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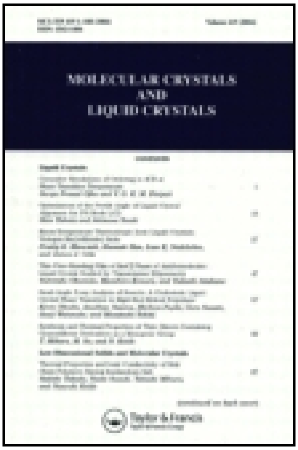

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Deformations of a Planar Nematic-Isotropic Interface in Uniform and Nonuniform Electric Fields†

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The electric field-induced deformations of a planar nematic(N)-isotropic(I) interface were studied, using a surface-nucleated N film prepared in a usual sandwich-type cell. When the applied AC voltage (10 Hz–100 kHz) was small, a uniform elastic distortion of the director was observed. But, at higher voltages, the planar interface became unstable and a striped pattern, having periodicity of a few hundred micrometers, appeared mostly along the rubbing direction of the substrate. The striped pattern was essentially static and was found to correspond to the undulation of the interface. The instability is interpreted in terms of the hydrostatics of nematics, and coupling between the N-I interface and the director is shown to be large responsible. The deformation of the interface in an intentionally nonuniform electric field was also observed. Based on a simple estimate of the interface profile, the N-I interfacial tension was evaluated to be 2.1×10^{-2} erg/cm^2.

I. INTRODUCTION

When two liquid media having distinct dielectric constants are in contact in an electric field, a net force appears at their interface, causing the interface to move to achieve mechanical equilibrium. If at least one of the media is liquid crystalline, the adaptation of the director to the external field may also have a significant effect on the equilibrium condition of the interface and hence the interface mor-

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phology through a characteristic boundary condition imposed at the interface. This paper reports the first clear observation of the electric field-induced morphological change of the nematic(N)-isotropic(I) interface.

The director-mediated field-induced morphological change of a liquid crystal interface was first considered by de Gennes[1] for a nematic free surface placed in a horizontal magnetic field. He showed that above a certain critical field, an undulated surface is energetically preferred to the gravitationally held plane surface. In this case, however, the field effect is largely dominated by the surface tension and the density gap at the free surface, and hence the amplitude of the undulation remains quite small (a few micrometers at best) while the spatial period reaches a few millimeters. As a result, no clear demonstration of this effect has so far been carried out.

On the other hand, the interface between the nematic and the isotropic phases is known to have a very small interfacial tension (of the order of 10^{-2} erg/cm^2) and also a small density gap (less than 10^{-2} g/cm^3). So the N-I interface seems an ideal place to observe the field-induced morphological change of a liquid crystal interface. In the present study, the N-I interface was prepared in a usual sandwich-type cell utilizing the 'wettability difference' of substrates to the N and the I phases.[2] In the absence of electric field, the N-I interface is planar and quite stable thus allowing repeated observations. We have studied, microscopically, the interface morphology as a function of an applied AC voltage with a parallel capacitor configuration. We found that at high voltages the N-I interface ceases to be planar, and a periodic deformation occurs. We also studied the effect of a non-uniform electric field using asymmetric electrodes and from the interface distortion we could estimate the tension of the N-I interface.

In the next section, we briefly discuss the hydrostatics of nematics in an electric field. The experimental results follow.

II. HYDROSTATICS OF NEMATICS IN AN ELECTRIC FIELD

Since the hydrostatics of nematics in an electric field is not well documented in the literature, a brief description will be given here to an extent necessary for later analysis. The fundamental quantity of hydrostatics is the stress tensor from which the equilibrium condition can be calculated. By following the standard procedure utilizing the virtual displacement, we can readily obtain the stress tensor $T_{\alpha\beta}$

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for a nematic liquid in an electric field i.e.:

$$T_{\alpha\beta} = E_\alpha D_\beta - \frac{1}{2}\delta_{\alpha\beta}E_\gamma D_\gamma - \frac{\partial f_d}{\partial(\partial_\beta n_\gamma)}\partial_\alpha n_\gamma - P\delta_{\alpha\beta}, \ (\alpha, \beta, \gamma = x, y, z), \quad (1)$$

where E and D are the electric field and the electric displacement, respectively, f_d the Frank elastic energy density, and $\mathbf{n}$ is the director. In the above, summation over repeated indices is implied. The first two terms are the Maxwell stress tensor, in which the electrostriction was neglected, because it does not contribute to the net force acting on the interface. The third term is related to the variation of the elastic energy when the medium is displaced while the director is fixed. And P stands for the hydrostatic pressure. Noting that the director adopts, in equilibrium, the configuration which minimizes the elastic deformation, we find that the hydrostatic equilibrium,

$$\partial_\beta T_{\alpha\beta} = 0, \quad (2)$$

can be attained if the pressure satisfies

$$P = -f_d + P_0, \quad P_0 = \text{const.} \quad (3)$$

In the isotropic phase, the above argument remains true if we set $f_d = 0$.

