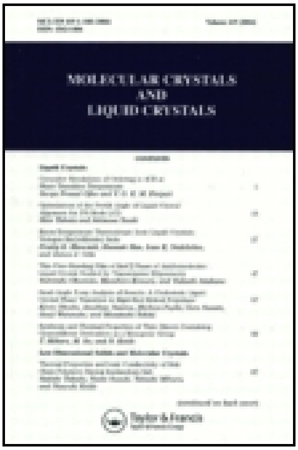

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New Aspect of the Voltage/Confinement Ratio Phase Diagram for a Confined Homeotropic Cholesteric

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NEW ASPECT OF THE VOLTAGE/CONFINEMENT RATIO PHASE DIAGRAM FOR A CONFINED HOMEOTROPIC CHOLESTERIC

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We have investigated the behavior of a cholesteric mixture, consisting of the negative dielectric anisotropy liquid crystal MBBA and a chiral dopant S811 (1% b.w.). In the phase diagram a.c. applied voltage versus confinement ratio, in addition to the transition previously observed, before reaching the domain of the transition TIC (Translationnary Invariant Cholesteric) – modulated TIC, we have observed a new stability domain for the topological bubble. These bubbles are now surrounded by the TIC domains and necessarily associated to an hyperbolic -1 defect of the in plane director component.

We have also obtained experimentally topological defect chains, formed by topological dipoles similar to the ones formed in 2 compound materials: liquid crystal/solid spheres or liquid crystal/liquid droplets.

Keywords: cholesteric liquid crystals; cholesteric textures; out-of-equilibrium process; topological defects

INTRODUCTION

In the last decade, many authors have studied the static and dynamic cholesteric textures obtained under electric field, both experimentally and theoretically [1–3]. Thus, quasi-thermodynamic equilibrium patterns, thermodynamic equilibrium patterns (under electric field) and spiral "out-of-equilibrium" patterns in the presence of a d.c. or a.c. electric field

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have been put into evidence. In this paper we want to focus our interest on a particular type of localized structures called bubbles [4,5], which can be obtained in a out of equilibrium process, such as cooling the LC from the isotropic phase or applying a high voltage and low frequency electric field.

Up to now, these bubbles associated to the presence of point topological defects, have only been observed in a particular region of the voltage – chirality phase diagram, in between the homeotropic and fingers stability domains [5].

In this paper we show that this topological object-(bubble) have also another stability region, when it is placed in the "Translationally Invariant Cholesteric" (TIC) region. The TIC region corresponds to a homogeneous amplitude and direction of the tilt of the director in the middle part of the sample.

EXPERIMENTAL

We have investigated the behavior of a cholesteric mixture, consisting of the negative dielectric anisotropy liquid crystal MBBA and a chiral dopant S811 (Merck, 1% b.w.) The mixture was confined between two ITO covered glass plates, with homeotropic alignment, obtained by using lecithin.

The confinement ratio $C = d/p$ (d = cell thickness, p = cholesteric pitch) was modified by varying the thickness of the cell, with a precision of 0.5 μm. By varying the two control parameters, the confinement ratio and the voltage [2,6], the phase diagram presented in Figure 1 was obtained. We applied a voltage at 2 kHz frequency, in order to avoid charge injection that would be involved at lower frequencies.

The observations were made using an Olympus polarizing microscope, with a CCD camera. The camera and an a.c. voltage generator (HP) are computer controlled.

In order to get reproducible measurements, the temperature of the cell was controlled using double regulation with an external thermostated fluid circulation in addition to a modified computer controlled Instec hot stage.

RESULTS AND DISCUSSIONS

Figure 1 represents the phase diagram of the cholesteric LC: a.c. applied voltage *versus* confinement ratio, $C = d/p$, where d is the thickness of the cell and p is the cholesteric pitch.

