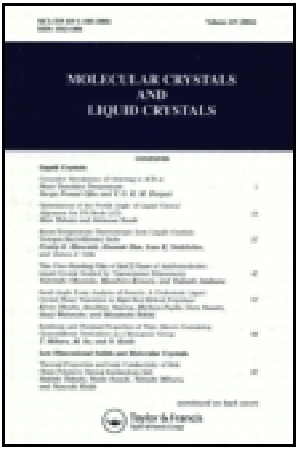

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

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

BEND ELASTIC CONSTANT IN FERROELECTRIC FREE STANDING FILMS OF TILTED SMECTICS

R. Najjar [a] & Y. Galerne [a]

[a] IPCMS/GMO, 23 rue du Loess, BP-20, 67037, Strasbourg, France

Version of record first published: 24 Sep 2006

Mol. Cryst. and Liq. Cryst., 2001, Vol. 366, pp. 421-429
Reprints available directly from the publisher
Photocopying permitted by license only

Bend Elastic Constant in Ferroelectric Free Standing Films of Tilted Smectics

R. NAJJAR and Y. GALERNE

IPCMS / GMO, 23 rue du Loess, BP-20, 67037 Strasbourg – France

A texture of circular concentric disclination walls is produced in a smectic C^* free standing film on applying an in-plane ac electric field. Intensity light profiles taken in the radial section of the circular walls allows us to evidence modulations of the tilt of the molecules. These molecular tilt angle modulations are due to a new elastic term $K^*c^2(\mathbf{rot c})\cdot\mathbf{N}$ in the free energy. We deduce the linear bend constant K^*, which originate from the chiral property of the system. We find $K^*/b \sim 2.5\ \mu m$.

Keywords: disclination walls; target-like texture; smectic C*; freely suspended film; ac electric field

I. INTRODUCTION

Liquid crystal phases have often been distinguished by the textures they exhibit. These textures arise when the liquid crystal phase is examined under polarized light microscopy either in transmitted or reflected light. Many physical properties, as the elasticity, may be studied from the textures that liquid crystals exhibit. In ferroelectric free standing films [1], these textures are numerous and often form spontaneously but they need not correspond to an equilibrium state. In this case, they should be produced artificially.

In this paper, we report on a circular texture, which is produced by the application of an ac electric field in the plane of a ferroelectric free standing film. If the layer normal is taken to be the **z** direction, then the projection of the molecular tilt direction **n** onto the layer planes determines the **c** director, which, in the case of ferroelectric sample, is perpendicular to the spontaneous polarization **P**. An external applied electric field, **E**, may be coupled to **P** to orient the film. The generated texture corresponds to a set of concentric disclination walls. It may extend over a large area of the film typically of a few mm range. In our case, the spontaneous polarization is small, P ~ 4 nC/cm^2 in the temperature range of existence of the SmC^* phase. The circular texture may also be obtained in sample with high spontaneous polarizations [2]. On catching the light intensity profile along an axis perpendicular to the disclination walls, we evidence modulation of the light intensity with unequal maximums. This light intensity modulation is connected to modulations of the molecular tilt angle θ. We deduce a mean tilt modulation connected to fundamental parameters of the film, and therefore an estimate for the new elastic constant K^*, linear in the bend distortion, and which originates from the chiral nature of the sample.

II. EXPERIMENTAL

Our system is a freely suspended film of p-decyloxybenzelydene p-aminocinnamaic acid 2-methylbutyl ester, commonly abbreviated as DOBAMBC. The bulk phase diagram of DOBAMBC is :

crystal — 76°C → SmC* ← 95°C → SmA ← 117°C → isotropic.

The experiments are performed on the film in the SmC* phase. The chiral SmC* phase is a layered phase in which the rod-shaped molecules have an average tilt angle θ from the layer normal.

