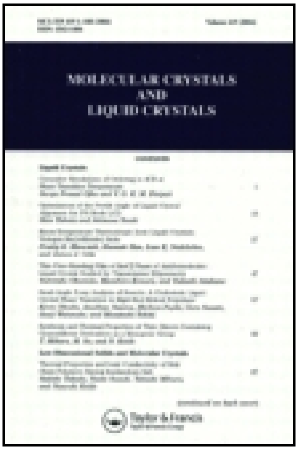

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Publication details, including instructions for authors and subscription information:
http://www.tandfonline.com/loi/gmcl19

Laser Beam Modulation Freezing on a Liquid Crystal Surface

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Version of record first published: 24 Sep 2006

To cite this article: D. Andrienko, O. Francescangeli, E. Ouskova, F. Simoni, S. Slussarenko & Yu. Reznikov (1998): Laser Beam Modulation Freezing on a Liquid Crystal Surface, Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals, 320:1, 69-76

To link to this article: http://dx.doi.org/10.1080/10587259808024384

Mol. Cryst. Liq. Cryst., Vol. 320, pp. 69–76
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Laser Beam Modulation Freezing on a Liquid Crystal Surface

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We report the first observation of the formation of permanent light-induced annular patterns in a planar cell filled with dye-doped liquid crystal. The sample is placed between one rubbed surface, giving unidirectional planar alignment, and one isotropic surface, providing degenerated planar alignment. The patterns appear under the irradiation of the isotropic surface through the liquid crystal layer. The experimental results are explained in terms of spatial modulation of the light polarization over the isotropic surface, due to conformation nonlinearity of the mixture. The light-induced adsorption of azo-dye on the initially isotropic surface leads to "freezing" of this modulation and the appearance of a twisted director structure.

Keywords: liquid crystal, azo-dye, light-induced director reorientation.

INTRODUCTION

Light-induced reorientation effects in liquid crystals (LCs) have been intensively studied for about twenty years because of possible astonishing applications and interesting fundamental aspects[1]. Usually these are bulk effects and are governed by a light field that acts on the entire LC volume. Aligning surfaces only determine the boundary conditions during the reorientation process. Different type of orientational effects has been recently reported[2-5] where the illumination of an aligning surface results in the appearance of a surface easy-orientation axis, ***e***, associated with a light-induced anchoring energy, *W*. These effects lead to the reorientation of the LC director ***d*** towards a direction either parallel or perpendicular to the exciting beam polarization, depending on the mechanism of interaction between the light and the LC.

Surface driven effects occur in azo-dye doped LCs when irradiated by polarized laser light. The effect consists in the appearance of an easy axis parallel to the light polarization over the isotropic surface of the LC cell[6-8]. Reorientation of the director towards ***E*** leads to the formation of a homogeneous twist-like texture in the LC volume corresponding to the irradiated area. Light-induced adsorption of dye molecules on the surface was supposed to be responsible for this surface memory effect[8].

As a consequence of the mutual influence of the bulk and surface driven reorientation effects, the propagation of a laser beam through the twisted director structure in a azo-dye doped LC cell is accompanied by the appearance of a ring pattern. In this paper we report a detailed study of this effect and in particular we show that this light-induced pattern can be frozen in.

EXPERIMENT

The experiments were performed with the dye-doped LC sample placed in a LC cell delimited by one reference glass substrate, providing unidirectional planar alignment, and one isotropic command substrate, providing degenerated planar alignment.

The inner surface of the command substrate was coated with an isotropic layer of a polyvinyl-cinnamate fluoride (PVCN-F), which is practically not sensitive to the visible light. The layer was prepared by spin-

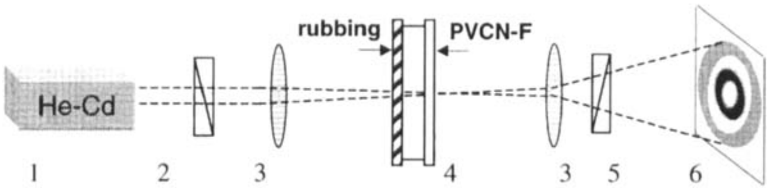


FIGURE 1 Experimental set-up: 1- He-Cd or Ar^+ laser; 2-polarizer; 3-lenses; 4 - LC cell; 5- analyzer; 6- screen or CCD-camera connected to the computer.

coating followed by heating at 100^0C for 30min. After heating, the layer was irradiated with non-polarized UV-light for 20 minutes to provide high quality degenerated planar alignment.

