Laser Induced Refractive Index Change in Nematic Liquid Crystals

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ABSTRACT

We report the observation of laser induced refractive index change for a homeotropically aligned nematic liquid crystal (BDH-E7) film of 10 mm thickness. Diffraction rings were observed when an intense Ar+ ion laser hits a homeotropically aligned nematic liquid crystal at normal incidence above a threshold of 110 KW/cm2, which correspond to the threshold of the Optical Freedericksz Transition (OFT). Above the threshold, as the laser intensity was increased, the number of observed diffraction rings likewise increased. The mechanism for optical molecular reorientation has a great dependence on elastic restoring forces. By exploring the dependence of bend elastic constant, K33 with Freedericksz transition, the value of the K33 was calculated at 2.6 x 10-12 N. To investigate the behavior of Dn as a function of intensity, an experiment was performed for oblique laser incidence. It was shown that the refractive index change increased linearly from values of 0.001 to 0.18 at laser intensities ranging from 50 KW/cm2 to 200 KW/cm2. The Kerr coefficient n2 was calculated for various laser incidence angles.

Keywords: liquid crystals, refractive index, optical freedericksz transition, director reorientation, laser

INTRODUCTION

The liquid crystalline state of matter has the optical properties of solids and the flow characteristics of liquids. In particular, liquid crystals are fluid states with spontaneous anisotropy (Brown, 1976). One of the optical properties of liquid crystals is birefringence ($\Delta n=n_e-n_o$) and phase retardation of polarized light. There are various theories explaining the behavior of liquid crystals under the influence of external perturbations (Lubensky, 1996; Freedericksz & Zolina, 1933; Frank, 1958). It has been shown (both theoretically and experimentally) that thermotropic (temperature-sensitive) liquid crystal molecules align their long molecular axis along the direction of perturbation. These perturbations may be in the form of magnetic, electric, or optical field (Priestley, 1974). The director is the unit vector that describes the preferred orientation of a liquid crystal system. Thus, liquid crystal molecule reorientation due to an applied field is equivalent (to a good degree of approximation) to director reorientation (Brown, 1976). The importance of parameters (index of refraction, viscosity, elasticity) involving macro level (bulk) response can be clearly seen when it is used in industrial applications, the most common of which are the liquid crystal displays (LCD) (Kedzierski et al., 1974). Since different types of LCD applications require different parameters (e.g., LCD

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for real time displays need faster switching time; LCD for portable displays need low power consumption) (Lubensky, 1996), it follows that in order to produce a good liquid crystal material, certain control over these parameters must be imposed. This study aims to quantitatively demonstrate some mechanisms involved when a liquid crystal is subjected to optical perturbation. The physical proof of Freedericksz transition will likewise be presented. The equations used to model our results are limited to nematic liquid crystals since other types of LCs have different state equations.

METHODOLOGY

A commercially available liquid crystal (BDH E7) was sandwiched between 2 circularly cut glass plates. The LC was homeotropically prepared (see Fig. 1, where initially the LC molecules are perpendicular to the glass plates) by applying lecithin to the glass plates and the thickness was controlled by a plastic spacer (~10 microns). The liquid crystal cell was sealed by ordinary epoxy. Microphotographs of the sample were taken before it was subjected to optical tests.

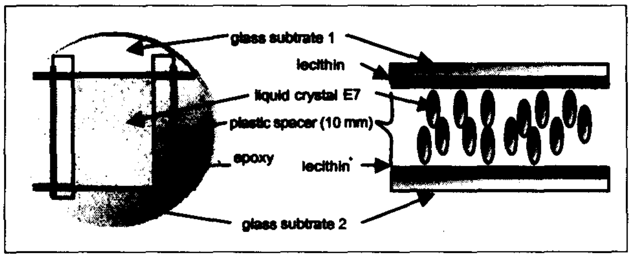

Fig. 1. The liquid crystal cell. Homeotropically aligned LC molecules orient their long molecular axis normal to the substrate.