The film is freely suspended on a square hole of a few millimeter size (Fig. 1). The square hole is realized by means of two movable plates between two fixed holders. Well controlled films of homogenous thickness are drawn in the SmC* phase by putting the movable plates in contact to each other, spreading some amount of the liquid crystal substance on their edges, and carefully driving the holders apart. The film width is given by the distance between the fixed holders, which is about 5mm, while the film length can be varied from 0 to 7mm.

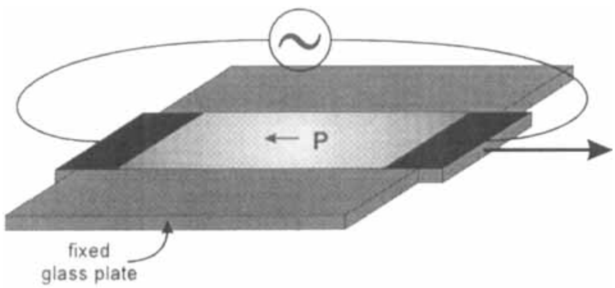

FIGURE 1. Sketch of a SmC* film freely suspended between glass holder. The movable holders are supplied with sputtered golden electrodes allowing the application of an ac electric field, which couples the spontaneous polarization **P**.

The film and its frame are placed inside a thermally isolated hot stage, the temperature of which is regulated by means of a microcomputer. In this manner, the temperature of the sample may be controlled to up to ~ 0.01°C inside the temperature range of existence of the SmC* (76°C - 95°C). The sample is submitted to an ac electric field **E** applied tangentially to the film. The electric field E is addressed by means gold electrodes sputtered on the two movable holders of the film frame. In this way, the film may be oriented uniformly with **P** parallel to **E**, i.e. **c** perpendicular to **E**. The sample is observed between crossed polarizers in transmitted light using an Orthoplan (Leica) microscope compensated from parasitic birefringence and able to resolve optical path differences between ordinary and extraordinary beams ~ 0.5nm. The transmitted light is imaged onto the face of a Cohu video camera. The video camera is connected to a PC via an IP8 (Matrox) video card.

III. FORMATION OF TARGET-LIKE TEXTURES

The idea is to produce the desired texture in order to measure the quantities we are interested in and to deduce the intrinsic physical properties of the system.

The textures in which the **c** director continuously rotates are viewed as arrays of stripes, which may be linear, radial but also circular. These stripes are interference fringes with variations of the light intensity. The variations of the intensity of the images are directly related to the spatial variations of the **c** director and to the variations of the molecular tilt angle θ. This is because the molecule are tilted and the compound birefringent.

Such striped textures may be produced in many ways. For instance, they may be produced by rotating a pin piercing the center of the film [3] or by applying a tangential flow of air [4]. Another way to produce striped texture with continuous rotation of **c** is to apply an ac electric field in the plane of the free standing film [2]. The resulting textures are concentric sets of circular stripes (Fig. 2). Indeed, the textures appear after applying a sinusoidal voltage (f ~ 0.5 Hz, V_0 ~ 1V) for a moment.

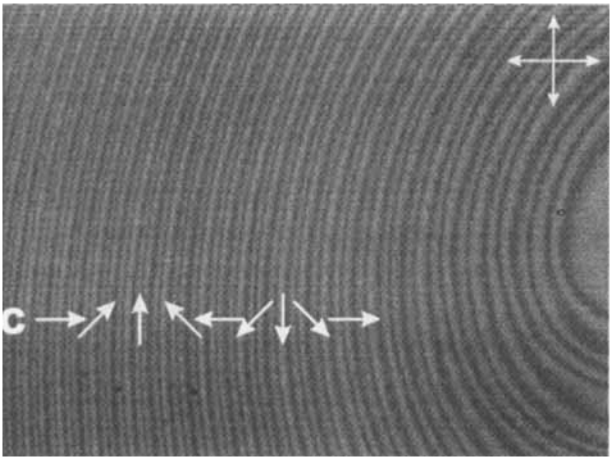

FIGURE 2. Photograph of a target-like texture produced by an ac electric field in a free standing SmC* film. The polarizers are parallel to the edge of the image. The fringes correspond to a continuous rotation of the **c** director. Locally, the disclination walls may be considered as linear.

