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: 07 Oct 2011

To cite this article: Federica Ciuchi & Riccardo Barberi (2011): Temperature Dependence of Order Reconstruction in a Splay Cell, Molecular Crystals and Liquid Crystals, 549:1, 37-42

To link to this article: http://dx.doi.org/10.1080/15421406.2011.581127

Mol. Cryst. Liq. Cryst., Vol. 549: pp. 37–42, 2011

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421406.2011.581127

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Order reconstruction has been presented by our group in the past as a useful tool to obtain a transition among different liquid crystal textures: the contribution of ions mobility, dielectric reorientation and order reconstruction has been well characterized using electric measurements across the cell. In this paper we present for the first time its temperature dependence and we show the features of the phenomenon.

OCIS codes: (160.3710) Liquid crystals; () biaxial order; (260.1440) Birefringence

1. Introduction

The controlled nematic order reconstruction under electric field has been presented as a new tool to achieve nematic textural changes [1,2] with variable topology, also allowing intrinsic textural bistability. The order reconstruction changes the nematic director orientation of $\pi/2$ by exchanging two eigenvalues of the nematic order tensor [3]. The average molecular reorientation is now obtained without any director rotation, but with a suitable deformation of the ellipsoid which represents the nematic order. A similar approach has been presented in the past by Sluckin in the space domain in [4] where an exchange of tensor order parameter eigenvalues takes place across a line defect. Recently the role of biaxial order reconstruction (BORN) in confined systems has been numerically and experimentally proved [5,6].

This phenomenon requires electric fields higher than those used in the well known Fréedericks transition but comparable with those used in the anchoring breaking phenomenon, in fact recently the equivalence of two phenomena has been suggested [7]. In this work we make a careful analysis of the electric current time dependence in order to separate the different contributions occurring in the signal: ions mobility, dielectric reorientation and order reconstruction.

The states involved in nematic order reconstruction effect are an initial slightly splayed nematic (H), then a bent state (V) and finally a π-twisted state.

In the H state, the director in the cell is oriented mostly parallel to the plates, while in the V state is aligned perpendicularly, moreover H and V do not have the same topology. For a nematic with positive dielectric anisotropy, the transition from H to V happens in the presence of a strong vertical electric field, through the intermediate state characterized

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by a thin wall, in the middle of the cell, where we expect that the order reconstruction takes place. The splay cell has been widely studied by Q tensor formalism [8], but from theoretical point of view the complete model is still missing since the formalism, now widely used to describe transitions through biaxial states, works very well near nematic-isotropic (NI) temperature transition. For temperature far from the NI transition, the Landau de Gennes expansion needs higher order term but no experimental data are available in order to calculate the missing expansion coefficient.

In this paper we measured the electric current at different temperatures below and above the NI temperature transition applying different voltages to the cell: below the threshold, right to the threshold, and above the threshold, then we fitted the current using Lorentz profiles. The values obtained are reported as a function of the threshold with a phenomenological model.

2. Experimental Details

The cell is made by two parallel transparent indium tin oxide (ITO) coated glasses which contain the nematic liquid crystal 5CB (4-cyano-4-n-pentylbiphenyl), with strong positive dielectric anisotropy. The electrodes on the two boundary plates are 2 mm width lines realized by photolithography of the ITO films: their crossed superposition gives one pixel of about 4 mm^2 area. The oblique symmetrical anchoring on the two boundary plates is obtained by polymeric coating, i.e., rubbed polyimide, and the resulting anchoring strength is strong, with a small pretilt of few degrees. The data reported below are obtained from a cell of thickness d 1.60 ± 0.05 μm measured by a standard interference technique before filling it with 5CB. Several cells have been measured showing results in agreement with those here reported.

Rectangular electric pulses of variable amplitude and fixed width $\tau = 1$ ms are applied to the cell, which is connected in series with a 5 kΩ electric resistance: its voltage drop V allows to measure the electric current which flows through the sample. The sample is placed in an heater (Calctec) which controls the temperature with a precision of 0.1°C and directly observed by means of a polarized microscope. We perform synchronous acquisitions of the electric current and light transmission across the sample, when the field is applied to the cell. The transmitted light intensity is measured by a photomultiplier also connected to the polarized microscope. The plate of the microscope is rotated to align the optical axis of the sample in the starting H configuration at 45° with respect to the optical axis of the crossed polarizers. In fact, this is the well known condition of maximum intensity for the transmitted light in presence of a birefringent sample.

