STUDY OF TIME –RESOLVED REFRACTIVE INDEX IN DYE DOPED POLYMERIC MATERIALS

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ABSTRACT

In our study we use DB14/PMMA an organic dye-doped polymer because it has good optical quality and has low glass transition temperature so that it can be easily processed to make large area thin films. Z-scan technique is used for the study of thermal lens effect. The refractive index change is observed due to photo thermal effect. For time constants the experimental values are about 10 times larger than the theoretical values which may be due to the assumption about the air-sample interface. The heat dissipation at the boundary of the sample is not considered. Due to the insulting effect of air it would take more time for the sample to reach thermal equilibrium.

Keywords: DB14/PMMA, Polymer, Refractive index, photo thermal.

INTRODUCTION

Our study deals with the mechanisms that how light interacts with matter to yield a time dependent refractive index. After the invention of laser, the high intensities available make it possible to study nonlinear effects where laser field strengths are a large fraction of typical fields in a molecule. Some applications made possible by nonlinear optics are real time holography, optical switching, optical fiber communication, etc. In many applications such as optical fiber communication, larger bandwidth is required and to achieve it, the response time for the device is required to be short which makes signal recognition a challenge. In z-scan experiment, a laser beam is focused into a sample and intensity measured through an aperture while the sample is translated along beam axis, hence the name z-scan.

Second harmonic generation was first observed the nonlinear optical effect in 1961, shortly after the first working laser was made by Maiman in 1960. Gordan observed the first thermal lens effect by inserting polar or non polar liquid cells in the resonator of a He-Ne laser. Akhmanov explained self-focusing in cubic nonlinear media with 2-D and 3-D Gaussian beams in the parabolic approximation. Harris performed an experiment measuring thermally induced beam distortion by solvents used in calorimetry. Castillo used pump-probe time resolved Z-scan to study the thermal changes in refractive index originates from one and two-photon absorption in organic solvents. In their experiment, a strong pump beam induces a refractive index change in the sample while a collinear weak probe beam is measured through the aperture. By using pulsed light, the temporal dependence of the signal could be measured allowing the pure thermal signal to be determined.

MATERIALS AND METHOD

The method of conversion of transient signals at fixed positions to position-dependent z-scan curves at fixed times is used to obtain the time-dependent nonlinear refractive index which we use as a tool to study nonlinear mechanisms. To be able to use Z-scan technique it is important for beam profile to be Gaussian. We use the mixture of MMA(methyl methacrylate) which turns into polymer after polymerization, chain transfer agent (CTA, 1-Butanethoil) which limits the chain length of polymer and initiator (tert-Butyl peroxide) which is a catalyst that starts the polymerization reaction. We use the optimized ratio of 2.2µl of CTA(chain transfer Agent) and initiator of 1ml of MMA which provides a balance between short chain length and brittleness.

Time-resolved refractive index: We can determine $\Delta\Phi_0(t_i)$ at time t_i by fitting the data to the equation as follows

$$T(z, \Delta\Phi_0(t_i)) = \frac{1 + 4\,\Delta\Phi_0(t_i)\,X}{(X^2 + 9)(X^2 + 1)} \qquad (1)$$

where $X = z/z_0$ and $\Delta\Phi_0(t_i) = k\,\Delta n_0(t_i)[1-\exp(-\alpha L)]/\alpha$.

Figure (1) shows the result of a fit of the data to z-scan theory. Also the Figure (1) shows the fact that the bi-exponential function given by the equation

$$\Delta\Phi_0(t) = a_1\,(1- \exp(t/T_1)) + a_2\,(1- \exp(t/T_2)) \qquad (2)$$

fits so well validates our model.

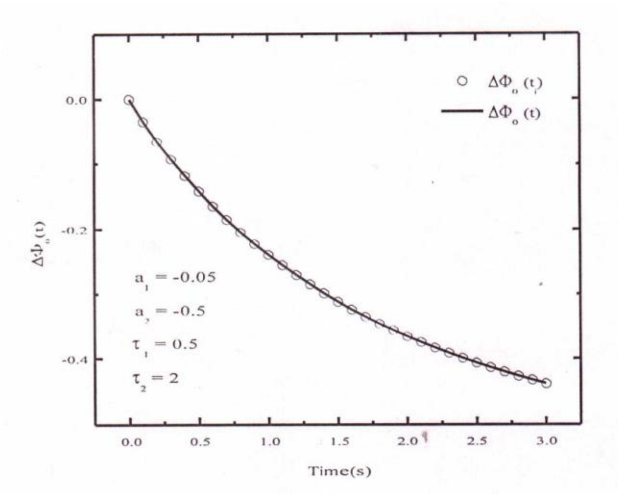

Figure 1. The Circles(°) are the data points determined by fitting the z-scan theory to the normalized transmittance. The line(—) ia s fit to bi-exponential function given by equation (2).

As such from each data points of $\Delta\Phi_0(t_i)$, we can determine the nonlinear refractive index $n_2(t_i)$ as a function of time by using the relation:

$$n_2(t_i) = \frac{\Delta\Phi_0(t_i)\,\alpha}{\kappa\, I_0(t_i)(\,1 - \exp(-\alpha L))} \qquad (3)$$

where $I_0(t_i)$ is the intensity in sample at t_i.