At low confinement ratio, starting from the nematic homeotropic zone (see Fig. 1), which appears black between crossed polarizers, increasing the voltage and passing the threshold voltage line (the starting part of the continuous line with empty circles, $V_T(C)$), we observe the transition

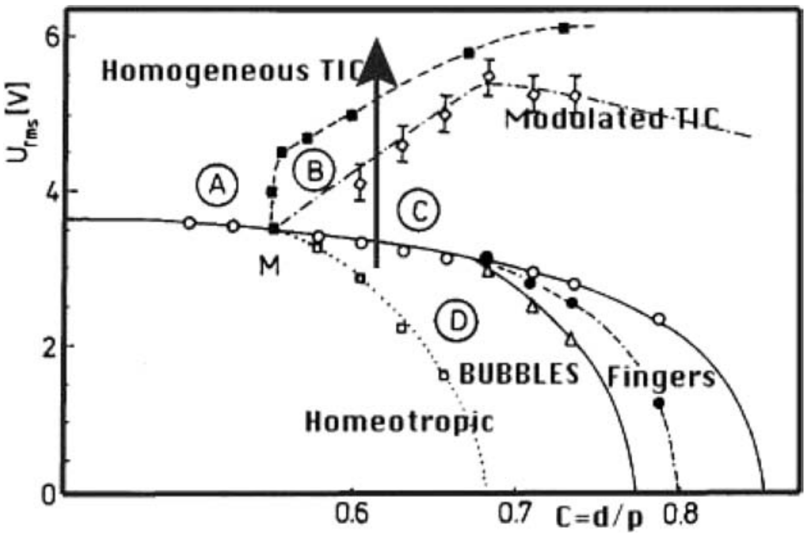

FIGURE 1 Phase diagram of a blend of MBBA-S811 chiral dopant with negative dielectric anisotropy, in the space parameter: ac electric voltage applied between the glass plates *versus* the confinement ratio C = d/p. The different domains A, B, C, D represent respectively: A and B) domain of homogeneous Translationally Invariant Cholesteric with a constant tilt of the director in the mid-plane of the plate. C) stripped domain of modulated tilt of the director in the mid-plane of the sample. D) a particular region of the homeotropic phase in which the singular bubbles remain stable. The arrow describes the progressive increase of voltage in presence of bubbles applied in the experiment.

to the homogeneous TIC phase. This is a second order phase transition very similar to the Freedericksz transition obtained for a nematic cell, corresponding, to the C = 0 situation.

At the increase of the confinement ratio, the threshold voltage $V_T(C)$ decreases, from the theoretical Freedericksz threshold: as known from the work of Ribiere *et al.* [2] the chirality has an influence opposed to that of the homeotropic anchoring, acting in the same sense as the electric field in its destabilizing effect.

For a confinement ratio higher than the one corresponding to the M point, the increase of the voltage starting from the homeotropic domain leads now to the appearance of a striped pattern, which is the modulated version of the TIC, in which the tilt amplitude vary when moving perpendicular to the stripe direction [2].

By further increasing the voltage, we cross the line associated to modulated TIC-TIC transition. (dash-dot line, with empty diamonds) [2].

With the control parameters corresponding to the D region and applying a short, high voltage pulse, corresponding to an out of equilibrium process, associated to a strong electroconvection inside the cell [4], we obtained stable bubbles, presented in Figure 2a. Figure 2b presents the assumed orientation of the director given by Reference [5], in a cut perpendicular to the glass plates and in the middle axis of the bubble (by the use of the nail convention).

- Starting from D zone in presence of stable bubbles surrounded by homeotropic domains, we increase the voltage, (see Fig. 1). Crossing the second order phase transition line $V_T(C)$ we observed that the initial bubble remains stable, surrounded now by the modulated TIC stripes pattern (Fig. 3a).
- Starting from the C zone and increasing again the voltage, crossing the modulated TIC-homogeneous TIC transition line, the previously obtained bubbles remain stable, and are now surrounded by homogeneous TIC domain, as seen in Figure 3b.
- At a further increase of the voltage up to the dashed line with black squares, we observed that the bubbles slowly disapear, leading to the normal homogeneous TIC domain A.

