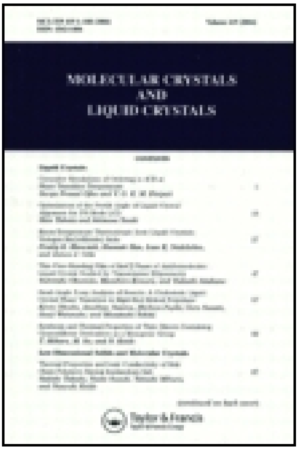

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

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Version of record first published: 24 Sep 2006

Mol. Cryst. Liq. Cryst., 1999, Vol. 329, pp. 499-506
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Two Mode of Domain Oscillations in Electrohydrodynamic Convection of Nematic Liquid Crystal

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Nonstationary electrohydrodynamic convection of nematic liquid crystals in dc electric field has been investigated experimentally. Two modes of domain oscillations: *longitudinal* – along the initial orientation of director and *azimuth* – along the crystallographic axes of hexagonal grid pattern have been found in oscillating domain lattice. It has been established that the transition from stationary grid pattern to oscillating one is similar to the first order phase transition.

Keywords: liquid crystal; electrohydrodynamic convection; grid pattern; domain oscillation; phase waves

INTRODUCTION

Pattern formation in hydrodynamic instabilities has been studied intensively over the last decades. The fundamental questions of these investigations are the formation of super-molecular order and the transition to spatiotemporal disorder in nonequilibrium systems.

During recent years, the EHC of nematic LCs has become the most prominent paradigm employed for pattern formation in anisotropic systems[1,2]. A great variety of spatio-temporal structures has already been observed: roll pattern[3, 4], traveling waves[5-7], phase waves[8-11], defect chaos[6].

Although the EHC effect is normally seen in dc and ac excitation it should be noted that pattern transitions in dc electric field were not extensively studied as opposed to the case of ac electric field. This is connected with the fact that LCs are subject to decomposition in dc electric field due to the injection of charges from the electrodes. In addition, the formation of double electric layers due to the injection of charges and their redistribution together with flexoelectric deformation in the LC layer essentially complicates the understanding of the mechanisms of pattern formation under the action of dc electric field[12, 13].

Recently, we found that the domain oscillation which is observed in EHC of NLC in dc electric field self-organizes in space into rotating spiral and concentric phase waves above threshold of hexagonal grid pattern (HGP)[8, 9]. However, the nature and mechanism of self-organization of domain oscillation are not cleared up to now.

The arm of this work is to investigate the transition process from stationary HGP to oscillating one and to try to explain the self-organization mechanism of domain oscillation in space into phase waves.

EXPERIMENTAL

The NLC (MBBA) with negative dielectric anisotropic was sandwiched between two transparent glass electrodes with a distance 25 μm and lateral dimensions of the cell 2 cm x 0.5 cm. All measurements were carried out at initial planar orientation of the director **n**. To obtain the uniform homogeneous orientation of molecules substrates were rubbed in one direction. The cell temperature was stabilized at 25 ± 0.1^0 C. DC electric field was applied across to the nematic layer.

The image of the pattern is observed with a video camera mounted on a polarizing microscope, digitized with a resolution of 512 x 512 pixels of 256 gray levels and fed to a computer. For study of spatiotemporal characteristics of patterns, the intensity along a line perpendicular to initial orientation of director was measured. In order to obtain local temporal information, the intensity of transmitted light through the area size of separate domain block was measured by a photodiode.

RESULTS AND DISCUSSION

HGP arises from two oblique roll systems at increasing voltage up to U_{GP}=8 V. The transition from the oblique rolls to the stationary grid pattern is continuos (direct bifurcation) and occurs as the pinching of the rolls until the rolls are divided into coupled triangle-like cells (Fig. 1a). The crystallographic axes of this structure **a** and **b** make the angles 125^0 and 55^0 relative to the initial orientation of director **n** and determined by the orientations of two systems of oblique rolls.