Let us now consider the free energy variation associated with a small displacement of the N-I interface from the planar configuration (see Figure 1). In this case, two other contributions must also be taken into account along with the work done by $T_{\alpha\beta}$: (1) the work necessary to enlarge the interface area, and (2) the work for changing the director orientation at the interface, if the displacement implies the director rotation. Summing up all the contributions, we can write the free energy variation as

$$\delta F = \iint \left[\frac{1}{2}\gamma(\nabla u)^2 + (T^N_{zz} - T^I_{zz})u + \frac{\partial f_d}{\partial(\partial_z n_\alpha)}\delta n_\alpha\right] dx\, dy, \quad (4)$$

where the integrand is evaluated at the interface. Here, γ is the interfacial tension, and the superscripts, N and I, refer to the N and the I phases, respectively. The first term is always positive and thus

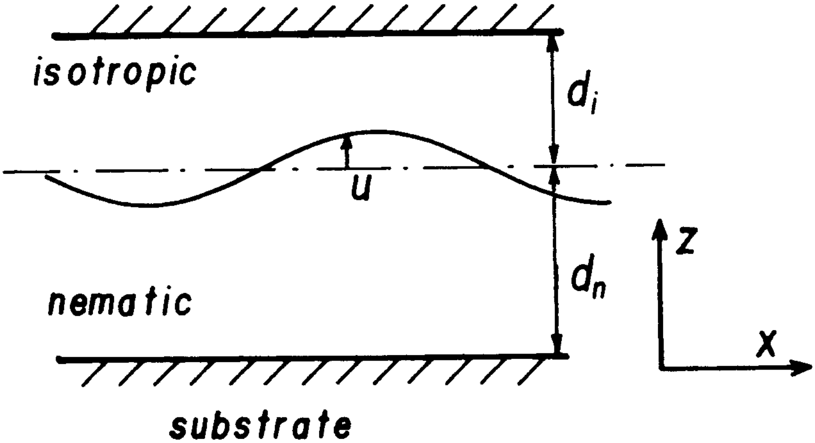

FIGURE 1 The nematic-isotropic interface in a sandwich-type cell and its distortion from the planar configuration.

tends to stabilize the planar interface. However, the third term may be positive or negative depending on the boundary condition and the nature of the displacement. It is this term that de Gennes considered to make the nematic free surface deform at sufficiently high magnetic fields. When the field is weak and as a result the elastic distortion is delocalized throughout the N layer, it can be shown that an interface having a dimension much larger than the N layer thickness remains virtually planar.

With the neglect of the third term in Eq. (4), the equilibrium condition for a planar interface simply reads

$$T^N_{zz} = T^I_{zz}. \tag{5}$$

Here we consider a liquid crystal of positive dielectric anisotropy and assume a planar boundary condition at the lower substrate, but an oblique orientation at the N-I interface as observed previously.[2] If the electric field is sufficiently strong, the maximum tilt of the director occurs somewhere inside the N layer. We write the corresponding (largest) dielectric constant along the z-axis as ϵ_M. Since every quantity now depends on z alone, the first integral of the Eular equation for the director becomes

$$D^2/2\epsilon_{zz} - f_d = D^2/2\epsilon_M, \tag{6}$$

where ϵ_{zz} is the zz-component of the dielectric tensor of the N phase.

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Because the third term in Eq. (1) is now given by $-2f_\alpha$, Eq. (5) reduces to

$$D^2/2\epsilon_M - P_0^N = D^2/2\epsilon^I - P_0^I. \tag{7}$$

This shows that, as far as the equilibrium condition of a planar N-I interface is concerned, the N phase behaves like an isotropic liquid having the dielectric constant ϵ_M.

When the field is strong, the third term can no longer be neglected in Eq. (4) and will make the planar interface unstable. This is because, at high fields, the elastic deformation energy is almost localized near the boundary and a small inclination of the interface can result in a great reduction of the free energy. However, it is a very complicated, essentially three dimensional problem. So, we shall only give a qualitative discussion based on a specific model of the instability, after we have presented the experimental results.

