Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl20

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Version of record first published: 15 May 2012.

To cite this article: Habib Khoshsima , Hadis Goodarzi , Sohrab Ahmadi Kandijani & Rana Asgari Sabet (2012): The Study of Dynamic Behaviour of Transient Grating in Azo Dye Doped Nematic Liquid Crystal, Molecular Crystals and Liquid Crystals, 560:1, 62-66

To link to this article: http://dx.doi.org/10.1080/15421406.2012.662316

Mol. Cryst. Liq. Cryst., Vol. 560: pp. 62–66, 2012

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2012.662316

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The Study of Dynamic Behaviour of Transient Grating in Azo Dye Doped Nematic Liquid Crystal

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In this experimental work, we investigated the dynamic behaviour of the transient holographic grating in an Azo dye doped nematic liquid crystal, formed by a pulsed laser. Relaxation behaviour of the grating was studied in two experimental geometries, when the director is parallel or perpendicular to the grating vector. Relaxation time constants for different writing angles were used to measure the diffusion coefficients. The obtained results show the anisotropic diffusion of the photo excited dye molecules.

1. Introduction

In recent years, the development of holographic and diffractive devices, which are used in optical storage, electro-optical switching, and displays, has been grown rapidly. Because of fast dynamic response and high sensitivity, liquid crystals seem very promising to be exploited for the above applications [1]. Nonlinear properties of liquid crystals will be improved considerably when they are doped with the proper dyes. Among different dyes, Azo dyes attract a lot of interest because of high optical sensitivity and isomerization between trans and cis states [2]. Because of the associations between density, flow, temperature, and reorientation, the dynamical responses of dye-doped liquid crystals (DDLCs) to a short intensive optical field are complex [3,4]. However, a large number of experimental techniques including radioactive tracers, nuclear magnetic resonance, and quasi elastic neutron scattering have been used to study the diffusion of organic molecules in solutions. Among these methods, the holographic grating relaxation investigation provides a sensitive and selective method for investigating dynamic processes of diffusivity in anisotropic liquid crystalline phases [5]. In this study, the mentioned holographic grating relaxation technique is used to measure the diffusion coefficients of the photo excited dye molecules in directions parallel and perpendicular to the director in Azo DDLC.

2. Experiments

In this experimental study, a planar cell with thickness of about 20 μm containing 1294-1b nematic liquid crystal (from AWAT PPW company, Poland) doped with 0.5% weight of

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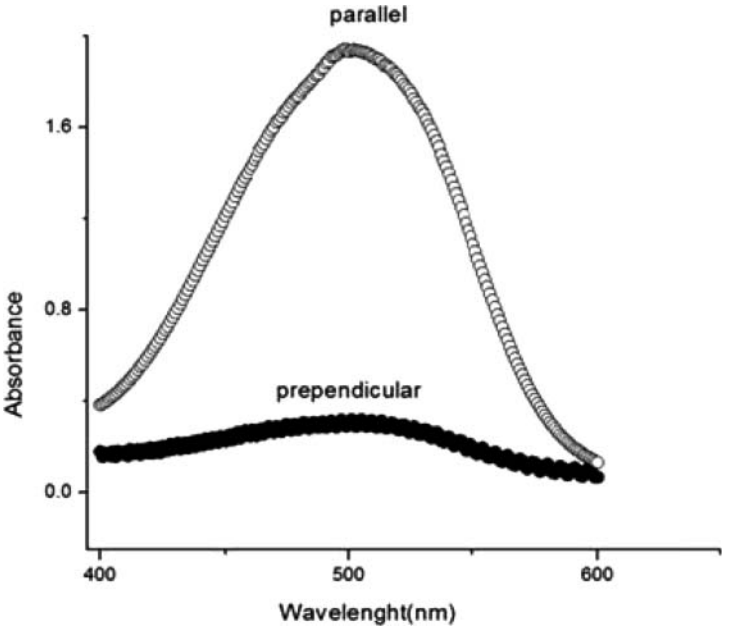

Figure 1. Absorption spectrum of the planar cell with dye doped liquid crystal. Absorptions are shown for light polarizations parallel and perpendicular to the liquid crystal director axis.

DR1 Azo dye (from Aldrich) is used. The polarized absorption spectrum of the sample, as shown in Fig. 1, was obtained with a Shimadzu spectrophotometer model UV 2450.

