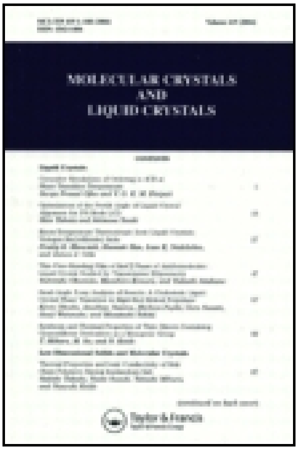

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

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V. A. Deleva [a], P. Toth [b] & A. P. Krekhov [a]

[a] Institute of Molecule and Crystal Physics, Russian Academy of Sciences, 450025, Ufa, Russia

[b] Institute of Physics, University of Bayreuth, D-95440, Bayreuth, Germany

Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2000, Vol. 351, pp. 179-186
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Electroconvection in Twisted Nematic Liquid Crystals

V.A. DELEV[a], P. TOTH[b] and A.P. KREKHOV[a]

[a]*Institute of Molecule and Crystal Physics, Russian Academy of Sciences, 450025 Ufa, Russia and* [b]*Institute of Physics, University of Bayreuth, D-95440 Bayreuth, Germany*

Electroconvection in twisted nematics has been studied experimentally and theoretically. The frequency dependence of the threshold voltage and rolls period for the different twist angles as well as the Lifshitz point versus the twist angle have been measured. The experimental results agree well with the predictions of linear stability analysis. Various types of secondary instabilities were found above the roll instability depending on the twist angle. The transition from 1D structure to the 2D domain pattern was investigated.

Keywords: electroconvection; twisted nematics; primary and secondary instabilities

INTRODUCTION

In contrast to the electroconvection (EC) in nematics with uniform planar orientation (see [1] for review), the case of planar but twisted configuration has not been so widely investigated up to now. There are only a few experimental observations of the domain structures in twisted nematics [2-4]. In particular, normal rolls oriented perpendicularly to the midplane director **n** of the undisturbed layer were observed in twisted nematics at onset [4]. The main experimental results were obtained only for a fixed a.c. electric field frequency (f=20 Hz) in the conductive regime of EC.

This paper presents results on EC instabilities in twisted nematics with different twist angles $0 \leq \Phi_T \leq \pi/2$ under an a.c. electric field in the whole frequency range of the conductive regime. At first we discuss the experimental and theoretical results on the primary roll instability. Then, the experimental results on the secondary bifurcations and possible scenarios of the pattern evolution with increasing voltage as function of the twist angle are presented.

EXPERIMENTAL

The nematic liquid crystal (NLC) MBBA is sandwiched between two parallel glass substrates with transparent electrodes. In order to achieve a uniform planar alignment, the surface of the electrodes was rubbed in one direction. The substrates were mounted in a hot-stage so that the upper substrate could be rotated relatively to the lower one. The rotation step was $\sim 2^0$. The distance between the substrates was fixed with 40 μm mylar spacers. The lateral substrate sizes were L_x=15 mm and L_y=15 mm, so that the aspect ratio of the NLC cell was L/d=375. The cell temperature was kept constant at 20.0 ± 0.1^0C.

The a.c. electric field applied across the nematic layer was generated by the 12-bit waveform synthesizer card WSB-100 (Quatech). The convection patterns were observed in a polarized microscope. The images were recorded with a CCD-camera and digitized using the frame-grabber DT3155 (756 x 581 pixels). The cut-off frequency f_c of the NLC sample was ~ 60 Hz.

RESULTS AND DISCUSSION

I. Primary instability

In the planar cell ($\Phi_T=0^0$) the first observed instability is the transition to stationary roll pattern with the roll axis oblique/normal to the initial director orientation for frequencies of the a.c. electric field below/above the Lifshitz point, respectively. Increasing the twist angle Φ_T leads to a slight change of the threshold voltage and the roll period as it was found earlier [4]. Observations of the dust particles show that for non-zero twist angle one has an axial flow parallel to the roll axis in addition to the convective flow. The axial velocity changes sign between neighboring rolls. Figure 1 presents the experimental data on the frequency dependence of the threshold U_c and roll period Λ for the twist angles $\Phi_T=0^0$ and $\Phi_T=90^0$ in comparison with the results of theoretical calculations. For the numerical simulations we used the standard set of electrohydrodynamic equations neglecting the flexoelectric effect (see [4, 5] for details). The material parameters of MBBA at 20^0C were taken from [6, 7]. We were not able to measure the conductivities $\sigma_\parallel$ and $\sigma_\perp$ for our MBBA sample but the appearance of oblique rolls at threshold at low a.c. frequencies in planar cell indicate that one should have at least a value of $\sigma_\parallel/\sigma_\perp$ larger than 1.8 [5, 4]. In our calculations we used the values of $\sigma_\parallel/\sigma_\perp=2.05$ and $\sigma_\perp=0.55\cdot10^{-8}$ $(\Omega\cdot\mathrm{m})^{-1}$ from a best fit to the experimental data on the threshold voltage at low a.c. frequencies and cut-off frequency for planar cell, respectively. The value of $\sigma_\parallel/\sigma_\perp=2.05$ larger than the conventionally used one (1.5) appears not to be unreasonable for not too clean material.