This experimental observation proves the existence of the new domain B of the phase diagram, where stable bubbles are surrounded by TIC. As it is the case for the limit line between the homeotropic domain and the bubble domain D, our experiments strongly suggest that the limit line between the

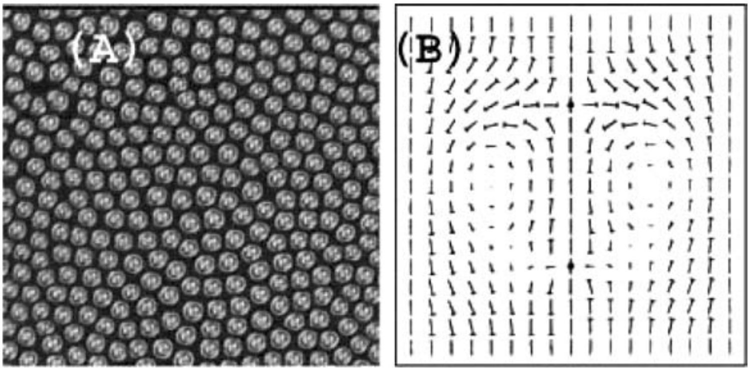

FIGURE 2 a) Polarising microscope observation of the stable bubble domain obtained in the D region of the phase diagram surrounded by homeotropic background, b) representation of a bubble cut perpendicular to the plate across its axe with the nail convention and following Reference [5].

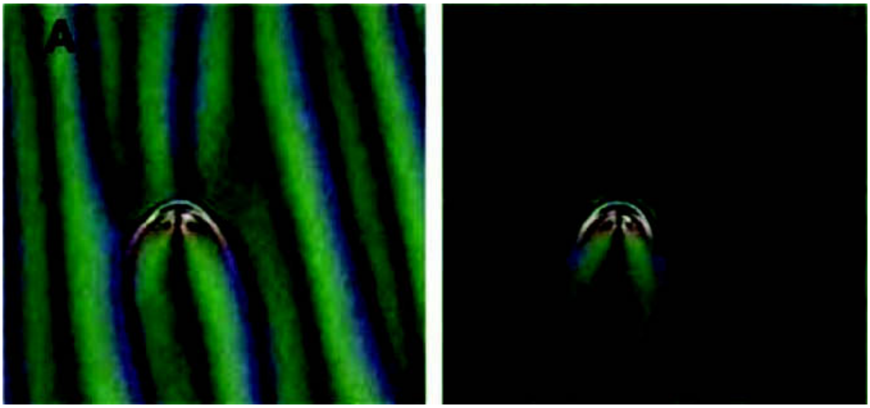

FIGURE 3 The appearance with optical polarising microscopy of the stable bubble formed in the D region when the voltage is slowly increased following the arrow of Figure 1 a) in the C region corresponding to the modulated TIC b) in the B region corresponding to the homogeneous TIC.

B and A domain arrive in the same point M. At this moment, no clear explanation can be given for this possible convergence of 3 transition line (TIC-modulated TIC line, Bubbles stability line, Freedericks transition line), on the point M and this suggest that some theoretical studies might be done to describe this particular behavior.

Focusing now our attention on the bubble surrounded by TIC (domain B) of the Figure 1, we notice that the initial crossed aspect of the bubble is now associated in the upper region with a black arch (Fig. 3b). Figure 4 represents schematically (with the nail convention) a possible interpretation of the director orientation in the mid-plane of the cell. The homeotropic upper arched region correspond to a distorted hyperbolic -1 core. This distortion of the hyperbolic -1 umbilic core is associated to the presence of favorable twist all along this arch.

Because the $+1$ umbilic structure of the bubble is surrounded by tilted homogeneus TIC, it is necessarily associated to the opposite -1 hyperbolic umbilic. This $+1$ and -1 association constitutes an analogue of an electric dipole, as in the case of colloidal particles in nematic liquid crystals [7]. It is important to remark that the orientation of the topological $+1$, -1 dipole possess here an orientation perpendicular to the tilt direction in the homogeneous TIC surrounding domain. It is consequently a situation which seems different from the colloidal case of Reference [7]: in that case the dipole is oriented parallel to the homogeneous nematic domain direction.