According to the absorption spectra, the dichroic ratio, $N = D_{\parallel}/D_{\perp} = 8.54$, is calculated, where $D_{\parallel}$ and $D_{\perp}$ are the absorptions at λ_{max} of the cell with light polarizations parallel and perpendicular to the director, respectively. The order parameter was also calculated using the relation $S = (N - 1)/(N + 2)$ as 0.71, confirming good alignment of the Azo dyes in their stable trans form parallel to the liquid crystal axis. The experimental setup for investigation of the holographic grating is shown in Fig. 2.

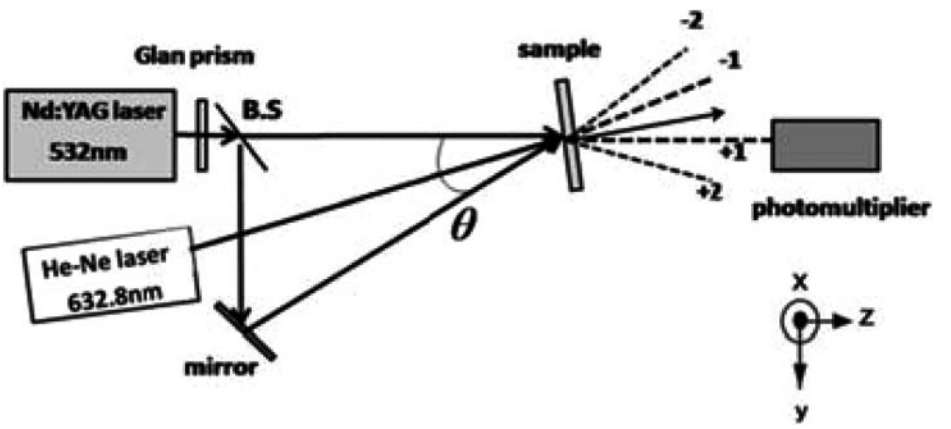

Figure 2. Experimental setup to study the relaxation behavior of the transient grating.

The second harmonic of a pulsed Nd:YAG laser, which has the pulse duration of 10 ns and pulse energy of 35 mJ with a 3 mm diameter of beam on the sample, is used to induce transient grating in DDLC. The laser beam is divided into two beams with equal intensity using a beam splitter where the two "p" polarized writing beams intersect on the sample at a variable angle θ. The sample was placed in the intersection of the writing beams in two forms; first the director was perpendicular to the grating vector and then parallel to that. A He-Ne laser ($\lambda = 632.8$ nm, 1 mW) with polarization perpendicular to the director axis and beam diameter of about 0.5 mm is also used to monitor the dynamic behavior of the pulsed laser induced grating in the sample. The first order diffracted probe beam is detected by a photomultiplier tube and recorded versus time with a digital storage oscilloscope.

3. Results and Discussion

When two coherent beams with the same polarization interfere, modulated intensity is created. Other than the excitation of the Azo dye molecules to higher excited states (cis isomers) in bright regions, which does not happen in the dark zones, two other effects may contribute to produce holographic grating. First, one is the increased concentration of the cis isomers in bright regions and the second is the reorientation of LC molecules due to the dye molecules orientation induced by the electric field of the light. Beside, some previous works report the grating formation as a simultaneous result of LC reorientation and photo isomerization which happen in LCs with low nematic-isotropic transition temperature or when the experiment is carried out in high temperatures [5]. However, since the sample in this experiment is studied at room temperature (25°C) which is very far from the nematic-isotropic phase transition (155°C) and because of the low dye concentration as well as very fast pulse duration, one can neglect the effect of LC reorientation and only consider the diffusion of photo excited dye molecules [5,6].

When the pump beam is removed, the rate equation for the number of the cis isomers per unit volume, N_{cis}, is expressed as: [7]

$$\frac{\partial N_{cis}}{\partial t} = -\frac{N_{cis}}{\tau_R} + D\frac{\partial^2 N_{cis}}{\partial^2 t}, \tag{1}$$

in which τ_R is the intermolecular relaxation time and D denotes the diffusion coefficient of photo excited dye molecules. Using the relation below for the N_{cis} at $t = 0$ (when the pump beam is removed),

$$N_{cis} = N_{cis}^{max} \sin\left(\frac{2\pi y}{\Lambda}\right), \tag{2}$$

relaxation time constant corresponding to the diffusion of the photo excited dye molecules is obtained as

$$\tau^{-1} = \tau_R^{-1} + Dq^2. \tag{3}$$

In these equations q depicts the magnitude of the grating vector ($q = 2\pi/\Lambda$) and grating period has the functionality of $\Lambda = \lambda/2n_{ave}\sin(\theta/2)$. Where, λ and n_{ave} represent the wavelength of the writing beams and the mean refractive index of the liquid crystal, respectively. θ also shows the angle between the interfering beams [8]. The range of writing angles in this experiment is varied from 0.5 to 3.8 degrees in 13 steps where the grating period is spanned between 5.03 microns to 38.2 microns.

