Optical confirmation of biaxial nematic (\(N_b\)) phase in a bent-core mesogen

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A bent-core mesogen with different end groups has been studied for different surface conditions in both planar and homeotropic cells using techniques for measuring biaxiality and optical switching. Biaxial nematic phase observed in between the uniaxial nematic and smectic phases is evidenced by a sharp increase in the biaxiality in a homeotropic cell measured using a photoelastic modulator. The material in this phase is switchable through the minor director with an in-plane electric field. In a planar cell, a step in the difference in the refractive indices resulting from the uniaxial to biaxial transition is also observed. © 2009 American Institute of Physics. [doi:10.1063/1.3255013]

Since the prediction of a biaxial nematic phase (\(N_b\)) by Freiser in 1970, this subject has continued to attract significant interest among scientists during the past decade for reasons of advancing fundamental science and its potential for use in displays. The switching mode in \(N_b\) is more likely to realize faster response and wider viewing angles. For modes such as Vertical Alignment (VA), In-Plane Switching (IPS), Twist Nematic (TN), and Optically Compensated Bend (OCB) using conventional \(N_b\) to achieving wider viewing angle displays, it is necessary to use expensive optical compensation films. However, the intrinsic biaxiality of \(N_b\) is extremely useful in reducing the light leakage for oblique viewing angle. The most plausible structure for \(N_b\) device to realize both fast response and wider viewing angle is the homeoptically aligned cell with an in-plane switching of the minor director. To achieve faster response, the minor director should be driven without involving the major director. If both the major and minor directors are involved in reorientation of molecules under electric field, the slower motion dominates the response time. This structure is of advantage to form a normal black state where the initial state without electric field has the darkest gray level. However, development of such a system has been hindered with a lack of materials possessing \(N_b\) and by difficulties of alignment. In this letter, we experimentally demonstrate a practical biaxial based nematic based device. For the electrostatic screening of the cell, the second substrate coated with ITO is fixed on the top. Both glass plates of the cell are spin coated on the inside with AL60702 (JSR Corp.) polymer for homeotropic alignment. We prepared two different homeotropic cells: with and without rubbing. The rubbing direction lies at an angle of approximately 45° with respect to the two electrodes for the in-plane switching. Standard commercial cells (E.H.C. Japan) with a thickness of 5 \(\mu m\) and antiparallel rubbed polyimide on two substrates are used to carry out experiments in the planar geometry.

Three LC phases are observed in the unrubbed homeotropic cell by scanning with temperature as shown in Fig. 3. In the presence of the in-plane electric field, the director even if it is slightly tilted in the homeotropic alignment should stay normally to the substrate due to the negative dielectric anisotropy of the material. And in between the \(N_m\) and Sm phases, we observe another nematic phase where the minor director is switched by an electric field of 1 \(V/\mu m\) as shown in Figs. 3(b) and 3(c). In order to align the minor director, we

![Molecular structure of PAL1.](image)

FIG. 1. Molecular structure of PAL1. The three directors and their refractive indices for \(N_b\) are denoted as \(n(m)\), \(n(n)\), and \(n(n)\).
weakly rub the homeotropic cell as there can be an inhomogeneous distribution of the minor directors due to extremely small elastic constant for the deformations around the long axis. By observing a 7.2 μm thick cell in a polarizing microscope, we find a small tilt of the major director, called the pretilt angle, from the normal position toward the rubbing direction in the temperature range of the \( N_u \) [Figs. 4(a) and 4(b)]. On applying an electric field of \( 1 \ V/\mu m \), the region between the electrodes gets darker and is independent of the cell’s rotation angle [Figs. 4(e) and 4(f)]. This indicates that the director is normal to the in-plane electric field and consequently to the surface of the electrodes.

On transition from \( N_u \) to \( N_b \), a large increase in the birefringence is observed. In the absence of electric field, the minor director aligns along the rubbing direction [Figs. 4(c) and 4(d)]. On the application of electric field of \( 1 \ V/\mu m \), a rotation of the minor director in the \( N_b \) toward the direction of the field [Figs. 4(g) and 4(h)] is observed. Just below a temperature of 65 °C in the nematic phase the cell shows behavior similar to the IPS mode. Therefore we can clearly see a qualitative difference between the two different nematic phases.

