

Conoscopic analysis of electric field driven planar aligned nematic liquid crystal

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This paper illustrates the conoscopic observation of a molecular reconstruction occurring across a nematic liquid crystal (NLC) medium in the presence of an external electric field. Conoscopy is an optical interferometric method, employed to determine the orientation of an optic axis in uniaxial crystals. Here a planar aligned NLC medium is used, and the topological changes with respect to various applied voltages are monitored simultaneously. Homogenous planar alignment is obtained by providing suitable surface treatments to the ITO coated cell walls. The variation in the conoscopic interferometric patterns clearly demonstrates the transition from planar to homeotropic state through various intermediate states. © 2014 Optical Society of America

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1. Introduction

All crystals are composed of constituent atoms arranged in various symmetries and are generally anisotropic. Depending upon the polarization, the light wave incident on such a crystal will experience different refractive indices along the x , y , and z axis. Conoscopy is an optical interferometric technique, traditionally used to investigate the orientation of an optic axis in crystals based on the refractive index modulation [1]. This method is widely applied in areas such as material sciences, biological studies, and mineralogy. The principle of conoscopy is based on the inherent birefringence of crystalline materials. When a highly convergent beam is incident on such a medium, each ray at an angle with the optic axis effectively decomposes into two mutually orthogonal components. These components, upon exit from the medium, create a phase difference

and will result in interference fringes after recombination. Based on the interference pattern obtained, it is possible to verify the optic axis orientation. Liquid crystals, owing to their elastic properties, can generate a molecular realignment, upon the application of an external perturbation [2–7]. Conoscopy can be effectively applied to predict the molecular reorientation in the liquid crystal medium with respect to an applied stimulus. In this paper, a conoscopic technique is used to analyze a complete molecular realignment occurring across a nematic liquid crystal (NLC) medium in response to an external electric field. Even though this method has been adapted to characterize the orientation of LC molecules, the demonstration of a continuous transition from planar to homeotropic state through several intermediate states is not reported yet [8–15]. This method can be effectively employed as a detection tool into areas such as liquid crystal based biosensors with immense applications in the field of medical diagnostics. The orientation changes of the liquid crystal molecules when interacted with biosamples can be

used for the fabrication of the same. The advancement in this field is quite promising and usually polarization microscopy in the orthoscopic view is used as the sensing method [16,17]. Using conoscopy, yet another method of polarization microscopy, the optic axis inclination of the birefringent medium can be analyzed more effectively using the interference patterns obtained. Therefore, the conoscopic analysis together with the properties of liquid crystal holds a promising future in the fabrication of biosensors.

2. Experiment

An NLC cell of 30 mm long, 1 mm wide, and 50 μm deep was fabricated using ITO coated glass slides. The sides of the cell were defined by placing a dry adhesive strip of 50 μm thick, between the upper and lower ITO coated slides. The glass substrates were dip-coated with cetyltrimethylammonium bromide (CTAB, Sigma Aldrich Co) to induce a planar alignment (parallel to surface) of NLC molecules. The cell was filled with NLC 5CB (4-n-pentyl-4-cyanobiphenyl, Sigma Aldrich Co) using a syringe pump and was kept undisturbed for some time to reach its steady state condition. The conoscopic technique is illustrated in Fig. 1. A diode laser of wavelength 405 nm was used as the light source. The planar aligned NLC cell was kept between crossed polarizers and in the path of a convergent optical beam to analyze the molecular reorientation based on the interferometric patterns. The resulting patterns were captured using a charge-coupled device (CCD-Pixelink BL471U). A dc voltage source was used to apply necessary voltage across the cell (along the z axis).

3. Results and Discussion

The mechanisms for refractive index modulations, in response to an applied field, vary in different anisotropic mediums. In NLCs, refractive index modulation occurs due to the reorientation of the molecules and is proportional quadratically on the electric field, known as the Kerr effect [18]. Also the response of NLC molecules with respect to the applied field depends on the dielectric anisotropy of the liquid crystal material. In positive uniaxial liquid crystals, the molecules tend to align along the applied electric field and for negative uniaxial liquid crystals, the molecules incline away from the electric field. Generally, to induce director axis reorientation in NLC medium, positive uniaxial

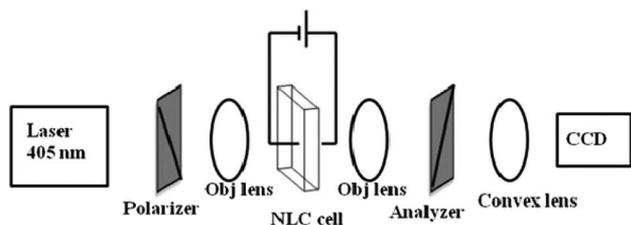


Fig. 1. Schematic of NLC cell kept between crossed polarizers.