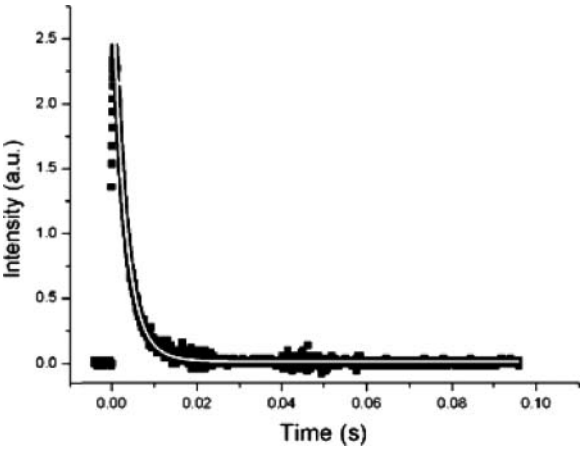

Figure 3. Dynamic behavior of the first order diffracted probe beam for $\theta = 2.2$ degrees. Squares are experimental data and gray line is the fitted curve.

Figure 3 depicts the dynamic behavior of the transient grating. When the writing beams interfere on the sample, diffraction of the probe beam quickly increases and relaxes after the writing beams are removed as a result of pulsed laser. The transient grating relaxes with the characteristic time constant τ. For small amplitude of the grating, the decay of the diffraction intensity can be described approximately by a single exponential function given by [5]

$$I(t) = \left[A \exp\left(\frac{-t}{\tau} \right) + B \right]^2, \tag{4}$$

In which A is the diffraction amplitude of the grating and B is the coherent background. To obtain the mentioned decay time one can fit the decay of first order diffracted light intensity with equation 4, as it is shown in Fig. 3.

Using the experimental results, the relaxation time of the transient grating is measured for various angles between the writing beams (θ) in two different orientation of the director with respect to the grating vector. Considering these results, inversed relaxation time constant, τ^{-1}, is plotted versus q^2, as shown in Fig. 4.

Based on the results, it is obvious that the relaxation time constant is shorter when the director is parallel to the grating vector, compared to the case in which the director is perpendicular to the grating vector.

Through the comparison of the experimental data with equation 3, diffusion coefficients in a certain direction are obtained as:

$$\mathrm{D}_{\perp} = 2.78 \times 10^{-6}\,\mathrm{cm}^2/\mathrm{s}, \quad \mathrm{D}_{\perp} = 0.60 \times 10^{-6}\,\mathrm{cm}^2/\mathrm{s}$$

Since the diffusion coefficient of the photo excited dye molecules has larger value when the diffusion direction is parallel with the director, evidently, it is an anisotropic parameter. This is resulted from easier movement of the photo excited dye molecules along the nematic director rather than that of in perpendicular direction.

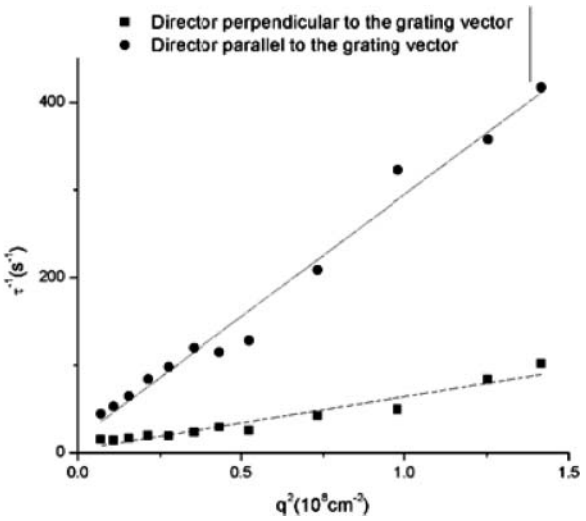

Figure 4. The reciprocal of the relaxation time constant versus q^2. The slope of fitted line is diffusion coefficient of dye molecules.

5. Conclusions

Relaxation behavior of the transient holographic grating induced by a pulsed laser is investigated in DR1 doped nematic liquid crystal mixture 1294-1b. Since photo isomerization of Azo dye molecules is responsible for the formation of this grating, the experimental results were used to extract diffusion coefficients of the photo excited dye molecules. Our results show that when the diffusion is parallel to the director, the diffusion coefficient is much larger compared to the diffusion in a direction perpendicular to the director and the observed diffusion anisotropy is due to the high mobility of photo excited dye molecules in the director direction.

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