The sample was illuminated by an Ar+ laser (TM00 mode, vertically polarized) focused by a lens (f=50mm) at intensities ranging from 50 KW/m^2 to 200 KW/m^2 (see schematic in Fig. 2). A plot of Δn vs. intensity was obtained.

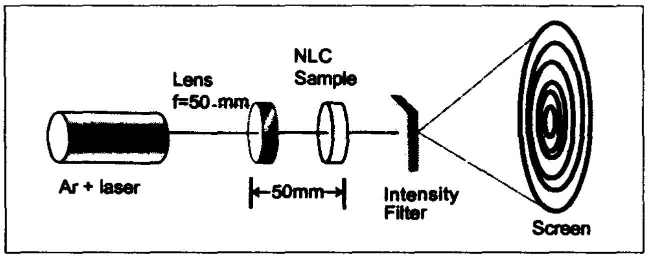

Fig. 2. At normal incidence, an intense Ar+ beam produced fringe patterns above a threshold intensity.

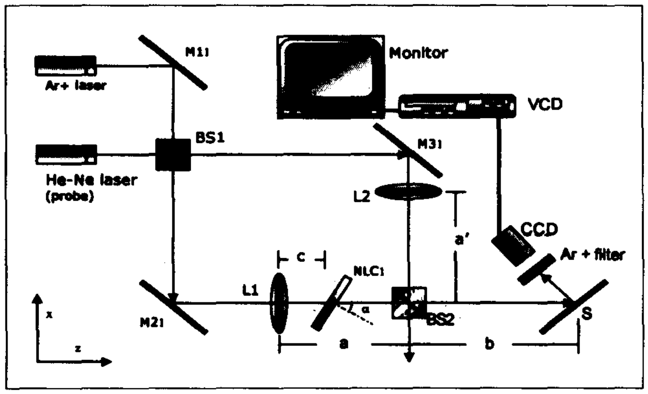

Fig. 3. Interferometry setup to quantitatively determine Dn as a function of intensity and incidence angles

The same sample was then introduced in a modified Mach-Zender interferometry setup (Fig. 3) to quantitatively determine Δn as a function of intensity and incidence angles. The intensity of the Ar+ laser was varied from 50 KW/cm^2 to 200 KW/cm^2 and was measured at incidence angles: 10, 20, 30, 40, 50, 60 and 70 degrees. The value of Δn was computed from the phase profile obtained from the recorded fringe patterns. The phase change experienced by the light as it traverses the NLC film of thickness d due to change in the index of refraction is quantified by the equation

$$(1)\quad \Delta\ \varphi = \frac{2\pi}{\lambda} d\Delta n$$

where λ is the laser wavelength in air, Δn is the change in index of refraction and d is the sample thickness. dΔn is the optical path difference.

RESULTS, DISCUSSIONS, AND CONCLUSIONS

Diffraction rings (Fig. 4) were observed when an intense Ar+ ion laser hits a homeotropically aligned nematic liquid crystal at normal incidence above a threshold of