The electric current data and the light intensity transmitted by the sample are acquired by a PC connected via a GPIB interface.

3. Results

The order reconstruction threshold E^{th} seems not sensitive to the thickness of the cell and it appears at different threshold varying the surface treatment [6, 9].

When the temperature is raised the threshold decreases and tend to zero at the clearing temperature. It is well known, both theoretically and experimentally that the scalar order parameter (S) [10,11] decreases as $(T_C\text{-}T)^{\alpha}$ increasing the temperature; the elastic constant are proportional to S^2 and the viscosity decreases as well. The Freedericks transition has a threshold dependent on the square root of the elastic constant and decreases as S raising the

temperature. This implies that the order reconstruction threshold is obviously influenced by all these parameters and has a behaviour similar to S.

The fit of the current data at different temperatures, as already reported, gives the time occurrence of the dielectric reorientation, ions peak and order reconstruction:

- the first peak is related to change of capacitance during the pulse;
- the second one shows a linear behaviour as expected by a simple drift model, the mobility obtained range from $(6.6 \pm 0.1)10^{-10}$ m^2/Vs to $(2.7 \pm 0.3)\ 10^{-9}$ m^2/Vs in the isotropic phase (checked as comparison).
- the third one shows a more complicated behaviour well fitted by a phenomenological curve and describe the time after the pulse application at which order reconstruction takes place. The characteristic time of the transition is obviously lower.

The phenomenological equation is:

$$\frac{1}{\tau} = \frac{1}{\tau_{th}} \left(\frac{E^2 - E_{th}^2}{E_{th}^2} \right) \tag{1}$$

Where τ_{th} is the fitted value, i.e. the characteristic time of BORN, E_{th} the threshold and E, τ respectively the applied field and the measured peak position. In Fig. 1 a typical current measurements is shown. The dielectric reorientation peak is much higher than the other two; for this reason for each pulse width two files are saved from the oscilloscope describing the measure of the voltage drop in two different scales. In the following figure one example for T = 26°C and a voltage under the threshold is reported: it is possible to see that the

