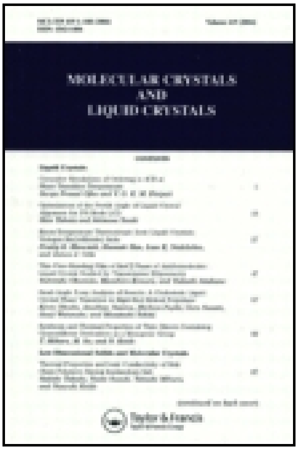

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An optical microscopy investigation of the SmA phase close to the nematic phase puts into evidence the interaction between focal conic domains on one hand, screw and edge dislocations on the other hand. We report here three different situations of such interactions. Our results point towards a dislocation model of the SmA → N transition.

Keywords: defects; edge dislocations; focal conic domains; nematic; screw dislocations; smectic A

INTRODUCTION

The Smectic A → Nematic (SmA→ N) phase transition has been since long the object of many investigations. The various defects and textures of both phases are now reasonably well understood at mesoscopic and macroscopic scales, at least for their static physical and topological properties. Contrariwise, the role played by the defects at the phase transition has been little investigated. This paper reports on optical microscopy observations of the several texture changes in the SmA phase when getting close to the N phase, and proposes elements of interpretation. When the nematic phase is approached, the

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evolution of the elastic constants is well known: both K_2 and K_3 diverge in the SmA phase [1], whereas the compression modulus B becomes smaller and tends towards a finite value (equal to or different from zero, according to the authors) [2]. These variations occur in a large temperature range (two or three degrees). Note that in this range, K_1 stays practically constant, when approaching the SmA $\rightarrow$ N phase transition. The question of $\overline{K}$ has been little investigated yet, either theoretically or experimentally (see however [3]); our results are interpreted by assuming that $\overline{K}$ too stays practically constant.

Let now us recall some general defect features of the SmA phase. These defects are:

Focal Conic Domains (FCDs)

The layers are parallel, so that there is no strain energy but only curvature energy. The normals to the layers envelop two focal surfaces on which the curvature is infinite (the energy diverges). The focal surfaces are degenerate into lines in order to minimize this large curvature energy. These lines are necessarily two confocal conics, an ellipse and a hyperbola, visible by optical microscopy (see Ref. [4] for further details). The energy of the focal conic domains f_{FCD} depends on $K_1$and $\overline{K}$ so that this energy does not vary significantly in the transition zone.

$$f_{\mathrm{FCD}} = f_{\mathrm{bulk}} + f_{\mathrm{core}} = 4\pi a\left(1-e^2\right)\mathbf{K}\left(e^2\right)\left[K_1 \ln\frac{2b}{\xi} - 2K_1 - \overline{K}\right] + f_{\mathrm{core}} \quad (1)$$

where a is the semi-major axis of the ellipse, b the semi-minor axis, e the eccentricity and $\mathbf{K}\left(e^2\right)$ the complete elliptic integral of the first species [5].

Screw Dislocation Lines, Edge Dislocation Lines, and Mixed Lines

The energy of a screw dislocation f_{s} and the energy of an edge dislocation f_{e} decrease in the transition zone. One has:

$$f_s = \frac{1}{128}\frac{B\mathrm{b}_{\mathrm{disl}}^4}{\xi_\perp^2} + f_{\mathrm{core}};\ f_e = \frac{1}{2}\sqrt{K_1 B}\,\frac{\mathrm{b}_{\mathrm{disl}}^2}{\xi_{//}} + f_{\mathrm{core}} \quad (2)$$

where B is the compression modulus and $\mathrm{b}_{\mathrm{disl}}$ is the dislocation Burgers vector. It is visible that the elastic contributions decrease when T $\rightarrow T_{AN}$. The only significant contribution very close to the transition (0.1°C) is the core energy. We are thus led to assume that this region close to the transition is the locus of the nucleation of a great number of dislocations.

We present in this paper several observations relating to the transformations of focal conic domains in the SmA phase near the phase transition. We assign these transformations to the interaction with dislocations.