For an accurate measurement of the retardation, a photothermal modulator (PEM) based system is used. It provides a simultaneous measurements of both retardation (\( \Gamma \)) and azimuthal angle (\( \Phi \), defined as the angle between the retarder axis of the cell and the polarizer). The effective birefringence can be determined as \( \Delta n_{\text{eff}} = \Gamma \lambda / 2 \pi d \), where \( d \) is the thickness of the cell and \( \lambda \) is the wavelength of the light source. We used red light emitting diode as the light source with a corresponding \( \lambda = 632.8 \) nm narrow-band (10 nm bandwidth) optical filter. The retardation is converted into \( \Delta n_{\text{eff}} \).

Temperature dependence of \( \Delta n_{\text{eff}} \) and of \( \Phi \) in homeotropic cell in the absence of the field is shown in Fig. 5. The cell is cooled at rate of 0.1 °C/min. The microscope based PEM system acquires a throughput of light from an area of approximately \( 150 \times 200 \) μm² of the cell in between the electrodes. The observed \( \Delta n_{\text{eff}} \) and \( \Phi \) correspond to their average values over several domains. In the \( N_u \), the measured \( \Delta n_{\text{eff}} \) is close to zero as expected for a homeotropic cell. For a rubbed homeotropic cell, one can clearly see a jump in \( \Delta n_{\text{eff}} \) at a temperature of approximately 65 °C accompanied by a small change in \( \Phi \) (Fig. 5). The minor director coincides with the rubbing direction as observed in the microscope. This increase in \( \Delta n_{\text{eff}} \) results from a transition to the \( N_b \) which corresponds to a biaxiality, \( \delta n = (n_2 - n_3) = 0.0085 \). To investigate the electro-optic switching, we applied 120 Hz square wave electric field with an amplitude up to 0.7 V/μm. \( \Delta n_{\text{eff}} \) as a function of temperature and the electric field is shown in Fig. 6. One observes that for the rubbed homeotropic cell, increasing the electric field initially results in a decrease in \( \Delta n_{\text{eff}} \) of both nematic phases. This is easily explained by a tilt of the major molecular directors back to the position of a perfect homeotropic alignment by electric field.
field as the material has negative dielectric anisotropy. The $\Phi$ of the retarder with electric field is found to rotate only in the $N_b$, since the minor director here is well defined. We thus find that the surface induced tilt can be eliminated by application of an in-plane electric field. This makes it possible to measure the optical biaxiality of $N_b$ and to avoid problems related to the surface-induced birefringence.\cite{15} The absence of an aligned direction of the minor director in the un rubbed cell causes a significant deterioration in the accuracy of the data. Higher fields cause a gradual alignment of the minor director in the un rubbed cell and a corresponding increase in $\Delta n_{\text{eff}}$ [Fig. 6(b)].

In order to confirm $N_b$, we also observe an optical signal in a planar cell. Our PEM measurements with a commercial planar cell also show a similar jump in $\Delta n_{\text{eff}}$ in the nematic phase (Fig. 7). The minor director in the $N_b$ of a planar cell has been reported in the literature to be parallel to the substrate.\cite{8,17} However in our experiment we observe an increase in $\Delta n_{\text{eff}}$ at the transition temperature which means that the minor director is aligned perpendicular to the substrate. On applying 2 V/\mu m to the planar cell, we do not observe any measurable change in $\Delta n_{\text{eff}}$ in either of the two nematic phases. This is because the minor director of the phase is already parallel to the electric field and $N_b$ with negative dielectric anisotropy will preserve its planar alignment under electric field.

We find $n_2-n_3=0.0085$ from the homeotropic cell, whereas from the planar cell, $n_2-n_1=0.0023$. In both cases the resolution in retardation drawn from the signal-to-noise ratio is better than $10^{-3}$ rad. For the cells used here, this is better than $5 \times 10^{-5}$ in birefringence. The discrepancy in between results for homeotropic and planar cells can possibly be explained by a difference in their surface conditions. However, it is reasonable that the biaxiality found in the homeotropic cell is closer to the value in reality. It must be stressed that biaxiality is not induced by the surface, however rubbing the surface breaks the symmetry and aligns the minor director along it. We find that in a planar cell the minor director is normal to the surface. Normally, the transverse dipole moments of molecules are favored normal to the surface but on the contrary, the molecular packing favors the minor director lying parallel to the substrate providing a competition with an overall win for the first case. This is likely to reduce the biaxiality in a planar cell. In summary, we observe a biaxial $N_b$ in homeotropic and planar cells using a quantitative technique where biaxiality is directly measured; we realize the most plausible device configuration for display applications.

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