RESULTS AND DISCUSSION

We study the dye-doped system DB14/PMMA which should exhibit only a photo thermal contribution to z-scan data. $\Delta n(t_i)$ is calculated from $\Delta\Phi_0(t_i)$ which is obtained from fitting the z-scan at discrete time t_i as follows

$$\Delta\Phi_0(t_i) = \kappa\, \Delta n_0(t_i) L_{eff}$$

$$= \kappa\, \Delta n_0(t_i)(\,1 - \exp(-\alpha L)\,/\,\alpha$$

(4)

Where $\Delta\Phi_0(t_i)$ is the on-axis change of phase at time t_i, k is wave number, L_{eff} is the effective length, α is linear absorption coefficient and $\Delta n_0(t_i)$ is the on-axis change of refractive index.

Δn at discrete times is plotted as a logarithmic function of time in Figures 2-4. Our theory for the change of refractive index for thermal lens effect as a function of time is given by

$$\Delta n(t) = \frac{\alpha P}{4\pi\kappa(1+T/2t)} - \frac{\partial n}{\partial T} \qquad (5)$$

is used to fit the data, where the negative sign is for defocusing. Table (1) shows the fitting parameters used in Figures 2-4.

Table 1

P(mW)	w_0(μm)	$\Delta n_{sat}(\times10^{-5})$	T(ms)
0.755	65.06±0.44	-0.857±0.05	83.8±2.8
1	65.06±0.44	-1.31±0.01	99.3±2.7
7.19	35.11±0.42	-6.452±0.047	34.3±1.2

The theoretical time constant is given by

$$T^{theory} = w^2_0 / 4D \qquad (6)$$

Where D is diffusivity given by k/ρc. Table (2) shows the comparison of T^{exp} and T^{theory}.

Table 2

P(mW)	w_0(μm)	T^{exp}(ms)	T^{theory}(ms)
0.755	65.01	83.8±2.8	9.25
1	65.01	99.3±2.7	9.25
7.19	35.11	34.3±1.2	2.7

Table 3

α(cm^{-1})	∂n/∂T(K^{-1})	κ(W/m. K)	ρ(kg/m^3)	c(J/kg. K)
1.72	1.5×10^{-4}	0.193	1.19×10^3	1.42×10^3

When we compare T theoretically calculated by using parameters in table (3), there are disagreement from T measured. The experimental values are about 10 times larger than the theoretical values which may be due to the assumption about the air-sample interface. The heat dissipation at the boundary of the sample is not considered. Due to the insulting effect of air it would take more time for the sample to reach thermal equilibrium.

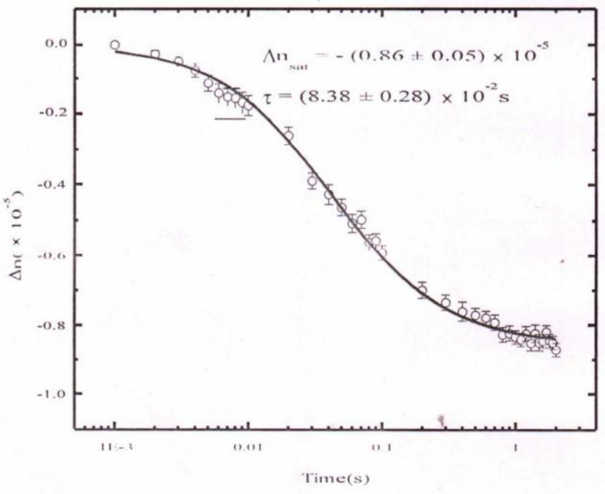

Figure 2. The refractive index change Δn(t), due to photothermal effect. The circles (°) are data points and line (—) is theory fit at P=0.755mW

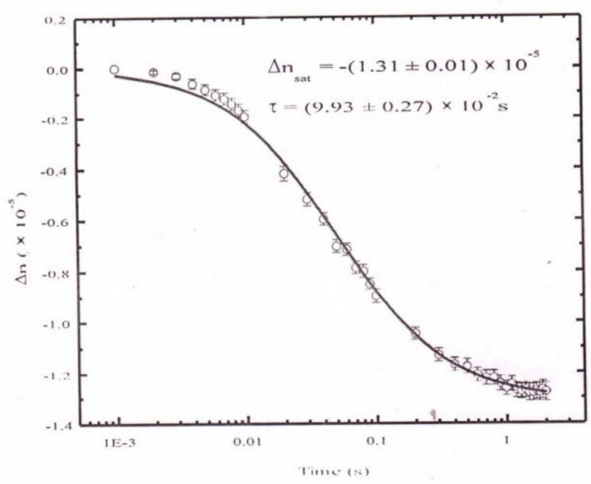

Figure 3. The refractive index change Δn(t), due to photothermal effect. The circles (°) are data points and line (—) is theory fit at P=1mW

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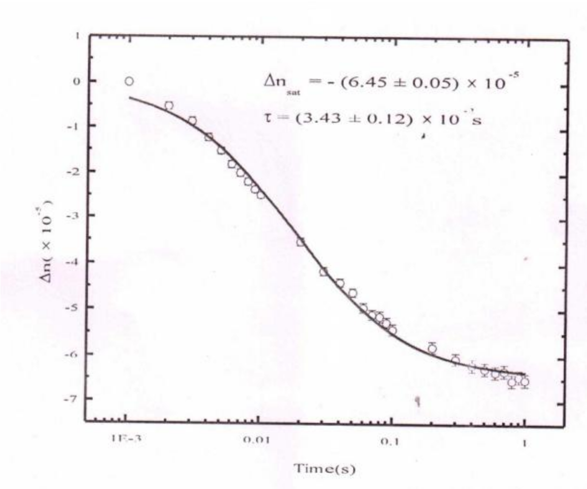

Figure 4. The refractive index change Δn(t), due to photothermal effect. The circles (°) are data points and line (—) is theory fit at P=7.19mW

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