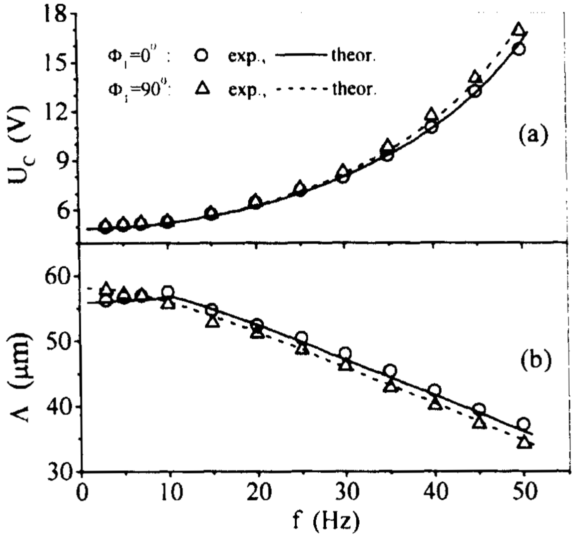

FIGURE 1 Dependence of the threshold voltage U_c (a) and roll period Λ (b) on the a.c. electric field frequency for twist angles $\Phi_T=0^0$ and $\Phi_T=90^0$.

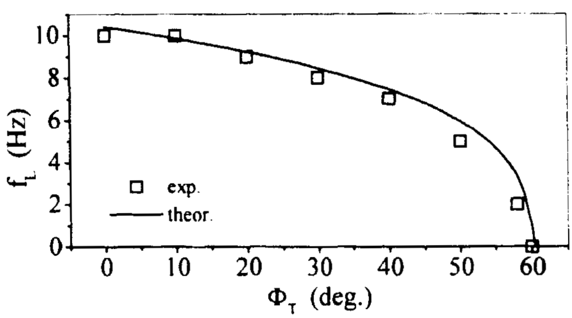

FIGURE 2 Lifshitz frequency f_L versus twist angle Φ_T.

We have found that with increasing twist angle the roll obliqueness decreases and the Lifshitz point shifts to the lower frequencies in accordance with the results of linear stability analysis. In Figure 2 the theoretical and experimental dependencies of the Lifshitz frequency f_L on the twist angle Φ_T are shown. For the twist angle above ~ 60^0 the oblique rolls disappear at the onset in agreement with theoretical calculations.

II. Secondary instabilities

Increasing the voltage above the primary threshold, non-stationary modulated structures have been found for twist angles in the range $10^0 \leq \Phi_T \leq 80^0$. The structures become very regular for $45^0 \leq \Phi_T \leq 80^0$. In Figure 3(a) the typical evolution from a roll pattern to a modulated structure with increasing applied voltage is shown. Slightly above onset a long-wave-length modulations of the rolls along their axis occur (U=8.3 V). At first the deformation is static and looks like the skewed varicose instability similar to the found in [8, 9]. As already mentioned for twisted nematics one always has a flow along the roll axis with opposite directions between neighboring rolls and further increase of the roll deformation amplitude at increasing voltage leads to a breaking of the axial flow along the rolls [grain boundaries in the form of vertical black lines in Fig. 3(a), U=8.6 V]. In this situation the axial flow continuity can be ensured by a connecting the flow lines either along the rolls (with the same direction of axial velocity) through the grain boundary, or between the neighboring rolls touching the grain boundary from one side (left or right). The process of switching between these types of flow-line connections is periodic in time and has been observed