III. EXPERIMENTAL

Sandwich-type cells of about 40 μm thickness were fabricated with NESA-coated glass slides having proper planar aligning layers (see Figure 2). The use of these two different types of aligning methods for each substrate is of crucial importance for preparing a stable planar N-I interface. Since the preparation method of the N-I interface has been described previously,[2] only the outline will be given below. The

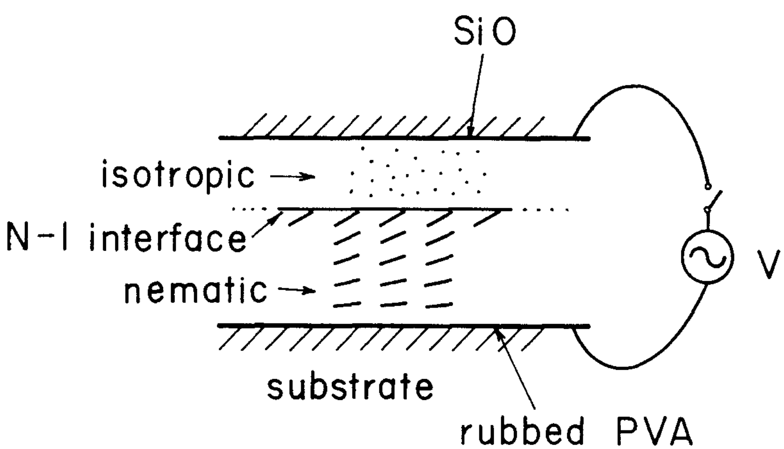

FIGURE 2 Necessary surface-aligning layers and the cell construction.

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liquid crystal used is *4*-cyano-*4'*-*n*-pentylbiphenyl (5CB). To expand the temperature range over which the N and the I phases can coexist, 5CB was mixed with 2.6 mole% hexamethylbenzene, which resulted in the N-I coexistence region ranging approximately from 30.2°C to 30.7°C. As the temperature is lowered from the isotropic phase through the coexistence region, the N phase is preferentially nucleated on the rubbed PVA surface, forming a uniform film of the N liquid. The thickness of the N film was quite uniform when observed between crossed polarizers using monochromatic light, and also it could be changed reversibly with temperature while the N-I interface was kept parallel to the substrate. The effective area of the N-I interface was 10×10 mm^2. For studying the field effect, a sinusoidal voltage of 10 Hz–100 kHz was applied to the cell, and the resulting deformation was observed with a polarizing microscope using either monochromatic or white light.

IV. RESULTS AND DISCUSSION

A. Deformations in uniform electric fields

The deformation of the N-I interface in a normal parallel capacitor configuration was observed. Here the cell was illuminated from the rubbed PVA side with white light, and the polarizer's axis was set parallel to the rubbing direction. So, when there is no deformation of the interface, the field of view should be dark between crossed polarizers. A 1 kHz AC voltage was applied to an N-I interface between a 25 μm-thick N layer and an 18 μm-thick I layer. When the voltage was below 2 V_{rms} the field of view remained dark, showing that only a uniform director distortion was occurring in the N layer. However, when the voltage exceeded 2.5 V_{rms}, the field of view was brightened gradually on application of the voltage, and finally a striped pattern appeared (see Figure 3(a)). The stripes were elongated mostly along the rubbing direction. This trend became clearer when a thinner N layer was used (see Figure 4), and in this case a repetition of two types of dark lines having different widths can be clearly seen. The occurrence of such instabilities was observed to be entirely independent of the frequency of the applied voltage. In addition, no trace of stationary fluid motion could be observed using the microscope. These are a clear indication of the static nature of the instability.

In order to further elaborate the origin of the striped pattern, the cell was cooled near to the lower boundary of the coexistence region

