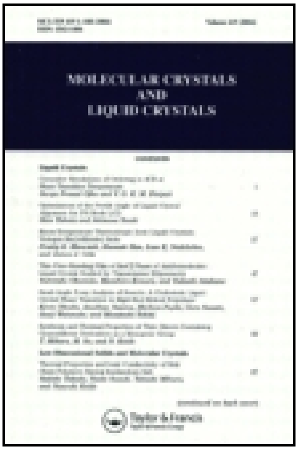

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Kinked Focal Conic Domains in a SmA

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We have investigated Focal Conic Domains (FCD) in several materials that have a transition from a SmA to a nematic phase (N): the focal lines are seldom an ideal ellipse and an ideal hyperbola, and suffer large transformations (in shape and in size) when approaching the transition to the nematic phase, or appear imperfect on cooling from the nematic phase. Some examples of these transformations are shown, including the temperature dependence of the ellipse diameter. Contrariwise, FCDs remain unchanged on heating up to or cooling down from the transition to the isotropic phase in materials that have a direct transition to the isotropic phase. We interpret the imperfections of the FCDs observed in nematogenic materials as due to the interactions of FCDs with dislocations. Such interactions are mediated through the presence of kinks *on the focal lines of the FCDs, to which the dislocations are attached.*

Keywords: achiral smectic A; defects; focal conic domains; kinks

INTRODUCTION

Ideal Focal Conic Domains (FCD, Fig. 1) are geometric constructions in which the layers are folded into Dupin cyclides, about an ellipse

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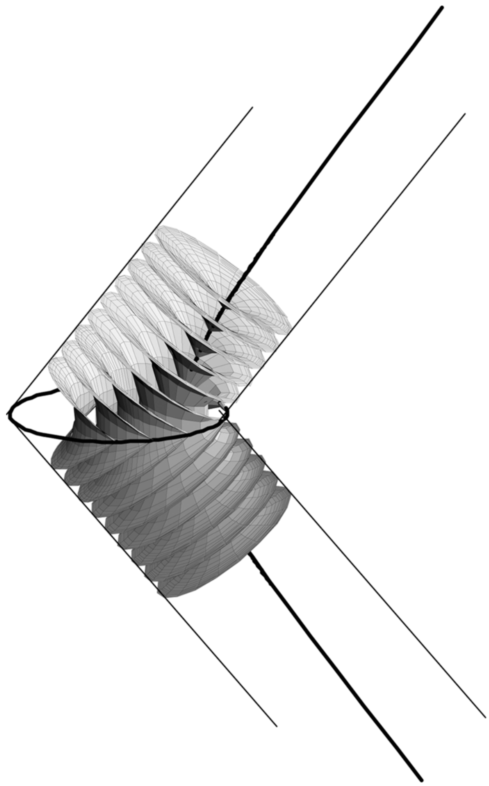


FIGURE 1 Ideal FCD; equidistant layers adopt the shape of Dupin cyclides; the singularities: ellipse and hyperbola are cofocal.

and a hyperbola that are cofocal. This geometry allows the curved layers to remain parallel and equidistant. The ellipse and the hyperbola are singularities in the director field (field of the layer normals in the case of smectic A) [1,2] and, as defects, are special realizations of disclinations. But fairly often in real samples *ideal* FCDs appear *imperfect*. Focal Conic Domains can be as large as tens of microns or larger and thus their configuration can be precisely inspected with the polarization microscope, which makes the investigation of the deviations to ideality rewarding.

FCDs are defects of smectic liquid crystal phases. In the ground state of these media periodically arranged layers, each of which is a 2D liquid, are flat, parallel and equidistant. Although samples that have a structure not very far from the ground state can be prepared, real smectic samples never appear in the ideal ground state.

The experiments show that the layers keep flat only if they are parallel to the bounding flat interfaces. In all other cases the distortions of the smectic structure might relax through *dislocations* (layer singularities involving layer thickness distortions) or *disclinations* (director singularities involving layer curvature).

How does an imperfect FCD look? Recently [3,4] we have demonstrated that an imperfect FCD is a Kinked FCD. A kink plays a role of the imperfection on a disclination. It has a shape of an orthogonal zigzag or a step on a disclination (Fig. 2a) and is the result of the interaction between a disclination and a dislocation(s).