The inner surface of the reference glass substrate was coated with a rubbed polyimide (PI) layer. It gave a strong anchoring of LC with small pretilt angle (~3^o) to the surface, and provided the planar alignment throughout the whole cell.

We used the liquid crystal pentylcyanobiphenyl (K15, EM Industries) doped with the dye methyl red (MR, Aldrich) at a weight concentration 0.5%. MR is a well-known photosensitive dye which undergoes trans-cis isomerization under visible light illumination[9], leading to conformational nonlinearity of LCs[10].

The LC thickness was fixed to 20 μm by the plastic strips. The cell was filled with the LC mixture in isotropic state; the filling was followed by cooling down to room temperature in a magnetic field parallel to the rubbing direction. In this way, a stable homogeneous director orientation along the rubbing direction was achieved.

The experimental set-up is schematically represented in Fig.1. The cell was set in the focus plane of the lens (focus distance F=26.6 cm) and was irradiated with the gaussian beam of either the He-Cd laser (wavelength λ=0.44μm, power P = 0÷10W) or the Ar^+ laser (λ = 0.488μm, P=0÷50W). The cell was faced to the laser beam with either the reference or the command surface. The polarization ***E*** of the beam was set up by the polarizer at an angle 45^0 to the initial LC director orientation ***d*** on the reference surface. Analyzer and polarizer were crossed polarized to each other.

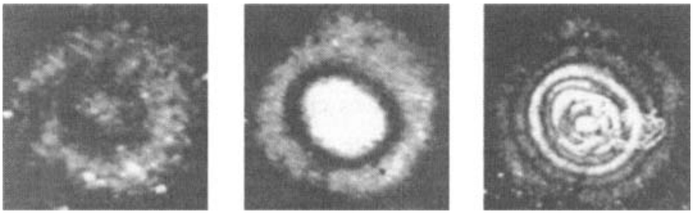
The magnified image of beam in the plane of the command surface was observed on the screen or dynamically recorded with a CCD camera connected with a computer and a VCR. The irradiated areas were analyzed by a polarizing microscope after the formation of the pattern.

RESULTS

We have studied the dependence of the director spatial distribution on the exposure time and the light intensity.

We have found that the order in which the beam passes through the cell greatly influences the director distribution obtained after irradiation. When the light beam impinges on the *command* surface, stable twist-like structures in the irradiated area are observed. Under weak exposure doses (a few minutes at P=10 mW with He-Cd laser), the spatial distribution of the twist angle corresponds to the gaussian distribution of the beam. Larger dozes result in saturation of the maximum twist angle over the irradiated area. In agreement with the results of Voloshchenko *et al.*[8], this is due to the appearance of an easy axis on the command surface parallel to the light polarization.

When the polarized light impinges on the *reference* surface, we observe the formation of the annular patterns for a beam intensity I greater than 10 W/cm^2 (Fig.2). The contrast of the pattern for a given value of I increases



a) b) c)

FIGURE 2 The light induced patterns induced with Ar^+-laser. a: I=10W/cm^2, b: t=3min; I=10W/cm^2, c: t=5min; I=20W/cm^2, t=3min.

with increasing exposure time t whereas the position of the rings does not change with t. Increasing in the beam intensity at a given exposure time results in an increase of the number of rings. At long exposure times the patterns appear distorted. This effect begins earlier for larger intensities: typically, distortions occur after 5 minutes at $I \approx 20$ W/cm^2 and after 10 seconds at $I \approx 100$ W/cm^2.