EXPERIMENTAL

We have investigated three different cyanobiphenyl compounds: 8CB, 9CB, 10CB.

8CB: Crystal 20 SmA 33.4 N 40 I.
9CB: Crystal 45 SmA 48.2 N 52 I.
10CB: Crystal 44.5 SmA 51.6 I.

The first two compounds possess a Nematic phase whereas the third one does not.

The temperature (measured with an accuracy ~0.01°C) has been slowly increased inside an INSTEC oven from the SmA phase to the Nematic or Isotropic phases. Planar samples originate either from E.H.C Co., Ltd (Japan) or have been made with a weak aligning polyimide evaporated substrate layer, or have been obtained from LCI, Kent State University (unrubbed polyisoprene films). There are many different kinds of defective textures in the SmA phase. We just report here the evolution of three of them made with 9CB and 8CB. Note that the phenomena are strikingly different in 10CB; the textures observed at the lower temperatures are not modified when the temperature is increased. The transition to the I phase is first order and the moduli K_1, $\overline{K}$, B do not vary significantly with temperature.

RESULTS AND DISCUSSION

9CB Planar Sample of Thickness $t = 50\,\mu m$; Interaction Between Ellipse and Dislocations

One observes in Figure 1a at least four easily visible ellipses with their confocal hyperbolae. The temperature gradient between the left hand side and the right hand side of the sample does not exceed 0.1°C. When the sample is heated, the distance 2*c* between foci decreases (see Fig. 1b). When the texture evolution is observed under heating, it appears that the eccentricity $e(=c/a)$ of each ellipse does not vary, whereas the major axis 2a decreases. There is a decrease of the focal