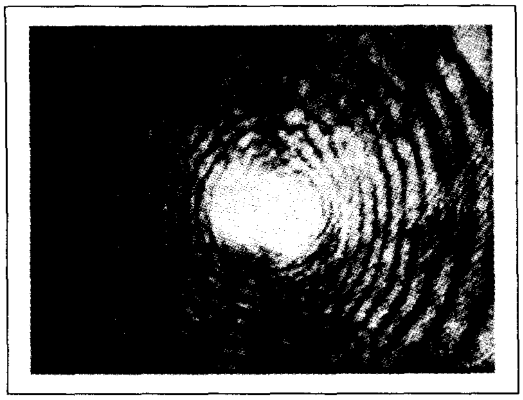

Fig. 4. Diffraction rings formed due to phase retardation of laser

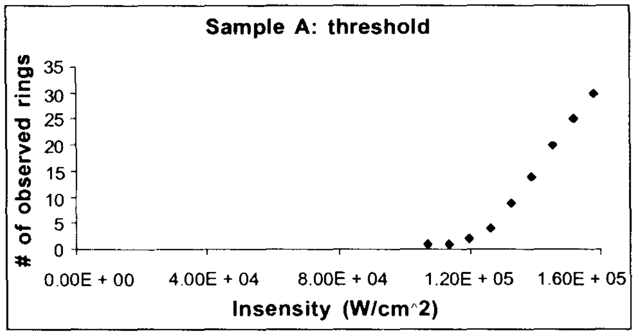

Fig. 5. Number of observed rings vs. intensity

110 KW/cm², which correspond to the threshold of the Optical Freedericksz Transition (OFT) (Durbin et al., 1981). Above the threshold, as the laser intensity was increased, the number of observed diffraction rings likewise increased (Fig. 5).

The diffraction rings were caused by phase retardation of light which was in turn caused by Δn due to reorientation of LC molecules. The mechanism for optical molecular reorientation has a great dependence on elastic restoring forces and by exploring the dependence of bend elastic constant, K_{33}, with Freedericksz transition, the value of the K_{33} was calculated from the equation:

$$(2)\quad I_{th} = \frac{c\varepsilon_e K_{33}}{\varepsilon_e - \varepsilon_o \sqrt{\varepsilon_e}} \left(\frac{\pi}{d}\right)^2$$

where I_{th} is the threshold intensity, c is the speed of light in vacuum, $\varepsilon_o = n_o^2$, $\varepsilon_e = n_e^2$. n_e and n_o are the extra-ordinary and ordinary refractive indices, respectively. d is the sample thickness and K_{33} is the bend elastic constant computed at 2.6 x 10^{-12} N. The standard value for NLCs at 20 °C is 17.1 x 10^{-12} N. The deviation from the standard may be attributed to (a) non-perfect homeotropicity (as evidenced in optical microscopy) (b) thermal effect, and (c) thinness of sample (other papers (Santamato et al., 1994) produced samples at ~300 mm). Furthermore, because of the said parameters, the K_{33} value obtained may not have been purely "bend" but some effective elastic constant.

To investigate the behavior of Δn as a function of intensity, an experiment was performed for oblique laser incidence. By measuring the distance between fringes (via pixel distance as recorded by the CCD) and how much they "expand", the phase retardation Δφ can be evaluated. By plugging it into equation (1), the refractive change Δn can be obtained. By varying the laser intensity, a plot of Δn vs. I was produced (Fig. 6). It was shown that the refractive index change increased linearly from values of 0.001 to 0.18 at laser intensities ranging from 50 KW/cm² to 200 KW/cm². The Kerr coefficient n_2 was calculated for various laser incidence angles from the slope of the linear regression of Δn vs. intensity plots from the equation, $\Delta n = n_2 I$ (Santamato et al., 1994). It was noted that the "S-curve" shape of the graph may be due to thermal effect (Lubensky, 1996) since the system was not designed to minimize the heat effect of high intensity laser. Further studies may be done to

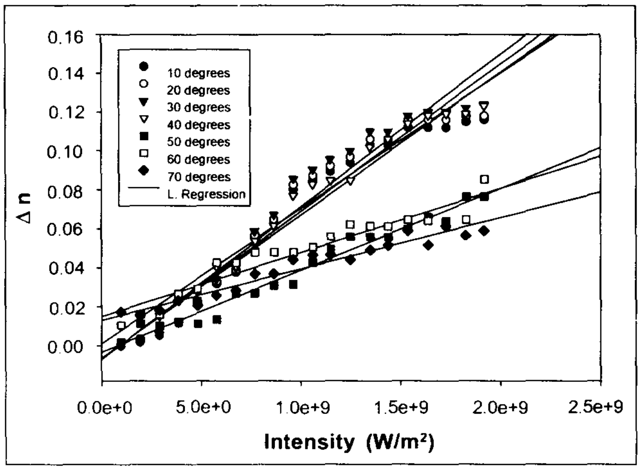

Fig. 6. Dn vs. intensity. The slope of the plot is n2.

improve the formulation and fabrication of these devices (probably with temperature control) so that we may benefit from using these devices as Kerr media.

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