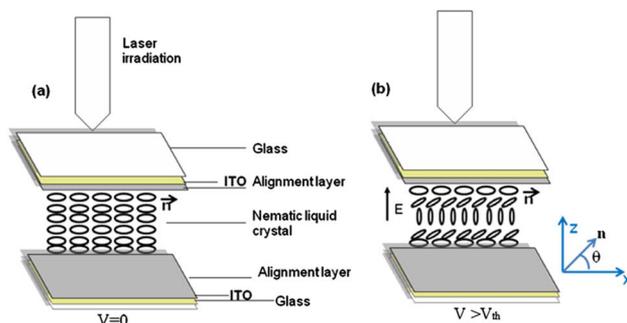


Fig. 2. Illustration of planar aligned NLC cell with laser irradiation along z axis: (a) field-OFF state and (b) field-ON state.

NLCs are used in the planar aligned mode and negative uniaxial NLC, in homeotropic alignment. The NLC 5CB (4-pentyl-4'-cyanobiphenyl) used here is reported to be positive uniaxial material and hence planar aligned NLC medium is used for the electro-optic investigation. In the field-OFF state (applied voltage, $V = 0$), the director of the NLC cell is oriented at 45° with respect to the transmission axes of the polarizer and analyzer. Molecular confinement between the cell boundaries is depicted in Fig. 2(a). Upon the application of an external force, three types of deformations known as splay, bend, and twist are possible in a NLC medium. When an electric field is applied perpendicular to the director, and the voltage across the cell (V) is greater than the threshold voltage (V_{th}), molecular reorientation occurs. This involves a combination of splay and bends deformations with elastic constants K_{11} , K_{33} , respectively, as shown in Fig. 2(b) [18]. In the planar NLC cell, liquid crystal molecules are considered to be in the X - Z planes and can be represented as $n = (\cos \theta, 0, \sin \theta)$, where n ; is the average molecular orientation known as the director, and θ (also known as tilt angle) is the angle between the direction of light propagation and optic axis. In the field-ON state, NLC molecules get reoriented along the direction of electric field, as a result of balance between the elastic restoring force and the applied electric force. The elastic-free energy density of the distorted medium is given in Eq. (1):

$$F_d = \frac{1}{2} K_{11} (\nabla \cdot n)^2 + K_{33} |n \times \nabla \times n|^2 + f_{\text{electric}}, \quad (1)$$

where f_{electric} is the force on the NLC medium due to the external electric field. Thus in the presence of an electric field, the NLC director gets reoriented, as the applied voltage is greater than the threshold voltage ($V > V_{th}$).

The conoscopic patterns obtained in the field-OFF state and at different applied voltages are shown in Figs. 3(a)–3(l), respectively. Interference pattern corresponding to the planar aligned NLC cell in the field-OFF state is shown in Fig. 3(a). This consists of a family of hyperbola, as well reported in literature for crystals with an optic axis oriented parallel to the surface [19]. As stated above, NLC is an anisotropic