In smectics the attachment of a dislocation to the disclination leads to the appearance of a kink on the disclination (see [3,4] for details). A change of the number of the dislocations attached to a disclination (number of kinks on a disclination) changes its shape (Fig. 2b). The experimental evidences for distorted ellipses are represented in our forthcoming paper [5] and the mechanisms of these distortions are discussed at length in [4]. In this article, after a brief presentation of microphotographs of kinked FCDs, we demonstrate that the interaction of FCDs with dislocations manifests not only as the deviation of the shape of the ellipse from the ideal shape but also is responsible for the temperature dependence of its (ellipse) size. We study the

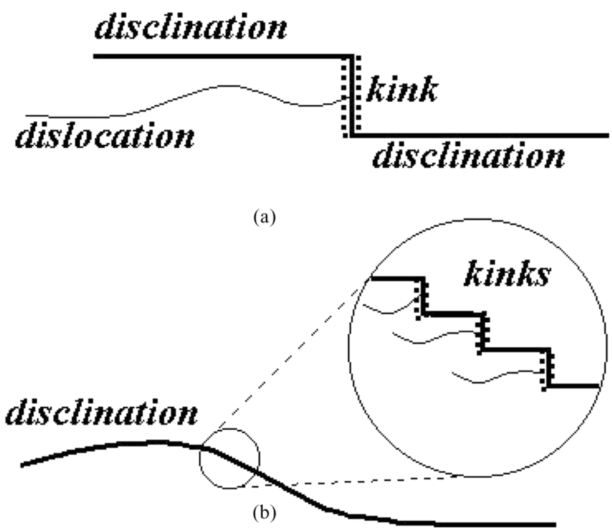


FIGURE 2 Kinked disclinations: a) an elementary kink (inside the dashed rectangle) on a disclination results from the attachment of a dislocation to a disclination; b) densely located kinks modify the shape of the disclination line.

TABLE 1 Temperature Phase Diagrams of the Investigated Smectic Materials

	Type of smectic material	Phase transition temperatures (°C)
8CB	nematogenic	Crystal 21.5 SmA 33.4 N 40 I
8OCB	nematogenic	Crystal 54.6 SmA 67.2 N 80.2 I
9CB	nematogenic	Crystal 45 SmA 48.2 N 52 I
10CB	non-nematogenic	Crystal 44.5 SmA 51.6 I

temperature behavior of the ellipse size in several smectic materials and find that the size of the ellipse is temperature dependendent only for nematogenic materials. In non-nematogenic materials, which exhibit a transition directly into the isotropic phase, FCDs remain unchanged on heating up to the transition to the isotropic phase.

EXPERIMENTAL

We have investigated several achiral materials all possessing a SmA phase: 8CB, 9CB, 8OCB, 10CB. Their phase diagrams are given in Table 1. Three of these materials are nematogenic liquid crystals, not the last one. Two kinds of samples have been prepared: confined samples with some fixed thickness values and free-standing films. The confined samples are made with two slides separated by Mylar spacers of 100 μm.

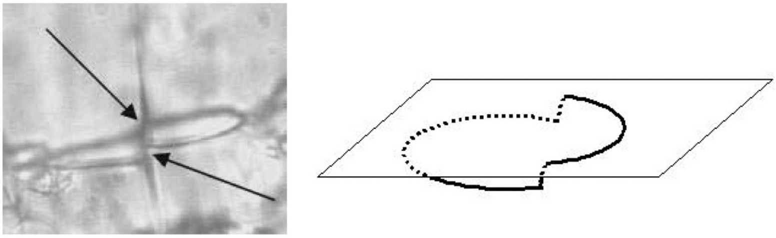
The freestanding films are prepared to be thick enough. This is achieved in two steps. First, a conventional thin film is obtained by sliding a glass plate with the smectic material over the metallic collar of the internal diameter 5 mm and of thickness 2 mm. After approximately several hours the film relaxes and the direct observation of the interference colours indicates the presence of the thin film. The second step consists in a careful deposition of an additional droplet of the same smectic material on the film, which serves as a substrate for the added material. The added material spreads towards its periphery producing terraces and FCD rows.

The temperature control is performed using a hot stage HS-2 from INSTEC which provides a thermo-stabilization accuracy better than 0.002°C and a temperature change at a controlled rate, which can be as low as 0.001°C/min.

RESULTS AND DISCUSSION

Distortions of the Shape of FCDs

We have observed experimentally that the kinks can appear on the ellipse as well as on the hyperbola. The photographs of the kinked



(a) (b)

FIGURE 3 A Turtle viewed from the side: a) a microphotograph of double kinked FCD (100 μm thick cell filled with 8 OCB); b) a schema explaining the shape of the double kinked ellipse shown in Figure 3a).

hyperbolae are presented in reference [3]. It is clear that because the ellipse is a closed plane curve, there are two principal possibilities for the kinks to be located either in-plane or out-plane of the ellipse plane. To distinguish these two situations we call them respectively a *Mouse* and a *Turtle*. Figure 3 illustrates a Turtle, a double kinked FCD with the kinks (shown by arrows) located out of the ellipse plane. The photograph was obtained after heating of a 100 μm thick sample of 8CB slightly above the SmA – N transition temperature followed by cooling to the SmA phase. Figure 4 shows Turtles viewed from above. The sample is a film of 8CB spread on a glass substrate polished by a napkin wetted in glycerol. In the same sample one can find also non-symmetrically kinked FCDs, such that one of the kinks is spread along the disclination and as a result the kinked FCD is a chiral object. This chiral object named chirally kinked FCD will be detailed in [5].

