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Determination of third order optical non-linearity in a liquid crystal by Z-scan technique for optoelectronic applications.

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Abstract: - In this paper we report the preliminary experimental data of the third order non-linearity in a liquid crystal 5HCB sample doped with methyl-red using Z-scan technique. We observe a negative nonlinearity in the sample, which is great optical nonlinearity ten times more than other results previously reported in liquid crystals. This phenomena is obtained in the nematic phase regime. For upper temperature, we observe a notable decreasing of the optical nonlinearity due to sample change to isotropic phase.

Key-Words: - Non-linear optics, electric susceptibility, nematic liquid crystals.

1 Introduction

Many applications of the nonlinear optical materials in several photonics devices such as holographic storage, optical amplifiers, optical switching and signal processing is based on the refraction index dependent of illumination intensity[1]. These elements are currently begin performed but there are an expectation that they may eventually to be improve their functions with new optical materials. Recently, in several areas of opto-electronics have been a huge interest for organics materials because the possibility of optimization of these nonlinearities through manipulation of their composition and aggregation state[2]. In particular, the organic liquid crystals are known to exhibit large optical nonlinearities which have been the subject of considerable study in last years[2-4]. The liquid crystals has shown being a competitive materials for photonics applications, especially for their potential use as inexpensive nonlinear optical element and for optical switches[5] and photorefractive holographic storage[6]. In consequence, is a priority to measure the nonlinear properties in materials to determine the optical limit device for suitable application.

There are numerous techniques for the measurement of non linear refraction index in materials. Non linear interferometry[7], degenerate four wave mixing[8], and beam distortion measurements, known as Z-scan[9], are the frequently techniques reported. The first two methods, interferometry and wave mixing, are potentially sensitive techniques but require a complex experimental set-up. The Z-scan technique, on the other hand, is based on the principles of spatial beam distortion due to self-focusing (or defocusing) processes derivated from the combination action of a intensity-dependent refractive of the media. With this technique is possible to measure with a single beam the sign and magnitude of the refractive nonlinearities offering simplicity as well as high sensitivity. As examples, this technique has been used to determine the optical nonlinearity in photorefractive liquid crystals, photopolymers and biological materials[10-12].

In this paper we report the preliminary results on a Z-scan detection technique applied to measure the sing of a new organic liquid 5HCB sample doped with methyl-red at 1%. Also, we measure the magnitude of the optical nonlinearity and we observe a great optical nonlinearity ten times more than other results previously reported in liquid crystals. This phenomena is obtained in the nematic regime.

2 Theoretical considerations

The Z-scan measurement technique is a simple experimental procedure that gives information on the optical nonlinearities of materials. This technique as originally formulated [9] is performed by sending an polarized Gaussian beam through a lens along *z*-axis. as is showed in the Figure 1.

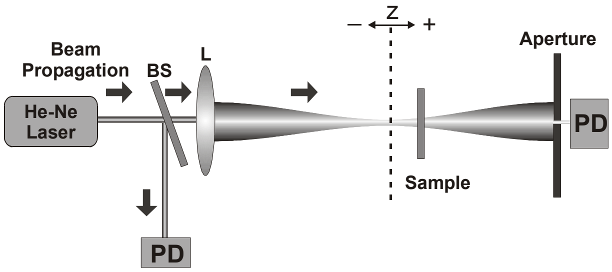

Figure 1. Typical experimental array to perform Z-scan technique. **PD:** Photodetector, **L:** lense, **BM:** beam splitter.

The sample is situated near the beam waist and moved along z direction. Lately the transmitted intensity is measured through a finite aperture in the far field as a function of sample position z, measured respect focal plane. If the sample has a positive non linearity and the sample is moved to one side of the beam waist, the detected intensity increased to a peak. When the sample is moved to the other side of the waist, the detected intensity decreases to a valley. The difference of the intensity from the peak to the valley has been shown to be proportional to the non-linear index refraction n_2 [9]. In the other case, when the sample has a positive non-linearity, we obtain a inverse Z-scan curve, i.e. a valley followed by a peak. The Figure 1 describes those situations. Consequently the Z-scan permits the calculations of non linear index refraction for different materials by a comparatively simple method.

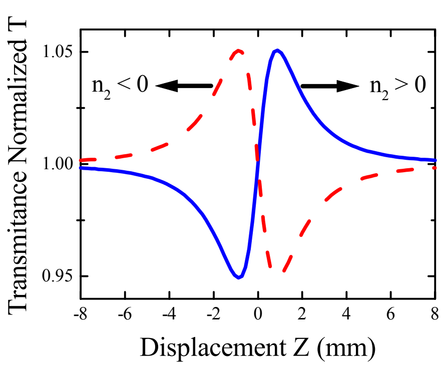

Figure 2. Z-scan theoretical curves for the transmittance as function of the z distance. His curves is obtained by equation (3). Continuous line corresponds to positive non linearity and dashed line to negative non linearity behavior.