A very important feature of the observed rings is that they are frozen due to the light-induced anchoring on the command surface. The analysis of the patterns by polarizing optical microscopy has shown the presence of spatially modulated twisted textures. The dark zones correspond to the planar alignment of the director. Differently, in the bright zones the director is twisted, the twist directions being opposite in neighboring zones. The maximum value of the twist angle in the pattern is of about 10 degrees.

DISCUSSION

Propagation of the light beam through the anisotropic nonlinear medium is the clue to the appearance of the homogeneous and annular patterns observed in experiment. Indeed, the phase retardation of extraordinary and ordinary light beams depends on the intensity of light propagating through the cell. Since the incident beam has gaussian shape, the phase difference between ordinary and extraordinary light waves changes onto the command surface. This results in a spatial modulation of the light polarization and subsequent modulation of the easy axis on the command surface, the direction of which depends on the light polarization. The rings appear when the phase difference between extraordinary and ordinary light waves is greater than π.

It is important to observe that the appearance of the annular pattern is not simply due to "freezing" of the polarization state of the light beam onto the command surface. Actually, the induction of the easy axis on the command surface results in the director reorientation toward this axis and changes the light propagation through the cell. Therefore, the equilibrium distribution of the easy axis onto the command surface may not coincide with the spatial distribution of the light polarization.

To describe the annular pattern formation, the equations for the director and the Maxwell equations for the light field in the cell should be solved self-consistently. This problem has been considered recently[11]. It was found that for the small director deviations the light-induced adsorption of MR molecules leads to the following director distribution in the cell

$$\varphi = \delta I c_{MR} t(1 - z/L)\cos qL ,$$

where $q = 2\pi(n_e - n_o)/\lambda$ is the phase shift between extra-ordinary and ordinary light waves in LC, c_{MR} is the stationary concentration of MR molecules near the command surface, δ is proportional to the efficiencies of absorption and adsorption of MR molecules, magnitude of interaction between LC and adsorbed MR molecules.

Thus, the orientation of the director on the command surface ($z = 0$) strongly depends on the phase retardation difference qL. In turn, this

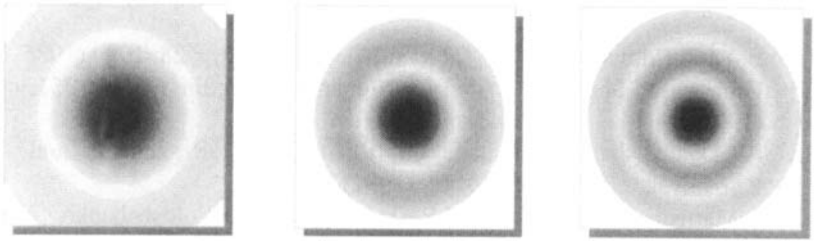


FIGURE 3 Light intensity distribution behind the parallel polarizers calculated for the π, 2π, 3π phase differences across the beam.

difference depends on the light intensity due to conformational nonlinearly of LC[10], namely

$$n_e - n_o = n_a(1 + \varepsilon_2 I),$$

where n_a is the linear part of the birefringence, ε_2 is the effective parameter of the cubic nonlinearity which is proportional to the concentration of cis-isomers of MR molecules. Since we irradiate the cell with gaussian laser beam, the intensity of light depends on the distance ρ from the center of the beam as

$$I = I_0 \exp(-\rho^2/a^2).$$

Therefore, phase difference qL changes along the ρ coordinate, leading to the periodic modulation of the director deviations and to the ring pattern observed in experiment. As an example, numerical calculations of the light intensity behind the parallel polarizers for the phase differences $n_a I_0\,\varepsilon_2 = \pi$, 2π, 3π (across the beam) have been performed and the results are reported in Figure 3.

Acknowledgments

The research described in this publication was made possible in part by Grant No. 2.4/923 from the Ukrainian State Found for Fundamental Studies Support and Grant No. UE1-315 of CRDF Cooperative Grants Program.

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