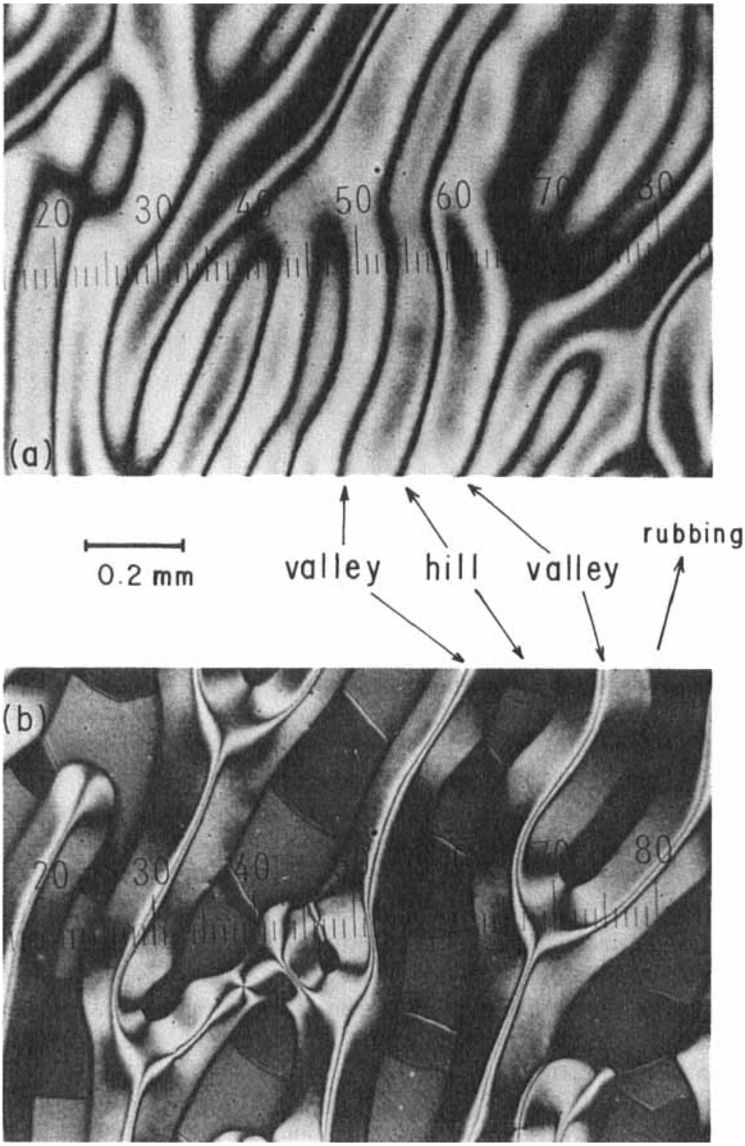

FIGURE 3 (a) Striped pattern observed at 2.5 V_{rms} between crossed polarizers with the rubbing direction set parallel to the polarizer's axis. The thickness of the nematic layer is 25 μm and that of the isotropic layer 18 μm. (b) The nematic layer in contact with the SiO film as the temperature approached the lower boundary of the coexistence region. The contact is occurring along the alternate dark lines. The voltage was gradually increased from 2.5 V_{rms} to 3.5 V_{rms} and was kept constant during the cooling process.

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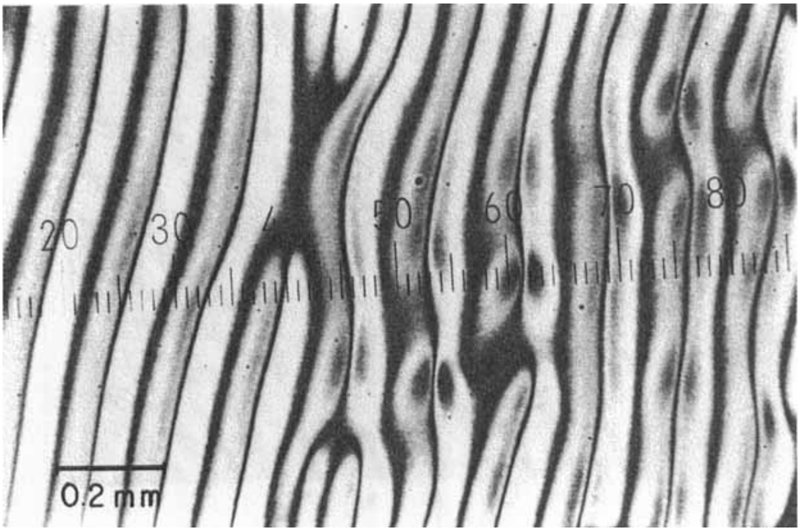

FIGURE 4 Striped pattern for a thin nematic layer (12 μm); the isotropic layer thickness is 31 μm. The applied voltage is 4.5 V_{rms}, 1 kHz.

where the I phase vanishes, while applying 3.5 V_{rms}. Through the cooling process, the pattern was invariable, but when the lower boundary was nearly reached, the N layer made contact with the SiO coated substrate just along the alternate dark lines (see Figure 3(b)). As the temperature was further lowered, the contact lines thickened toward the remaining alternate dark lines, where the I phase finally disappeared. This observation shows that the striped pattern is accompanied by an undulation of the interface in which hills and valleys are located at the mutually alternating dark lines. The brightening of the region between dark lines also indicates that some degree of twist deformation is occurring. Since there is no external agent other than the interface undulation to induce the director twist, the maximum twist can be thought to occur at the N-I interface. This situation is schematically illustrated in Figure 5.

In the previous paper,[2] we showed that the director is inclined from the N-I interface by 0.49 rad with the anchoring strength of the order of 10^{-3} erg/cm^2 for the present material. So, in general, the undulation of the N-I interface results in changes of the polar and the azimuth angles of the director at the interface. Since the effect of the finite anchoring strength comes in only when the elastic deformation is localized within a few micrometers from the interface, we assume strong anchoring as an approximation to simplify the argument below.