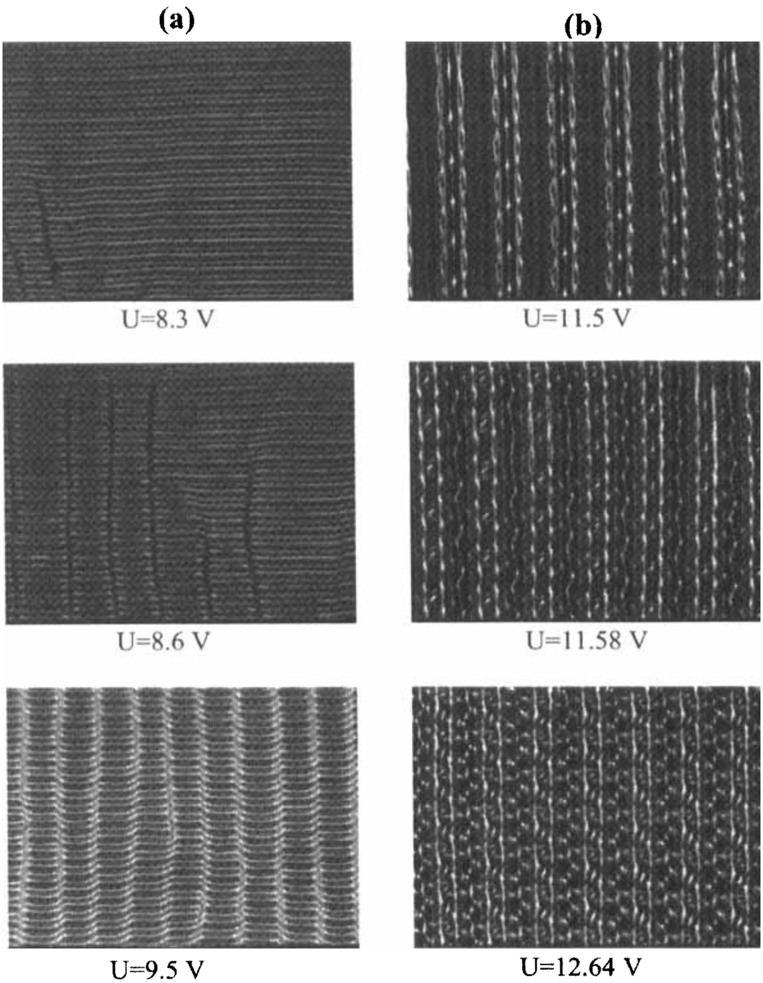

FIGURE 3 Typical pattern evolution above the onset of roll structure: (a) - twist angle $\Phi_T=60^0$, a.c. frequency f = 30 Hz ; (b) - $\Phi_T=90^0$, f=35 Hz.

in form of oscillations of fine structure of grain boundaries. The fine structure consists of a periodic sequence of white short lines oriented either "up" or "down" [see snapshot in Fig. 3(a), U=9.5 V] where the alignment changes periodically in time. At higher voltages the system of grain boundaries becomes more regular and finally, a 2D-pattern is formed [Fig. 3(a), U=9.5 V]. The periodicity of such a structure along the roll axis is of the order of two spatial periods of the normal rolls. Further increase of the voltage leads to a decrease of the structure period up to a value of the order of the roll period and eventually to a transition to weak turbulence.

The modulated structures above the roll threshold for the NLC cell with twist angle $\Phi_T=90^0$ look quite different [Fig. 3(b)]. Here one observes a helical character of the roll deformation with the amplitude of helicity grows with voltage [Fig 3(b), U=11.58 V]. Further increase of the voltage leads to the grid pattern (GP) formation [Fig. 3(b), U=12.64 V]. The stability of the GP is strongly sensitive to the presence of defects. Depending on the defects density GP is destroyed or begin to oscillate above the critical voltage of stationary GP formation.

In order to characterize the transition to GP, the intensity of the light transmitted through the NLC cell was measured at increasing and decreasing voltage in the neighborhood of GP-formation threshold for various ramp rates. The vanishing hysteresis gap in the light transmittance at decreasing ramp rate indicates that the transition to GP is supercritical (forward bifurcation).

We have performed an experimental and theoretical study of the primary instabilities in twisted nematics in the conductive regime for different twist angles $0 \leq \Phi_T \leq 90^0$. The experimental data obtained are in a good agreement with the theoretical results of linear stability analysis. The transition to 2D structures above the onset of roll pattern for twist angles $10^0 \leq \Phi_T \leq 80^0$ and $\Phi_T = 90^0$ was investigated. Depending on the twist angle two different scenarios of the evolution of the roll patterns were found.

Acknowledgment

We thank L. Kramer and W. Pesch for stimulating discussions and A. Hertrich for help in the programming. V.D. and A.K. wish to acknowledge the hospitality of the University of Bayreuth. Financial support from DFG Grants No. Kr-690/12-1, 436-RUS-113/220 and INTAS Grant No. 96-498 is gratefully acknowledged.

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