When applied voltage is increased slightly above U_{GP}, this structure becomes unstable and domain oscillations of very low frequency appear. It is clear from the Fig. 1b that intensity profile changes only along the initial orientation of director **n**, therefore we called this mode of domain oscillations as *longitudinal*. The oscillations of adjacent domains occur in opposite direction, as shown in Fig. 2b. The amplitude of these oscillations is rather small and is about 2÷3 μm.

At U = 9.7 V the amplitude of *longitudinal* oscillations achieves certain critical value and another mode of domain oscillations with lower

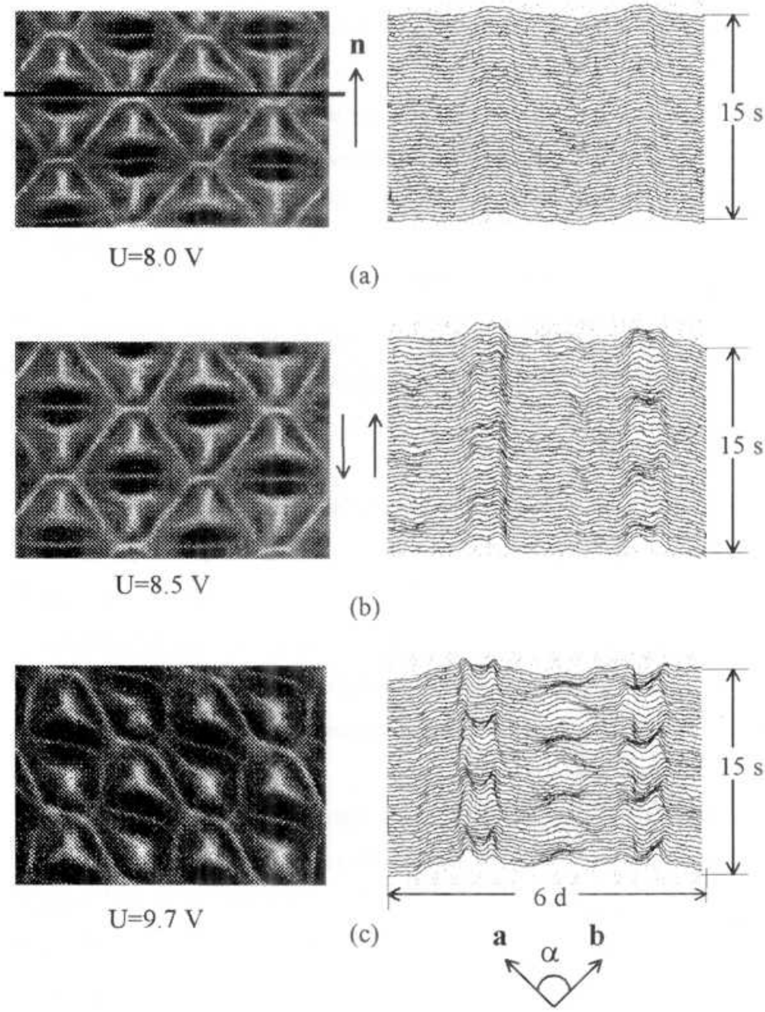

FIGURE 1 Light intensities measured along a line perpendicular to the initial orientation of director **n** within time intervals of 0.3 s plotted on top of each other.

frequency occurs along the crystallographic axes **a** and **b** of HGP (Fig. 1c). Thus, this mode of domain oscillations can be described as *azimuth*.

Optical observation shows that this mode of domain oscillations is accompanied by the rotation deformation of domains in NLC layer. Since these oscillations occur as a periodic deformation of the triangle-like domains along the crystallographic axes of HGP, the amplitude of this oscillation mode is constant in time. In this regime, the HGP is divided into oscillating domain blocks that generate concentric phase waves. The adjacent blocks oscillate along various crystallographic directions with phase difference in π. Although in general this system demonstrates the complex spatiotemporal behavior, the domains oscillate in block coherently. The size of oscillating blocks grows in time and once it becomes comparable with the characteristic correlation length of the system, the desynchronization of domain oscillation occurs in block and phase wave generation stops simultaneously. The origin of desynchronization is that the central part of domain block oscillates so fast that the outer region is unable to follow it. We believe that propagation of waves can be regarded as the diffusion process of oscillation phase into the undisturbed region of HGP and interaction between two modes leads to self-organization of domain oscillation in space into phase waves. It is worth to note, that for the case of ac electric field also two phase waves modes were found also[10, 11], but their characteristics and properties are essentially different[8, 9].