For the nonlinear analysis, let us consider a material which is perturbed for a optical field $\boldsymbol{E}$. The induced polarization $\boldsymbol{P}$ in the media is well known by the relation[13] $\mathbf{P} = \varepsilon_0\left(\chi^{(1)}\mathbf{E} + \chi^{(2)}:\mathbf{EE} + \chi^{(3)}:\mathbf{EEE} + \ldots\right)$ where ε_0 is de permittivity of the free space and $\chi^{i\,(i)}$ is the electrical susceptibility tensor of the order i. Taken a centrosimetric media, neglected the second term for the polarization $\boldsymbol{P}$ and focusing only to the third order contribution, the nonlinear refraction index is given as:

$$n = n_0 + \frac{\Delta n}{2}E^2 = n_0 + \gamma I \qquad (1)$$

where n_0 is the linear refractive index, Δn is the is a nonlinear refractive index, I is the intensity of the laser radiation incident and the coefficient γ is associated to real part of the third order electrical susceptibility $\chi^{(3)}$ expressed as:

$$\gamma = \frac{1}{2n_0\varepsilon_0 c}\mathrm{Re}\left(\chi^{(3)}\right) \qquad (2)$$

where c is the speed of the light at the vacuum. Here is important to mention that the induced nonlinear refraction index given by equation 1 is a local response, due to each point on the material depends only the radiation intensity in the same point. If we consider a sample with negligible absorption, on-axis normalized transmittance T as a function of the propagation coordinate z is given approximately as[14]:

$$T(z) = \frac{S(z)}{S(z\to\infty)} \approx \Delta\Phi\frac{4x}{(1+x^2)(9+x^2)} \qquad (3)$$

where $S(t)$ is the signal monitored by the photodetector at time t, $\Delta\Phi$ is the on-axis nonlinear phase at the focus, $x = \frac{z}{z_0}$ is the distance normalized respect to the Rayleigh range distance z_0 of the Gaussian beam. The nonlinear phase shit $\Delta\Phi$ is expressed by:

$$\Delta\Phi = \frac{2\pi d}{\lambda}\gamma I_0 \qquad (4)$$

where d is the sample thickness, λ is the wave length of the incident beam and I_0 is the on-axis intensity at the focus.

3 Experimental Set-up and results

The experimental array consist in the typical Z-scan system showed in Figure 1. The illumination source is a linear polarized He-Ne laser at λ=632.8 nm with a FHWM= 0.45 mm. The laser beam is divided by a beam splitter in two arms, on of them is used as reference incident beam. The second one beam passes through a positive lens f=17.5 cm and illuminate the liquid crystal sample is situated near to the focus. The intensity transmitted is monitored by the silicon photodetector provided with an aperture. The liquid 5HCB sample doped with methyl-red at 1% was prepared in the Photonic and Optical Physics laboratories at INAOE. The sample was located into a termal box isolated, which the temperature is controlled electronically. We measure the transmitted intensity by the sample for negative and positive position z respect the focal length and finally we calculate the transmittance respectively. These measurements were performed for 4 different temperature. The experimental results are shown in figure 3.

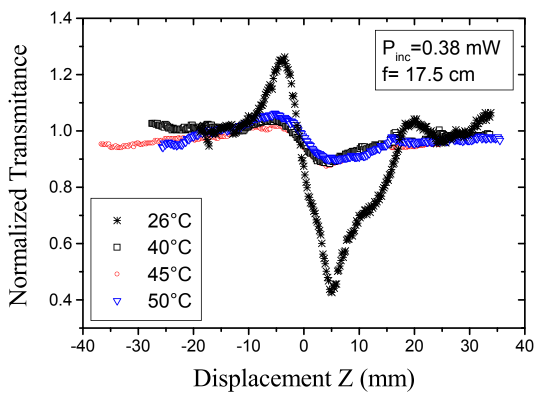

Figure 3. Experimental Z-scan trace for theoretical curves for the 5HCB sample doped with methyl-red at 1%. An important enhance of the negative nonlinearity is observed for T=26°C (cross).

We observe a negative nonlinearity in the sample and a relevant increment in the peaks of the characteristic Z-scan curve for temperature T= 26°C. In this case, we measure a nonlinear effect 10 times bigger than other liquid crystals For upper temperatures, we observe a drop of this trace. This behavior is explained as following. Most of the more popular liquid crystals are composed of molecules that are strongly elongated in one direction, called nematic phase configuration[3]. Under this molecules array, the dielectric and magnetic susceptibilities are anisotropic and produces a great nonlinearity (Eqs. 1 and 3). This phase, identify by the average orientation of the molecules, is keeping still a critical temperature T_c. For temperature over T_c, the orientations of the molecules is broken and it adopt a random orientation, called isotropic phase. The typical transition temperature T_c for the usual liquid crystals is reported in the range 35-80°C [15]. In consequence, the nonlinearity observed decrease according with others results reported[15, 16].

4 Conclusions

In this paper we report the observation of a negative optical nonlinearity in a new sample liquid crystal. The increment in optical nonlinearity is about 10 times bigger than other liquid crystal previously reported. This phenomena is due the experiments was perform under transition temperature T_c. To determine the termo-optical contribution and saturable absorption effect we propose a future experiments to complement this experimental data.

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