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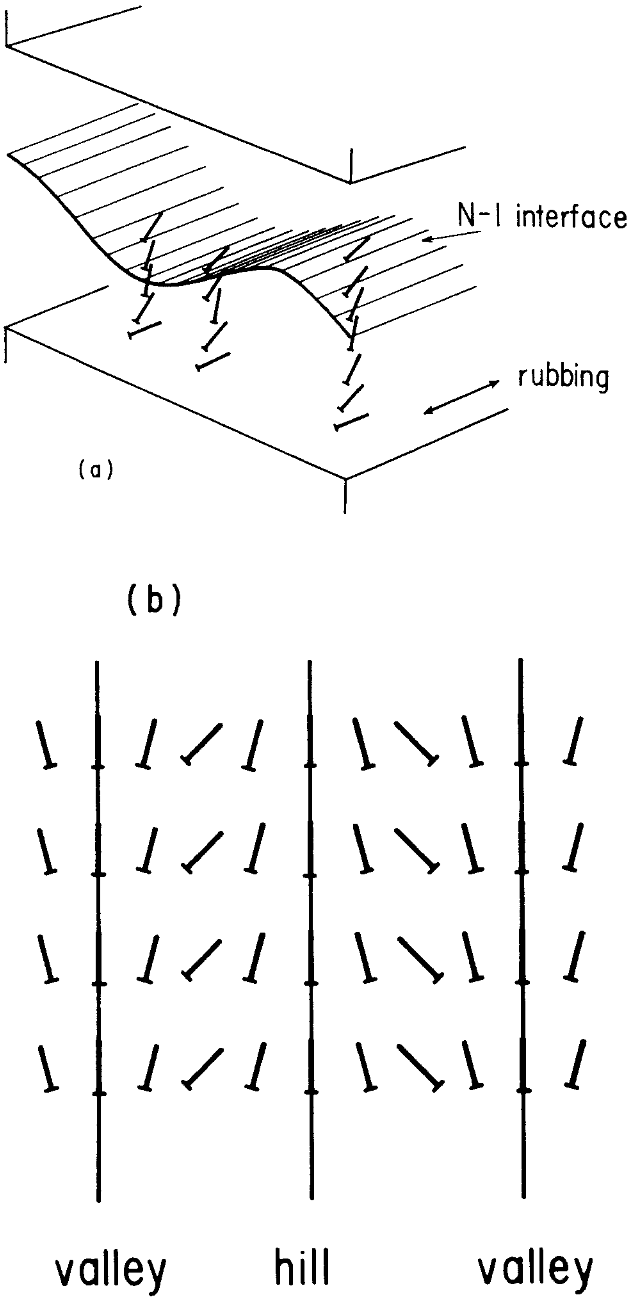

FIGURE 5 Schematic illustration of the deformed nematic-isotropic interface (a), and the director orientation at the interface as projected onto the substrate (b).

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Let θ and ϕ be the polar and the azimuth angles of the director with respect to the co-ordinate axes shown in Figure 1 with the x-axis taken along the rubbing direction. Then, if the interface is planar, $\phi = 0$. And let θ_i be the angle that the director makes with the local normal of the interface. Since the director orientation is degenerate with respect to rotation about the interface normal, the changes in θ and ϕ at the N-I interface associated with the displacement u satisfies the following equation to second order in ∇u:

$$\delta\theta_i = -\frac{\partial u}{\partial x} - \frac{\partial u}{\partial y}\delta\phi_i - \frac{1}{2}\cot\theta_i\left(\frac{\partial u}{\partial y}\right)^2. \tag{8}$$

Here we shall consider the fluctuations of the interface having wavelengths much larger than the cell thickness. Therefore, the problem can be treated one-dimensionally. In order to evaluate the free energy gain associated with $\delta\theta_i$ and $\delta\phi_i$, i.e. the third term in Eq. (4), we make a direct estimate of the free energy change instead of calculating the third term. First, note that the principal contribution to the free energy gain comes from $\delta\theta_i$, while $\delta\phi_i$ implies the introduction of twist deformations and thus increases the free energy.

The total free energy at constant applied voltage is

$$F = \iiint_{nematic} [f_d - D^2/2\epsilon_{zz}]dxdydz - \int D^2/2\epsilon^I\, dxdy. \tag{9}$$

The free energy change due to $\delta\theta_i$ and $\delta\phi_i$ can, therefore, be written as

$$\delta F = \iiint_{nematic} \left[\delta f_d - \frac{1}{2}E^2\delta\epsilon_{zz}\right] dxdydz. \tag{10}$$

When the field is strong and thus the elastic deformation is localized within the distance ξ from the interface, the first term in the above equation is inversely proportional to ξ, whereas the second is linear in ξ. So, when the voltage is high, the main contribution comes from the elastic term. In this case, the free energy gain due to $\delta\theta_i$ may be roughly given by

$$K\frac{\theta_i}{\xi}\delta\theta_i, \tag{11}$$

and the free energy loss due to $\delta\phi_i$ by

$$\sin^2\theta_i \frac{K}{2}\left(\xi\left(\frac{\partial\delta\phi_i}{\partial x}\right)^2 + \xi\left(\frac{\partial\delta\phi_i}{\partial y}\right)^2 + \zeta\frac{\delta\phi_i^2}{d_n}\right), \tag{12}$$

where K is a typical elastic constant, and ζ is a parameter depending on the degree of deformation occurring in the N layer; when the field is low, $\zeta \sim 1$, but when the field is so high that the director aligns almost perpendicular to the substrate, twist deformations along z-axis occur with little energy loss and thus $\zeta \sim 0$.