In-plane kinks can modify the shape of the ellipse transforming it in a closed plane curve reminding the contour of a shadow from a mouse. We observed the FCD with a Mouse shape of focal disclination in thick freestanding smectic films (Fig. 5a). The in-plane kinks in Figure 5b. play a role of bridges between the arcs of the cofocal ellipses of different diameters [4].

Temperature Evolution of the FCD Size

We have examined the temperature evolution of FCDs in non-nematogenic material (10CB) as well as in the nematogenic ones (8CB, 8OCB, 9CB). In 10CB the FCDs do not change their size and shape until the temperature transition, when the interface with the isotropic phase touches the FCD. This constancy of the size is

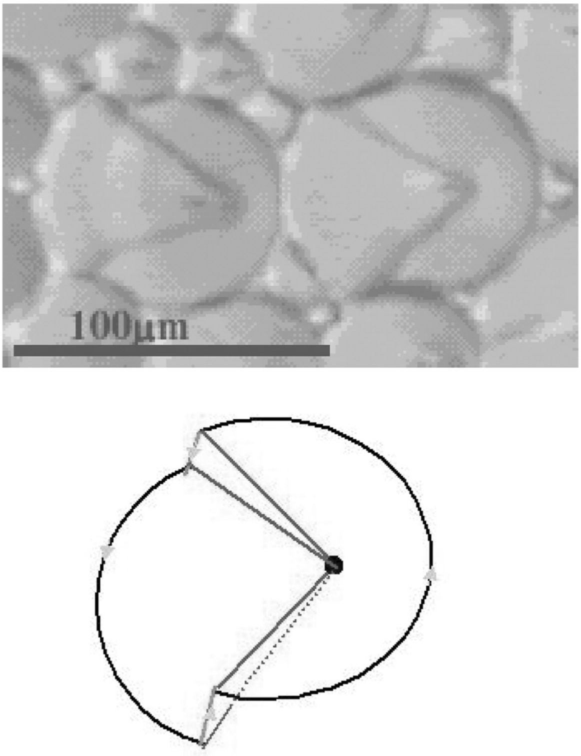
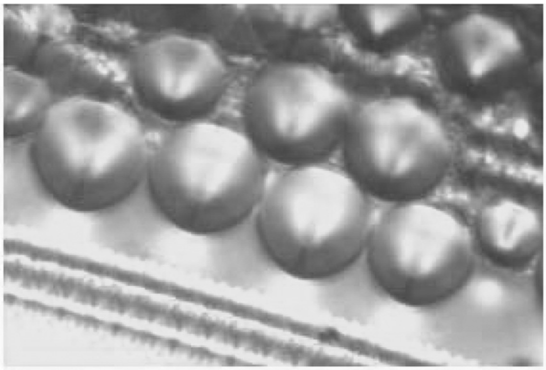


FIGURE 4 Turtles viewed from above: symmetrically double-kinked FCDs.

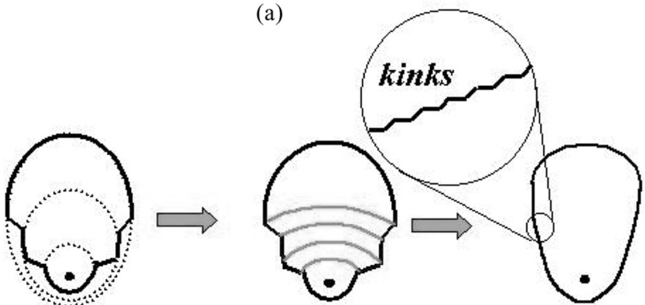
illustrated Figure 6 where the temperature dependence of the major axis of the ellipse is represented.

In contrast to the non-nematogenic material there is a clear tendency to the decrease of the FCDs size upon heating, up to their disappearance (Figs. 7a–c). The temperature at which a given FCD disappears depends on its size: smaller FCDs disappear first. Figure 8 shows a plot of the temperature dependence of the longer diameter of the ellipse.