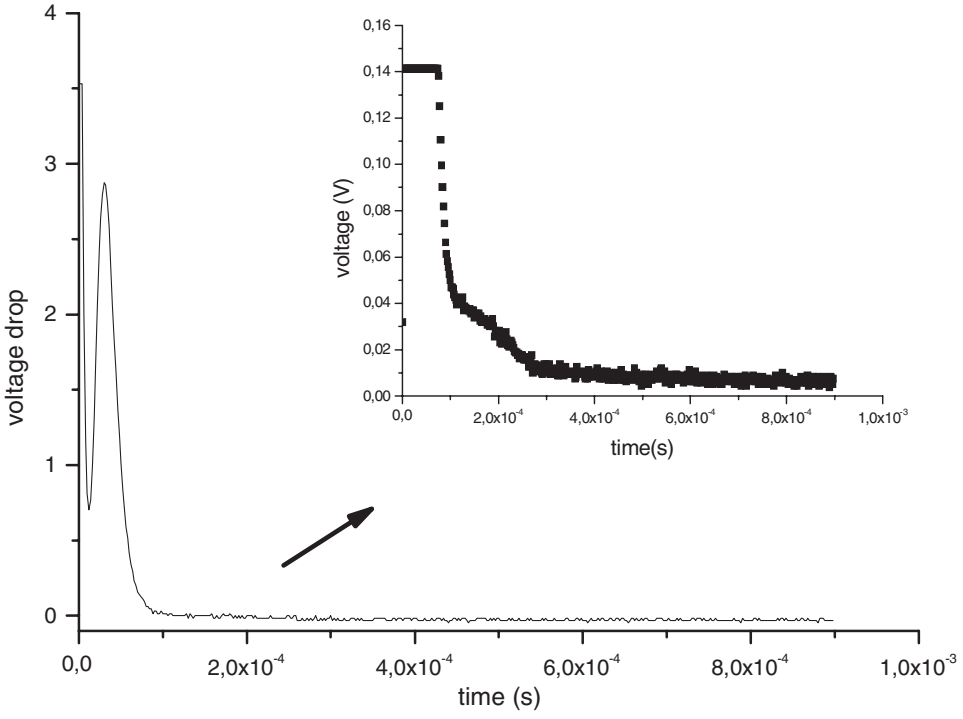

Figure 1. Current peaks position as a function of inverse applied electric field.

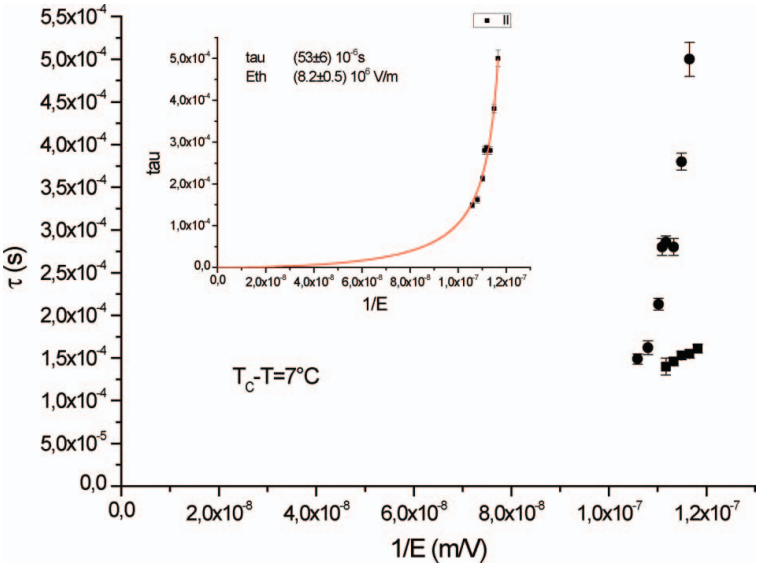

Figure 2. Ionic (squares) and order reconstruction (circles) current peaks position as a function of inverse applied electric field. In the inset the fitting of order reconstruction peak is shown.

dielectric peak is 100 times higher. For a voltage above the threshold two peaks appear clearly. The amplitude difference can be explained considering that all the molecules are involved in the dielectric reorientation while the ionic peak is due to a low concentration of ions in the liquid crystal and the order reconstruction peak is due to a thin wall (tenth of nm) in the middle of the cell.

In Fig. 2 the peaks time position for a specific temperature, is reported as a function of 1/E, the ionic contribution shows a linear behaviour while the order reconstruction follows a more complicated trend already described in [12].We use a phenomenological equation to fit all the data (the inset in fig. 1 shows the goodness of the fit) and the results are reported in Fig. 3. The phenomenological equation has been reproduced numerically in ref. [13].

The order reconstruction characteristic time seems slightly to decrease or at least to remain constant with temperature. This result confirms that the eigenvalues exchange is an intrinsic property of the system.

We can measure the threshold either directly from microscopic observations or infer it from the phenomenological fit, the series of data show the same trend (Fig. 4)

$$E_{th} = (4.2 \pm 0.6) * 10^6 * (T_C - T)^{(0.37 \pm 0.01)} \tag{2}$$

The threshold behavior also suggests that it is easier to induce biaxiality in a liquid crystal approaching the transition temperature, in fact increasing T the order tensor tends to become isotropic. The absolute eigenvalue exchange is lower and we expect a decrease of order reconstruction threshold.

This kind of measurements are very delicate; the S/N ratio increases with the temperature and the order reconstruction peak is hardly visible already 4°C below T_{NI}.

These experiments are done at fixed pulse width, but further current measurements at different pulse width in the range 100μs-10 ms can be done as well. Anyway, we expect that the characteristic time does not change since the threshold is constant in this range [1].