When an important number of bubbles are present in the B region, they can associate and from chains as seen in Figures 5a and b. Figure 5a

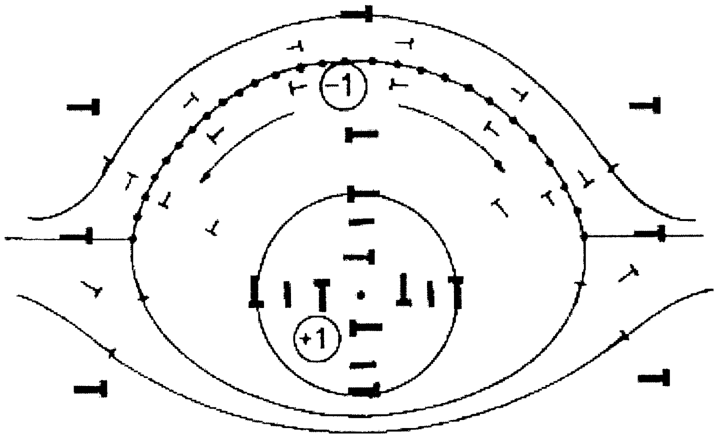

FIGURE 4 Possible director orientation in the mid plane of the plate corresponding to the Figure 3b represented with the nail convention. The arked elongated homeotropic region in the upper part corresponds to the distorted core of a -1 hyperbolic umbilic.

describes the case of an assembly of dipoles surrounded by the homogeneous TIC having the same tilt orientation in the field of observation. But it is well known (in analogy with the fully degenerate homeotropic Freedericks transition) that a slightly out of equilibrium homeotropic-TIC

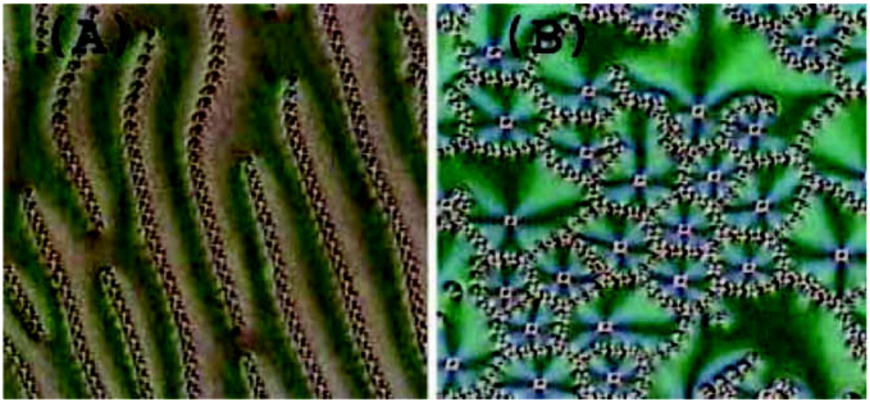

FIGURE 5 Formation of chains of topological dipoles starting from bubbles domain formed in region D of the phase diagram a) surrounded by an homogenously oriented TIC obtained with a very low increase of the voltage b) surrounded by a non homogeneous slightly out of equilibrium TIC obtained with a faster increase of the voltage.

transition can give rise to a field of umbilic associated to the randomless direction of the tilt azimuthal angle. Figure 5b gives an exemple of the type of bubble chain orientation obtained in that case.

CONCLUSIONS

We describe the existence of a stability domain for the bubble surrounded by TIC.

The experiment suggests the existence of a unique point of convergence of the 3 transition lines:

- stability limit line of the bubbles.
- transition line between TIC and modulated TIC.
- transition line between homeotropic phase and tilted one.

Starting from the bubble surrounded by TIC domain, we observed defect chains formed by topological dipoles in analogy to the ones formed in two compound materials: liquid crystal/solid spheres and liquid crystal/liquid droplets: In our case, the dipoles seems to orient in a direction perpendicular to the director tilt direction.

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