To explain the difference in the temperature behaviour of the ellipse size depending on the presence of the nematic phase on the phase diagram, let us stress that in smectics there are two ways for the relaxation of the distortions, namely: isometric and nonisometric [6]. At the isometric distortions the positional component of the order parameter is preserved as in the ground state: the layer remain parallel and equidistant at the expense of their non-zero curvature. The FCDs are isometric defects, while dislocations, which introduce local positional



(a)



(b)

FIGURE 5 Mouse, FCDs kinked in the plane of ellipses: a) microphotograph of FCDs in thick free standing films; the focal disclination is an imperfect ellipse transformed into a curve of a mouse contour; b) schema explaining the transformation of the ideal ellipse into Mouse.

disorder, are non-isometric defects. Distortions in smectics are induced either by external fields or by the anchoring surface conditions, if they are antagonistic at the bounding substrates as it is in our case. The antagonistic anchoring conditions can be satisfied by the appearance of FCDs or dislocations whose elastic energies are size and temperature dependent. In practice FCDs coexist with dislocations but their energy contribution to the total smectic elastic energy is little temperature dependent, whereas that one of dislocations is large [4]. Because the compression modulus B strongly decreases on heating in nematogenic smectics, the dislocations should be more favourable at the higher temperatures. The questions is only how significant is the decrease of B within the smectic phase. It turns out that the non-nematogenic and nematogenic smectics differ by their

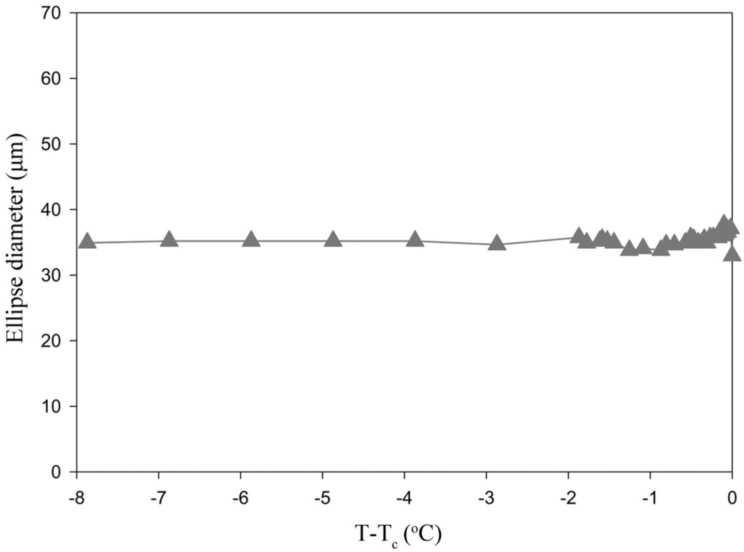


FIGURE 6 Temperature dependence of the ellipse major axis for non-nematogenic smectic 10CB. The same behaviour has been observed for four different FCDs.

temperature dependence for the modulus B. For non-nematogenic smectics B is very weakly temperature dependent, while for the nematogenic smectics B decreases according to some critical exponent when approaching the phase transition to the nematic phase [7–10]. Therefore the replacement of the FCD texture by the distortions involving dislocations on heating approaching the phase transition to the nematic phase can be explained by the switching from the 'isometric deformation' regime, in which the layers are mostly affected by

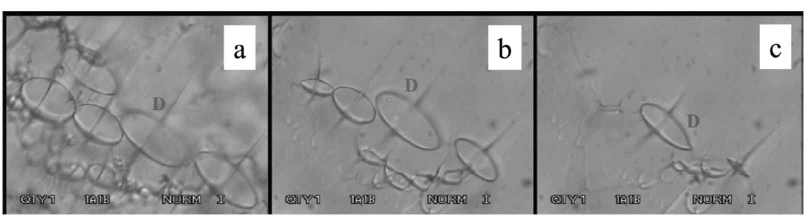


FIGURE 7 Microphotographs illustrating the temperature decrease of the ellipse size in nematogenic smectic 8OCB: a) $T - T_c = -11.2°C$, b) $T - T_c = -0.160°C$, c) $T - T_c = -0.158°C$ ($T_c = 67.200°C$). The letter D marks the FCD corresponding to the plot in Figure 8.