They exhibit target-like patterns with coaxial bright and dark fringes. They appear in thin as well as in thick films. The texture may be obtained faster by increasing the applied ac voltage. In the idealistic case, one might obtain a single domain of piled circular stripes extended over the whole film. In practice, this is rarely the case, and we usually obtain multi-domains of circular textures, where neighboring domains rotate in opposite direction. However, by adjusting the frequency of the sinusoidal signal, one may approach the idealistic case and obtain a few number of domains only. The parameters of the applied voltage given above correspond to those, which give the less numerous domains. Under this condition, each domain is the more extended and the curvature of the stripes is the less pronounced, i.e. R>>λ where R and λ are respectively the radius of the circular wall and the wavelength of the distortion. Under these conditions, the stripes may be considered as locally linear and the bend width measurements may be performed without significant errors due to the curvature of the stripes.

Each circle consists of four dark fringes corresponding to places where the **c** director is either parallel or perpendicular to the polarizers. The generated texture is characterized by a continuous rotation of the director because while rotating the microscope stage, the stripes continuously drift in a perpendicular movement. Thus, a circle with four fringes is a circular disclination wall. The **c** director field within the film may then be mapped by analyzing the light intensity distribution. The texture may be viewed as an array of circular concentric disclination walls, where **c** continuously rotates describing concentric disclination walls with alternate splay and bend domains. The width of both sign of bend domains may then be measured as a function of the wavelength λ of the distortion. The molecular tilt modulations may also be measured for different wavevectors q.

Contrarily to Ref. 3, the array of concentric disclination walls is not produced by imposing an external rotational force. At the beginning, the film is uniformly oriented. Next, the ac electric field is applied and the orientation of **P**, and hence of the molecules, follows the polarity of the applied field. On the film borders, i.e. in contact to the meniscus, the molecules are anchored. This situation leads to the formation of a disclination wall. A disclination wall is then created. As a consequence, the number of disclination walls increases every period of the electric field signal. However, they do not increase indefinitely because some disclination walls sometimes collapse in the central part of the target-like texture.

IV. MOLECULAR TILT MODULATION

The tilt modulation measurements are performed directly on intensity light profiles, which are caught perpendicularly to the stripes. Let us recall that the stripes can be considered as locally linear since the curvature of the stripes is weak. In addition, the width of the measurement window is weak compared to the curvature radius of the stripes if $l^2 << R\delta x$ where l (~ 10μm) is the width of the measurements window and δx (~ 1μm), typically, the size of a pixel.

All the measurements are performed without any electric field. Once the target-like texture is obtained, the voltage is cut off. Then, the circular disclination walls begin to relax while progressively collapsing in the center of the target-like texture. However, the time over which they collapse is large enough (~ 60min) to allow measurements in quasi equilibrium state at a local scale (~ λ, the wavelength of the distortion). As the walls collapse, the wavelength of the distortion progressively increases in the film. In addition, the walls drift towards the center of the free standing film. Thus, if the measurement window is kept fixed, walls with different λ will pass through it. Then, successive light intensity profiles may be caught until the stripes have totally collapsed and the film has come back to the uniform orientation. In this way, it is easy to scan a large range of λ. The splay domains are clearly distinctive from the bend ones, because the splay domains are larger than the bend ones. This is because, in smectics, the splay and bend 2D elastic constants are different ($K_s > K_b$) [5]. Thus, the bend fringes are the narrower ones. We measure the splay and bend widths directly on the light intensity profiles recorded when the fringes are oriented at 45° with respect to the polarizers. the splay and bend domain widths are pointed between two consecutive minimums. The intensity modulations are marked by fringes with unequal amplitude (Fig. 3). They are measured for different wavevector q on a film of thickness N ~ 25 smectic layers. Let us point out here that the thickness of the film is very thin compared to the helix pitch, which is ~ 1500 smectic layers. Thus, the intrinsic twist distortion may be neglected in our system. However, the tilt modulations are significant when λ is small. These measurements allow us to evidence the elastic term, $K^{*}c^{2}(\mathbf{rot c})\cdot\mathbf{N}$, where K^{*} is an elastic constant linear in the bend distortion and **N** the film normal.