Substituting Eq. (8) into Eq. (11) and summing up Eq. (11) and Eq. (12), we obtain

$$\delta F = \iint\left[K\frac{\theta_i}{\xi}\left(-\frac{\partial u}{\partial x} - \frac{\partial u}{\partial y}\delta\phi_i - \frac{1}{2}\cot\theta_i\left(\frac{\partial u}{\partial y}\right)^2\right)\right.$$
$$\left. + \sin^2\theta_i\frac{K}{2}\left(\xi\left(\frac{\partial\delta\phi_i}{\partial x}\right)^2 + \xi\left(\frac{\partial\delta\phi_i}{\partial y}\right)^2 + \zeta\frac{\delta\phi_i^2}{d_n}\right)\right] dxdy. \tag{13}$$

In this equation, only the term involving $\partial u/\partial x$ is linear in u. Which is actually the term that de Gennes considered for the nematic free surface. As de Gennes noticed, this term leads to a reduction of free energy only when the interface is deformed uniformly throughout the entire interface, if the introduction of disclinations is avoided. In a thin layer, in particular, such a long wavelength deformation requires a very long time to establish and thus might be practically unobservable. In order to make a shorter wavelength deformation based on this mechanism, we must allow the inclusion of disclinations. At this point, we must notice that we started the observation from a uniformly aligned sample. As a result, the system must overcome a rather large energy barrier to introduce disclinations, which diminishes the possibility of observing this type of deformation. In fact, if this mechanism works, the resulting deformation must be periodic along the rubbing direction, which is in contradiction with the reality.

In contrast to the nematic free surface in a horizontal magnetic field, the present system allows a free energy reduction while avoiding the appearance of disclinations. The terms involving $\delta\phi_i$ in Eq. (13) are related to this effect: When a certain deformation along the y-axis is generated, there always exists an optimum distribution of $\delta\phi_i$ which results in a gain of free energy. To see that this effect can offer

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a reasonable explanation of the observed deformation, we treat two extreme cases, i.e. low and high field limits, which are easily amenable to analytical calculations. We assume $\partial u/\partial x = 0$ below. When the field is low, the lateral gradients of $\delta\phi_i$ may be neglected in comparison with the twist deformation term. So, in this case, the Eular equation for $\delta\phi_i$ simply reads

$$\sin^2\theta_i\, K\,\zeta\,\frac{\delta\phi_i}{d_n} - K\,\frac{\theta_i}{\xi}\,\frac{\partial u}{\partial y} = 0. \tag{14}$$

Then the free energy gain is

$$\delta F = -\iint\left[K\,\frac{\theta_i}{\xi}\left(\frac{d_n\theta_i}{2\xi\,\zeta\,\sin^2\theta_i}\left(\frac{\partial u}{\partial y}\right)^2 + \frac{1}{2}\cot\theta_i\left(\frac{\partial u}{\partial y}\right)^2\right)\right]dxdy. \tag{15}$$

When the field is high, however, the lateral gradients may be dominant, because ζ can be thought to decrease more rapidly than ξ as the field increases. The Eular equation now becomes

$$\sin^2\theta_i\, K\,\xi\left[\frac{\partial^2\delta\phi_i}{\partial x^2} + \frac{\partial^2\delta\phi_i}{\partial y^2}\right] + K\,\frac{\theta_i}{\xi}\,\frac{\partial u}{\partial y} = 0, \tag{16}$$

from which we find

$$\frac{\partial\delta\phi_i}{\partial y} = \frac{-\theta_i}{\xi^2\sin^2\theta_i}\,u. \tag{17}$$

We can then write the free energy gain as

$$\delta F = -\iint\left[K\,\frac{\theta_i}{\xi}\left(\frac{\theta_i}{2\xi^2\sin^2\theta_i}\,u^2 + \frac{1}{2}\cot\theta_i\left(\frac{\partial u}{\partial y}\right)^2\right)\right]dxdy. \tag{18}$$

Finally, replacing the third term in Eq. (4) with these expressions and formally expanding the stress tensor term to second order in u, we obtain the total free energy change associated with the interface displacement.