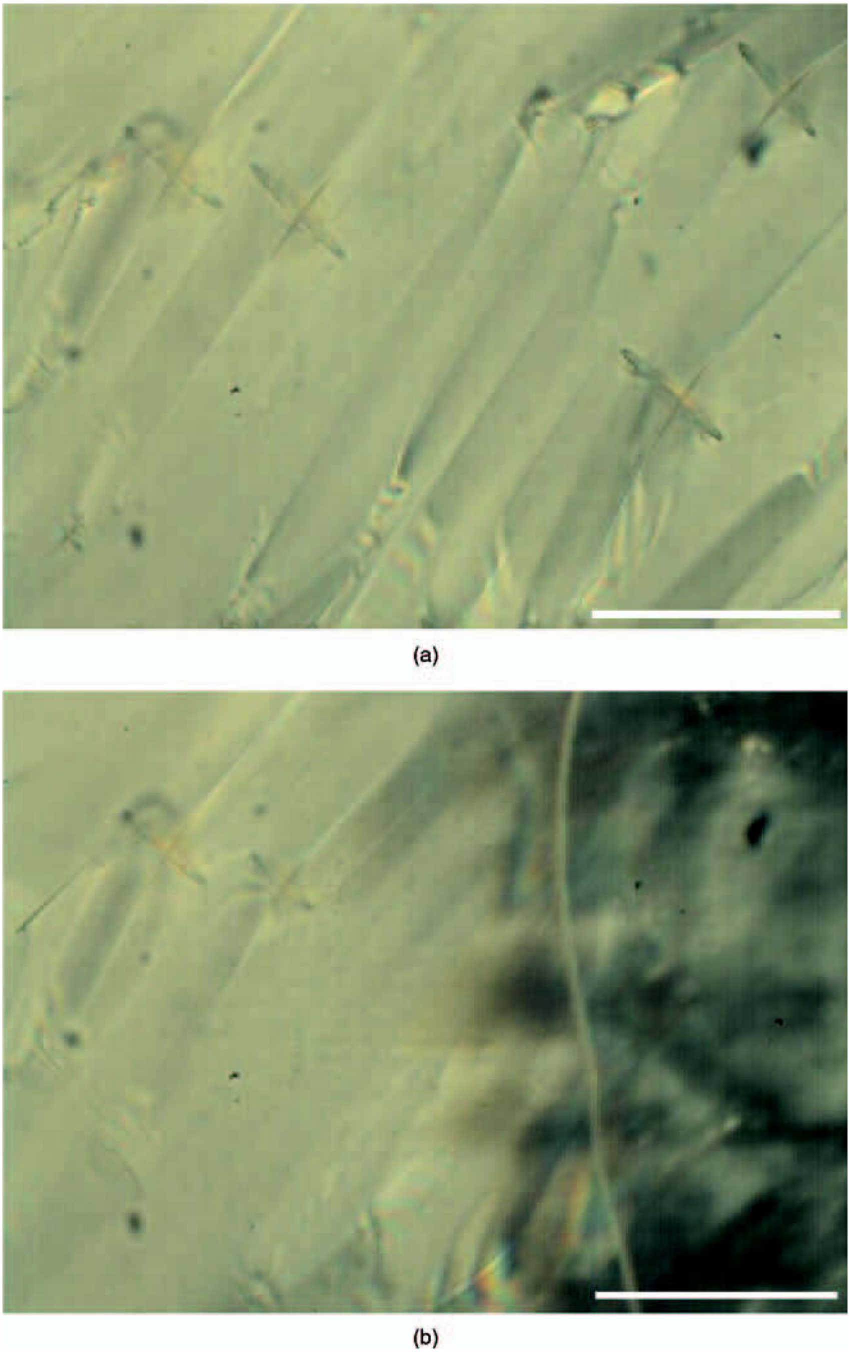

FIGURE 1 9CB; $t = 50\,\mu m$; weak planar anchoring; bar $\sim 100\,\mu m$. The temperature is increased from a) to b). a) $T = 48^\circ C$; observation of several focal conic domains of small eccentricity; b) $T = 48.1^\circ C$; the major axis $2a$ of the ellipses has decreased.

conic domain energy (Eq. (1)). As already known [6], the set of a focal conic domain and of its attached dislocations is topologically equivalent to a dislocation of Burgers vector $b_{disl} = 2c$. The simultaneous decrease of c which attends the decrease of a at constant eccentricity means that the dislocation lines attached to the ellipse (see [4] and [6]) decrease in number. These dislocations have been annihilated by mobile dislocations of opposite signs, coming from the matrix.

9CB Planar Sample of Thickness $t = 50\,\mu m$; Interaction Between Dislocations and Hyperbolae

A well-known result obtained long ago in 8CB by C. Williams is that hyperbolae are privileged locations for screw dislocations [7]. This phenomenon is made visible by the appearance of a strong contrast along the hyperbola (see Fig. 2a). If the total Burgers vector of the dislocations clustered along the hyperbolae is large enough [4, 8], these dislocations can split into disclinations, which most of the time take a helical shape. It is probably what we observe here. In Figure 2b, we can observe a jog on the hyperbola. We remind that the hyperbola is a wedge disclination. This jog, which is perpendicular to the rotation vector of the wedge line is therefore a disclination segment of twist character, to which a dislocation is necessarily attached. This jog moves along the hyperbola when the temperature is increased, dragging then along a dislocation which is attached to the hyperbola.

8CB Planar Sample of Thickness $t = 25\,\mu m$; Full Breaking of a Fragmented FCD

Another texture, which can be very often found in the SmA phase when increasing temperature is detailed in the sequence of the Figure 3. Figure 3a presents a SmA defective texture close to the SmA $\rightarrow$ N phase transition ($\Delta T \sim 0.1^{\circ}C$). We can see one fragmented domain: a part of an ellipse and a part of a confocal hyperbola [4,9]. This is due to the sample thickness t, which is smaller than the size of the focal conic domain. Figure 3b shows the evolution of the domain when approaching the phase transition: the incomplete ellipse breaks down into two disclination lines (of strength $k = 1/2$), which attach to two segments originating from the hyperbola. Note that, since the domain is fragmented, the hyperbola is a wedge disclination of strength $k = 1/2$ – in a complete domain, its strength would be $k = 1$. Topological rules of conservation are thus obeyed.This phenomenon, which is due to an interaction between fragmented focal conic