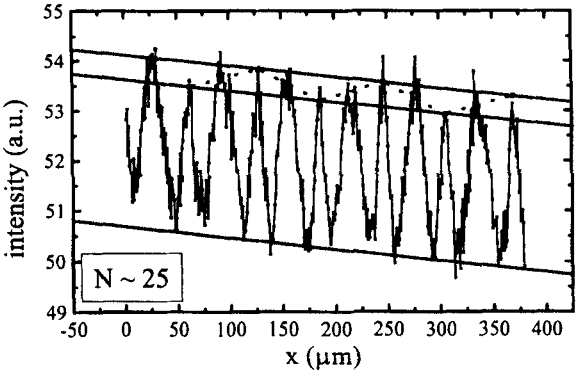

FIGURE 3. Light intensity variations measured perpendicularly to the distortion. It exhibits unequal intensities between the bright fringes, with a four-fringes period. The narrower fringes are the bend distortions.

Let us point out that this term is analogous to the elastic splay spontaneous term, $K_1\ c^{2}\cdot\mathrm{div}\mathbf{c}$, that has been evidenced in pre-freezing SmC_A films induced at the free surface of an isotropic liquid crystal droplet of MHTAC, a non-chiral compound [6]. We deduce a mean tilt modulation and hence a value for the K^{*}/b, where b is the 2nd Landau coefficient. In particular, its absolute value is found to be about ~ 2.5 ± 1 μm. This value is one magnitude order smaller than its non-chiral equivalent K_1/b that has been evidenced in pre-freezing SmC_A films.

V. CONCLUSIONS

As a summary, we have measured some physical characteristics of a distortion, which exhibits a continuous rotation of the **c** director in a ferroelectric free standing film. The distortion is artificially produced by the application of an alternating electric field tangentially to the film plane. The resultant situation is the creation of an array of circular and concentric disclination walls. When observed between crossed polarizers, this array of circular walls is viewed as circular stripes, which mark the places where the **c** director is either parallel or perpendicular to the polarizers. This particular situation allows us to measure some physical characteristics of the distortion as the bend domain widths of both signs and the molecular tilt modulation deduced from the light intensity modulations. These quantities may be related to intrinsic physical properties of the system. They allow to determine a K^*/b ratio in absolute values, where b is a landau coefficient and K^* the new elastic constant linear in the bend distortion. We find in particular $K^*/b \sim 2.5$ μm, which is one magnitude order smaller than its non-chiral equivalent K_l/b evidenced in SmC_A induced films. Unlike K_l, which originates from surface effects, K^* is directly related to the chiral character of the sample.

Acknowledgements
The authors thank L. Oswald for synthesizing and crystallizing the LC compounds that we have used.

References

[1] R.B. Meyer and P.S. Pershan, Solid State Commun. 13, 989 (1973).

[2] S. Uto, E. Tazoh, M. Ozaki and K. Yoshino, *Jpn. J. Appl. Phys.* **36**, L1198 (1997).

[3] P.E. Cladis, Y. Couder and H.R. Brand, *Phys. Rev. Lett.* **55**, 2945 (1985).

[4] Ch. Bahr and D. Fliegner, *Liq. Cryst.* **14**, 573 (1993).

[5] V. Candel and Y. Galerne, *Liq. Cryst.* **15**, 541 (1993).

[6] R. Najjar and Y. Galerne, (submitted to PRL).