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i. Low Field

$$\delta F = \iint \left[\frac{1}{2} \left(\gamma - \frac{K\theta_i}{\xi} \cot \theta_i \right) \left(\frac{\partial u}{\partial y} \right)^2 - K \frac{d_n \theta_i^2}{2\xi^2 \zeta \sin^2 \theta_i} \left(\frac{\partial u}{\partial y} \right)^2 - \frac{1}{2} a u^2 \right] dxdy \tag{19}$$

ii. High Field

$$\delta F = \iint \left[\frac{1}{2} \left(\gamma - \frac{K\theta_i}{\xi} \cot \theta_i \right) \left(\frac{\partial u}{\partial y} \right)^2 - \frac{1}{2} \left(a + \frac{K \theta_i^2}{\xi^3 \sin^2 \theta_i} \right) u^2 \right] dxdy \tag{20}$$

Here, a is the expansion coefficient for the stress tensor contribution, cf. Eq. (5). These equations show that the planar N-I interface is always unstable in a sufficiently strong electric field with respect to a fluctuation having a wavelength larger than a certain critical value. However, as mentioned earlier, a fluctuation with too long a wavelength is virtually unobservable due to a very small growth rate. The deformation which is to be actually observed may be the fluctuation mode with the largest growth rate. When the free energy is given by

$$\delta F = \iint \left[\frac{1}{2} g \left(\frac{\partial u}{\partial y} \right)^2 - \frac{1}{2} h u^2 \right] dxdy, \ g, h > 0, \tag{21}$$

the critical wavelength, λ_c, is given by

$$\lambda_c = 2\pi (g/h)^{1/2}. \tag{22}$$

A simple hydrodynamic consideration shows that the mode with the largest growth rate has approximately the wavelength, $\sqrt{2}\lambda_c$. In addition, the growth rate scales as h^2/g.

To test the validity of the present analysis, a numerical calculation was performed for $d_n = 25$ μm and $d_i = 18$ μm at the applied voltage of 2.5 V rms, using the previously determined material parameters,[2] i.e. $K \sim 2 \times 10^{-7}$ dyn, $\theta_i = 1.08$ rad, etc. The coefficient, a, was

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calculated to be 175 erg/cm^4. In Figure 3, the deformation has a wavelength of about 300 μm. Using Eq. (22) and Eq. (20), and assuming $\gamma = 2 \times 10^{-2}$ erg/cm^2, we find $\xi \sim 6$ μm in order to reproduce the observed wavelength. This value seems quite reasonable and shows that the coupling between the interface shape and the director is mainly responsible for the interfacial instability.

The significant difference between Eq. (19) and Eq. (20) is that the free energy gain due to $\delta\phi_i$ in Eq. (20) is isotropic in the x,y plane whereas that in Eq. (19) is not. This result is intuitively quite convincing, because the factor that gives a directionality to the N-I interface can only be the rubbing direction. However, when the field is so strong that the director aligns almost perpendicular to the substrate, there no longer exists any reason for the N-I interface to feel the rubbing direction. So, at high fields, the interface will tend to be liberated from the restriction imposed by the lower boundary. On the other hand, in Eq. (19), the coupling between the N-I interface and the director gives rise solely to a renormalization of the interfacial tension, inducing an anisotropy in it. This anisotropy, in fact, correctly accounts for the direction of the observed stripes. In reality, however, a gradual transition from the low field regime to the high field one occurs as ζ approaches 0. And, if we make the N layer thin while keeping ξ constant, ζ can be expected to increase. This is because the director profile inside the N layer is independent of its thickness, if the voltage across the layer remains constant; while the deformation energy is inversely proportional to the thickness. This is also in agreement with the observation that the directionality of the striped pattern is improved as the N layer thins.

B. Deformation in nonuniform electric field

The deformation of the N-I interface in an intentionally nonuniform electric field was observed at a relatively low field at which no instability takes place in a uniform field. To make the field nonuniform in a rather controlled manner, a small part (350 μm diameter) of NESA coating was removed from the center of the upper substrate. Since the removed region is much larger than the cell thickness, this part can be considered to be largely field-free, even when the voltage is applied to the electrodes. Moreover, since the dimension of the removed part occupies only 1/1000 of the whole effective area of the cell, most of the N-I interface can be expected to remain planar on application of a voltage.

Figure 6 shows the micrographs taken just before and after the removal of the voltage (1.3 V rms, 1 kHz) at the removed region