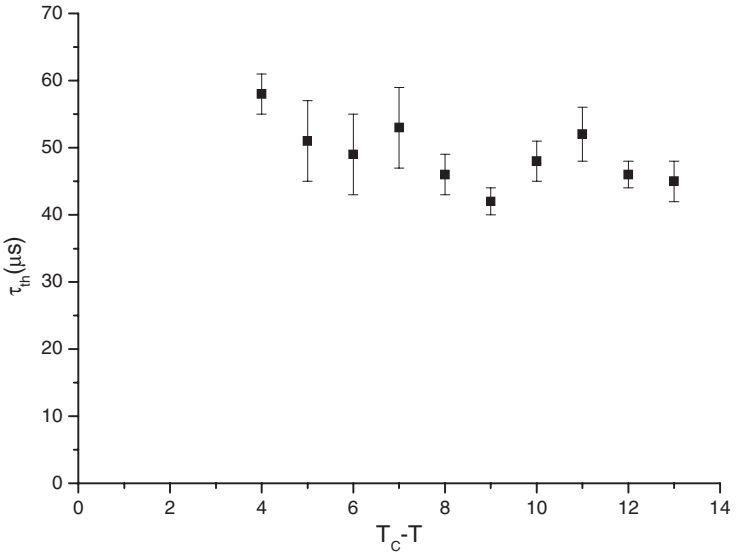

Figure 3. Characteristic time of biaxial order reconstruction as a function of reduced temperature.

When the pulse width is less than 100 μs, becoming comparable to the characteristic time of the order reconstruction, the threshold increases abruptly, by consequence ξ_E (electric coherence length i.e. the size of the wall which gives birefringence) reduces, hence the electric signal becomes hardly detectable.

In any case the value found for order reconstruction time is very close to the value theoretically predicted. The theory proposed until now doesn't take into account the influence of the surface. As reported in [10], there is quite strong dependence on the tilt angle at the surface (and on the anchoring energy of the substrate) which should be

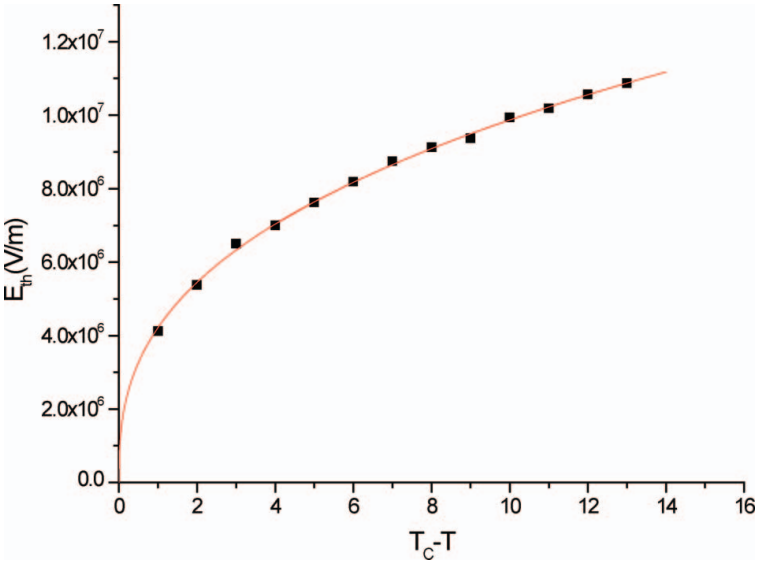

Figure 4. Typical threshold approaching nematic-isotropic temperature transition.

modeled theoretically as well as the dependence on T. The main drawback is that we don't know the phenomenological parameter in order to expand the Landau energy at higher order in S.

4. Conclusion

We have measured the biaxial order reconstruction time scale at different temperatures, the results show a typical time almost independent from temperature.

Recently some authors [14] show the dynamics of a splay cell by a confocal microscope. They presented a novel method to directly image axial dynamics in anisotropic media with a high degree of temporal and spatial resolution, but the electric current remains a practical method to observe this phenomenon, since the other techniques have sensitiveness drawbacks related to the optical set up at temperatures higher than the room temperature. The data here presented may help to find the higher order terms of the Landau De Gennes expansion

The authors thank A. Pane for technical support in clean room.

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