By means of temporal Fourier analysis method, it was found that both modes coexist in the developed regime of domain oscillations. Typical power spectrum of the local light intensity transmitted through NLC cell is presented in Fig. 2. There are two peaks and their harmonics are present in the power spectrum. With increasing voltage, these two modes increase

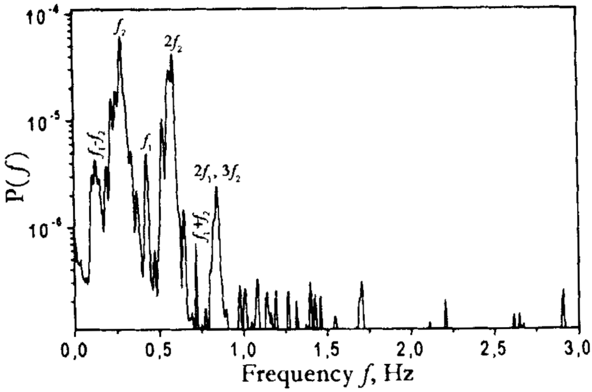

FIGURE 2 Power spectrum of the light intensity transmitted through the area of NLC cell size of separate domain block at U=9.7 V.

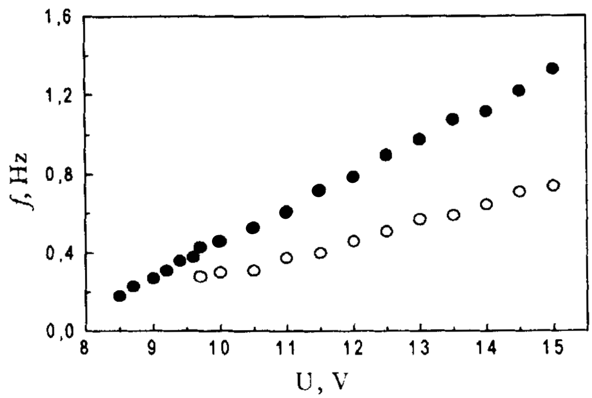

FIGURE 3 Voltage dependence of the domain oscillation frequencies: longitudinal mode (•) and azimuth mode (o).

linearly and *azimuth* mode is about twice as high as *longitudinal* mode (Fig.3). At further increasing voltage, the interaction between these two modes leads to the turbulence that is accompanied by the widening of the power spectrum. Thus, the transition to turbulence in this system occurs through the destruction of quasiperiodic regime of domain oscillation (the scenario Ruelle-Takens[14]).

In order to determine the type of phase transition, the behavior of transmitted through NLC cell light intensity at increasing and decreasing voltage in the interval from 0 V up to 8.5 V (the critical voltage when HGP begin to oscillates) has been investigated. It was established that the behavior is not equivalent, i.e. hysteresis takes place in the system. This experimental fact indicates that the transition from stationary HGP to oscillating one is similar to the first order phase transition. It was found that the frequency of domain oscillations is nonzero at the onset of the oscillations, which differs from the case of ac electric field[15]. In the case of dc field domain oscillations with frequency less that f_c=0.15 Hz does not appears. This indicates to hard mode type of instability[16].

CONCLUSION

We have studied experimentally the nonstationary EHC of NLC in dc electric field. The results obtained here are summarized as follows:

(i) Two modes of domain oscillations, *longitudinal* and *azimuth*, have been found in oscillating domain lattice. It seems that the interaction between these two modes of oscillation causes the self-organization effects of domain oscillation into phase waves.

(ii) It has been established that transition from stationary HGP to oscillating one is similar to the first order phase transition.

(iii) We have determined that *hard mode* onset of domain oscillation occurs in EHC of NLC for the case of dc electric field.

Acknowledgment

Financial support of this work by the INTAS (grant No. 96-498) is gratefully acknowledged.

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