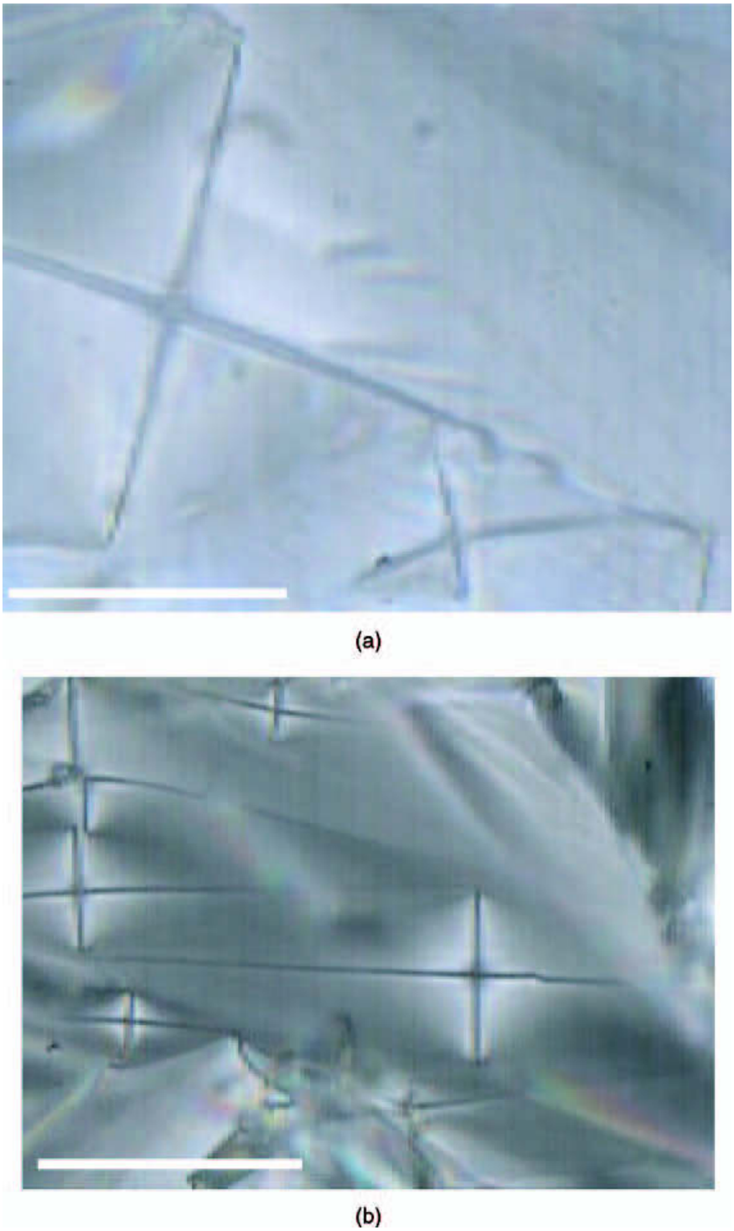

FIGURE 2 9CB; $t = 50\,\mu m$; weak planar anchoring; bar $\sim 50\,\mu m$. a) $T = 47.3°C$; screw dislocations gathering along an hyperbola; b) $T = 47.9°C$; observation of a jog, moving along the hyperbola towards the core region of the focal conic domain.