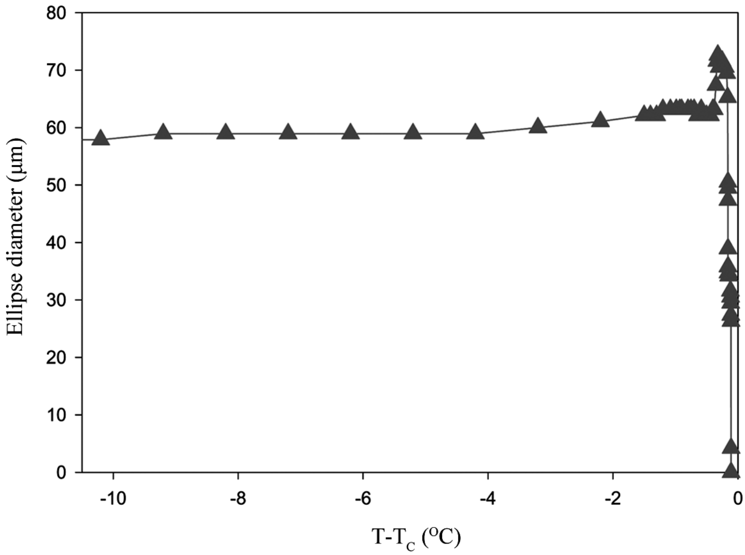


FIGURE 8 Temperature dependence of the ellipse longer diameter for nematogenic smectic 8OCB. Some analogous behaviour has been observed for four different FCDs.

curvature deformations that keep them equidistant, to the 'non-isometric' one, in which layer thickness distortions are taking over. (for a general discussion of isometric distortions in liquid crystals with quantified translation symmetries, see [6]. Now we have to explain how the interaction of the dislocations with a FCD can decrease its size up to the disappearance of the FCD.

The attachment of a dislocation to a disclination leads to the appearance of a kink (see [4] for details). A change of the number of dislocations attached to a disclination (number of kinks on a disclination) changes its shape and for an ellipse can results in the change of its eccentricity or size. As explained in [2], dislocations are attached to an ideal ellipse, and their presence can be described in terms of microscopic kinks [4]. The sum total of the dislocations attached to an ideal ellipse is

$$\left|\vec{b}\right| = 4c = 4ea \tag{1}$$

(see [10]), where $e = c/a$ is the eccentricity, $c = \sqrt{a^2 - b^2}$, a and b the semi-major and semi-minor ellipse axes respectively. The equation above shows that the decrease (increase) of the number of the dislocations, attached to the ellipse at constant eccentricity leads to the

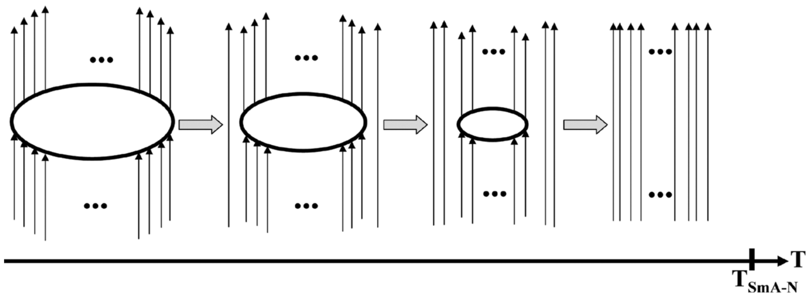


FIGURE 9 Detaching of dislocations from the ellipse leads to the decrease of its diameter, according to Eq. (1). Globally the total Burgers vector is conserved, whereas the total Burgers vector of the dislocations attached to the ellipse is decreased.

decrease (increase) of the ellipse size. The dislocations attached to the ellipse are all of the same sign. The dislocations of the opposite sign, which can be generated approaching the phase transition to the nematic phase can annihilate with the dislocations attached to the ellipse and as a result the ellipse size will decrease, as it is schematized in Figure 9. Another mechanism is by the annihilation of opposite kinks at the apices of the ellipse; such opposite kinks carry half infinite dislocation segments which, when reunited by the annihilation of the kinks, are freed from the ellipse, also resulting in the decrease of its size.

CONCLUSION

A FCD can be imperfect, the imperfections being carried by kinks on the FCD ellipse and hyperbola. The present paper is about kinks located on the ellipse. Depending on the location of the kink with respect to the ellipse plane we have observed two main types of imperfect FCDs, which we call the Mouse (in-plane kinked FCD) and the Turtle (out-plane kinked FCD). Photographs of kinked FCDs are presented. The interaction of FCDs with dislocations manifests not only as the distortion of the ellipse shape but also is responsible for the temperature dependence of its size: the ellipse diameter decreases approaching the transition to the nematic phase up to its complete disappearance within the smectic phase at temperatures distanced from the temperature of the phase transition. In non-nematogenic materials, which exhibit a transition directly into the isotropic phase, FCDs remain unchanged on heating up to the transition to the isotropic phase. We have measured the temperature dependence of the ellipse diameter for nematogenic and non-nematogenic smectics.

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