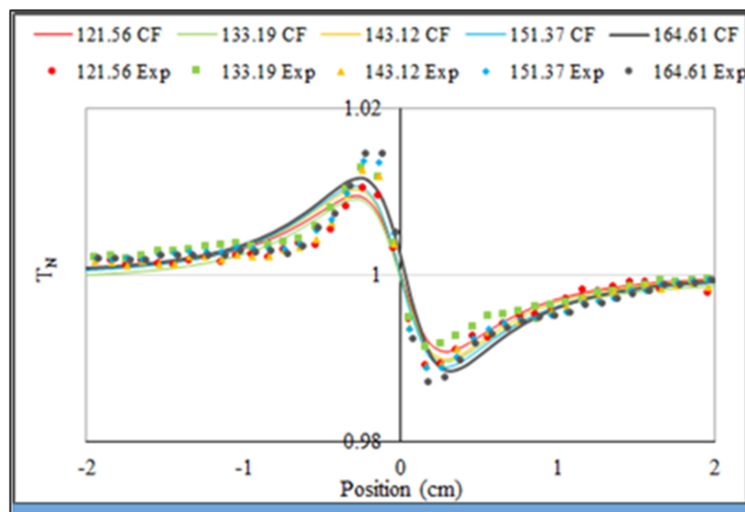

Fig. 6. Z-scan plot of L-tryptophan at six different powers varying from 121.6 mW to 164.6 m

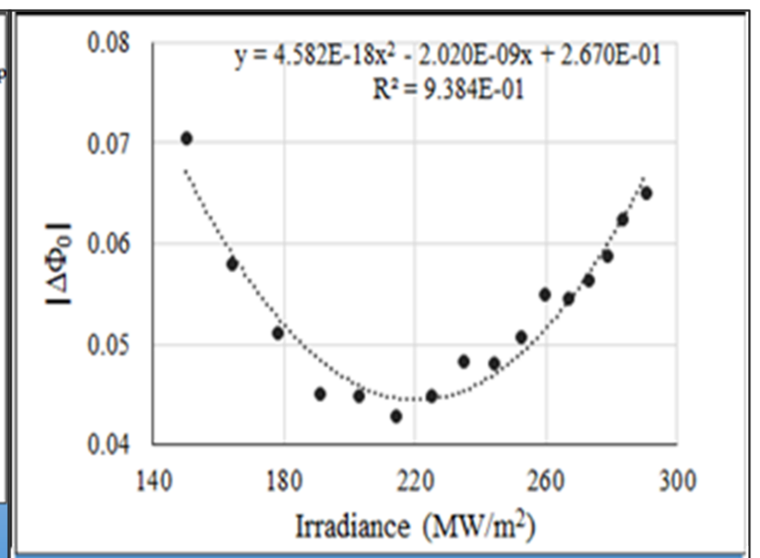

Fig. 7. Variation of $|\Delta\Phi_0|$with irradiance I_0

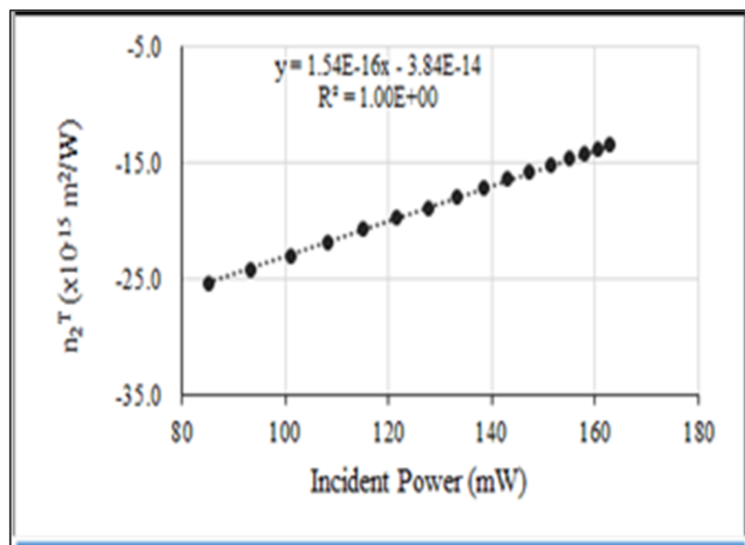

Fig. 8. Variation of $n_2^T$with incident power

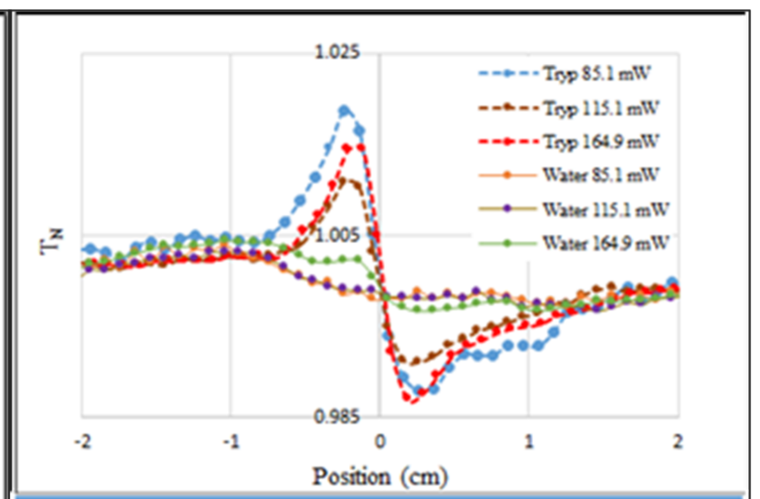

Fig. 9. Z-scan plot of L-tryptophan and deionized water at three different powers

4. CONCLUSION

- The optical nonlinearity is mainly due to the thermal lensing of the medium.
- The quadratic variation of on axis phase shift $\Delta\Phi_0$ with fluence I_0 is a result of nonlinear absorption.
- The thermo-optic coefficient, the coefficient of nonlinear absorption and the coefficient of nonlinear refractive index, all the three negative in sign.
- The thermo-optic coefficient of L-tryptophan aqueous solution is comparable to deionized water ($-8.0 \times 10^{-5}\ K^{-1}$)as mentioned by Young H. K. et. al.
- The negative value of β indicates absorption of saturable nature.
- The effect of nonlinear absorption increases with increase of incident power and the total absorption of the medium decreases throughout the incident power regime.
- The value of n_2^T is found to vary linearly throughout the incident power regime as seen from Fig. 9.
- In the case of Z-scan with CW irradiation the index of refraction is molded by absorption of radiation by the material. The effect of absorption cannot be removed from the CA data by normalization with OA data and the corresponding parameters like the absorption coefficient and refraction coefficient can both be deduced by analyzing the variation of phase-shift with incident power.

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