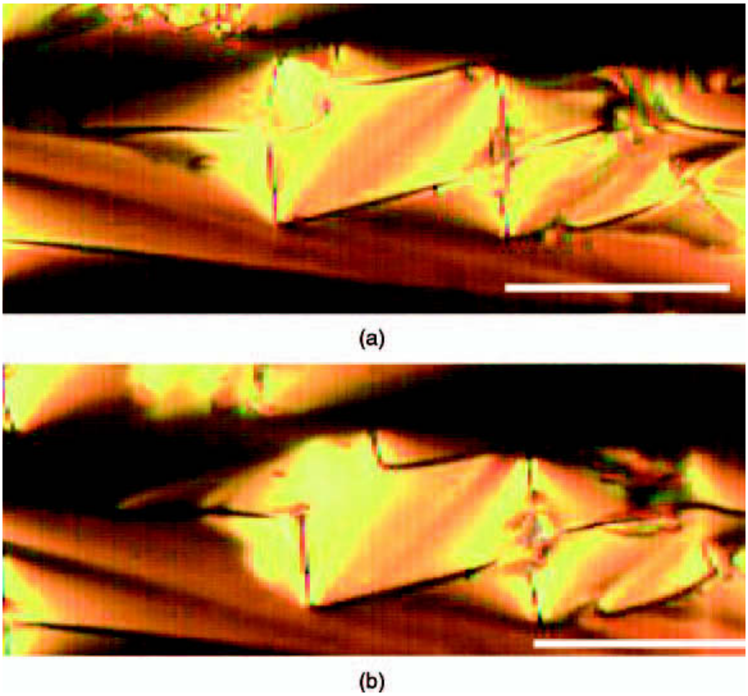

FIGURE 3 8CB; $t = 25\,\mu m$; weak planar anchoring; bar $\sim$30 μm. a) Observation of fragmented focal conic domains ($\Delta T \sim 0.5^{\circ}C$); b) Closer to the phase transition ($\Delta T \sim 0.1^{\circ}C$), the focal lines break down into two disclination lines, which subsist in the nematic phase.

domains and dislocation lines, will be discussed at length in a forthcoming publication.

CONCLUSION, OTHER ELEMENTS OF DISCUSSION

The foregoing observations of the modifications and disappearance of FCDs imply that the dislocations play a dominant role near the transition, due to their high mobility and their multiplication; such results appear as a characteristic feature of samples showing a SmA-N transition, (they are not documented, as indicated above for 10CB, when the SmA transforms to an isotropic phase), and seem to point towards a defect model of the transition, as suggested by several authors [10,11]. We will give more details on the mechanisms of the FCD modifications in a forthcoming publication [12]; these mechanisms are also visible in the case of homeotropic samples.

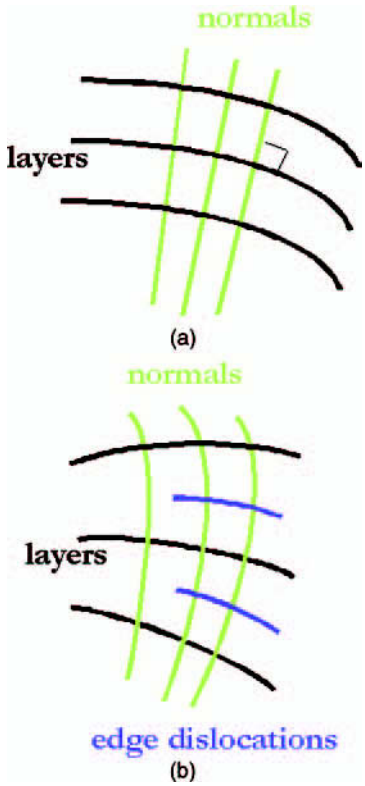

FIGURE 4 a) Darboux's theorem is obeyed: the lines normal to the layers are straight lines; b) Darboux's theorem is not obeyed: the lines normal to the layers are not straight lines; the layers are no longer parallel due to the presence of edge dislocations.

Let us conclude by a final remark relating to another type of FCD-dislocations interaction. Darboux [13] has shown that, given a FCD, its focal lines intersect at right angles in projection. This property, which is most often experimentally observed, relies on the fact that the layers are parallel, and thereby their normals are straight lines. Departures to Darboux's theorem (see for instance Fig. 3a) are sometimes observed, which means that the normal to the layers are not straight lines anymore and indicates the presence of a large density of edge dislocations (see Fig. 4) inside the FCD. Departures to Darboux's theorem have been observed in all types of samples we have investigated.

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