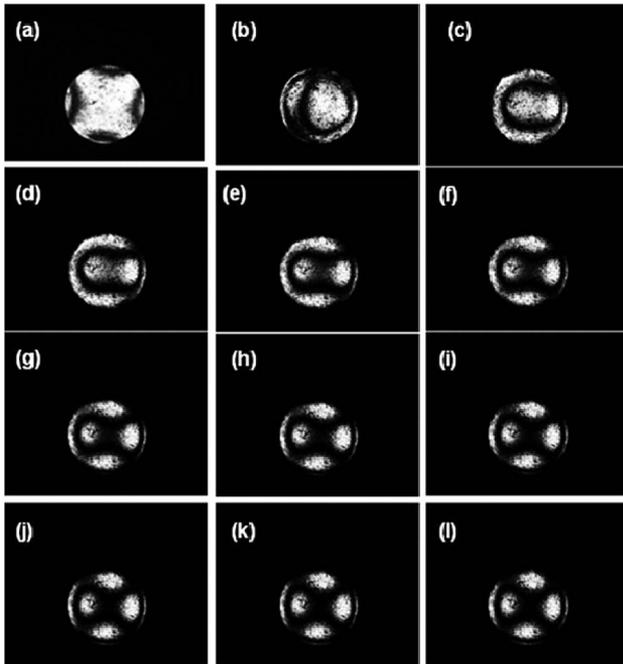


Fig. 3. Conoscopic interference pattern obtained for planar aligned NLC medium (a) static state, $V = 0$ V; (b) $V = 10$ V; (c) $V = 15$ V; (d) $V = 20$ V; (e) $V = 25$ V; (f) $V = 30$ V; (g) $V = 35$ V; (h) $V = 40$ V; (i) $V = 45$ V; (j) $V = 50$ V; (k) $V = 55$; (l) $V = 60$ V.

material in which the optical properties depend on the direction of propagation and polarization of the light waves. When a plane polarized light with amplitude E is incident on an anisotropic medium, at angle θ with the optic axis, each ray is divided into two rays. These rays, e (extraordinary) and o (ordinary), have different indices of refraction, vibrating in mutually orthogonal directions D'' and D' , respectively, as shown in Fig. 4 [20]. After emerging from the cell, these rays create a phase difference, δ , between them and can bring to interfere if an analyzer is kept behind the cell. Transmitted intensity obtained from Fig. 4 can be written as

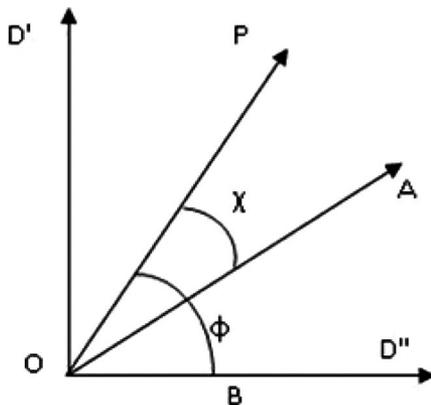


Fig. 4. Representation of vibration components transmitted by polarizer and analyzer.

$$I_t = E^2 \left[\cos^2 \chi - \sin 2\phi \sin 2(\phi - \chi) \sin^2 \left(\frac{\delta}{2} \right) \right]. \quad (2)$$

In the above relation, I_t is the resulting light intensity, E is the amplitude of the incident wave, δ is the phase difference, χ is the angle between the polarization directions of the polarizer and analyzer, and ϕ is the angle between D' and the polarization direction of polarizer. When the analyzer and polarizer are kept crossed, the above Eq. (2) can be rewritten as

$$I_t = E^2 \left\{ \sin^2 2\phi \sin^2 \left(\frac{\delta}{2} \right) \right\}. \quad (3)$$

The intensity at each point corresponds to a particular direction through the cell. Thus, from Eq. (3), it can be seen that the intensity depends on the values of ϕ and δ . With reference to Eq. (3), maximum transmission is given by $\sin 2\phi = \pm 1$, and minimum intensity occurs at points where $\sin 2\phi = 0$. The emergent beam from the NLC cell will remain at the same polarization state, if the phase retardation is a multiple of 2π . Therefore, the optical beam gets extinct by the analyzer and remains dark. Here the optic axis of the planar aligned NLC medium is considered to be along the substrate surface. Thus the conoscopic pattern for planar aligned NLC medium consists of a family of dark hyperbolic fringes known as isochromates. The CCD image in Fig. 3(l) consists of isogyre, melatope, and isochromates that correspond to crystals with the optic axis oriented perpendicular to the surface [19]. The changes in the conoscopic pictures are presumed due to the reorientation of molecules from the horizontal (planar) to vertical (homeotropic) state through several intermediate states. Thus the molecular reorientation occurring across the NLC cell, in response to an applied voltage, can be effectively imaged and analyzed using conoscopy. From the Figs. 3(a)–3(l), it is observed that the director axis reorient from the initial planar state to the final homeotropic state.

4. Conclusion

In summary, conoscopy was successfully employed for the director axis reorientation in a planar aligned NLC medium in the presence of an external perturbation. A complete reorientation of NLC molecules, from the planar to the homeotropic state through several intermediate states, was monitored with respect to the applied dc voltage.

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