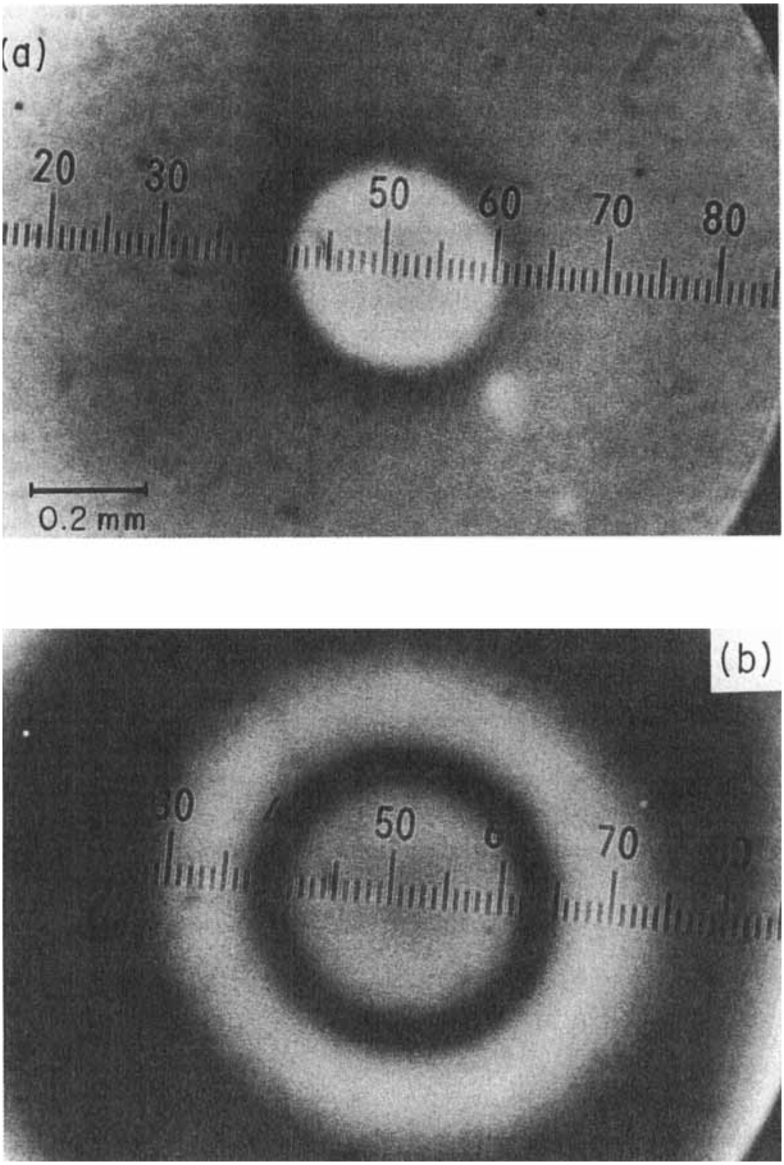

FIGURE 6 Deformations of the nematic-isotropic interface in nonuniform electric field. (a) Just before the removal of the applied voltage (1.3 V_{rms}, 1 kHz) after 1.5 hours of application. (b) Just after the removal of the voltage. Observed between crossed polarizers with the rubbing direction inclined by 45° from the polarizer's axis. Monochromatic light was used, and in (b) the alternation of dark and bright rings means a concentric change of the nematic layer thickness. Note that the planar interface was recovered in about 1.5 hours after the removal of the voltage.

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using monochromatic light (560 nm) with the rubbing direction inclined by 45° from the polarizer's axis; the voltage was applied for 1.5 hours before it was turned off. The bright disc in Figure 6(a) shows the field-free region. When the voltage was removed, the director immediately adopted a configuration which suited the shape of the N-I interface. Therefore, the concentric dark bands in Figure 6(b) are the indication that the N-I interface is concentrically deformed. The interface profile was estimated from this picture based on the fact that the fringe to fringe spacing corresponds to about 5 μm change in the N layer thickness (see Figure 7).

The interpretation is rather simple. We showed in Section II that the equilibrium condition of the planar interface is given by Eq. (7). This implies that, if the N-I interface is extended to a field-free region, the pressure difference, $P_0^N - P_0^I$, appears across the interface. To achieve mechanical equilibrium in the field-free region, the pressure difference must be balanced by the deformation of the interface. The quantitative statement of the condition is nothing but the Young-Laplace equation[3] which reads

$$\gamma(1/R_1 + 1/R_2) = P_0^I - P_0^N = D^2/2\,(1/\epsilon^I - 1/\epsilon_M), \tag{23}$$

where R_1 and R_2 are the principal radii of curvature of the N-I interface.

From Figure 6(b), we find $R_1 \sim R_2 \sim 8$ mm in the field-free region. Using $d_n = 20$ μm and $d_i = 23$ μm, we calculated numerically the electric displacement, D, and the maximum dielectric constant, ϵ_M;

$$\begin{aligned} D &= 2.9 \times 10^{-10}\ \mathrm{C/cm^2}, \\ \epsilon_M &= 12.4\,\epsilon_0(\epsilon_0 = 8.854 \times 10^{-12}\ \mathrm{F/m}), \\ (\epsilon^I &= 10.9\,\epsilon_0). \end{aligned} \tag{24}$$

Substituting these values in Eq. (23), we obtain the N-I interfacial tension as

$$\gamma = 2.1 \times 10^{-2}\ \mathrm{erg/cm^2}, \tag{25}$$

which is in reasonable agreement with those in the literature.[4]

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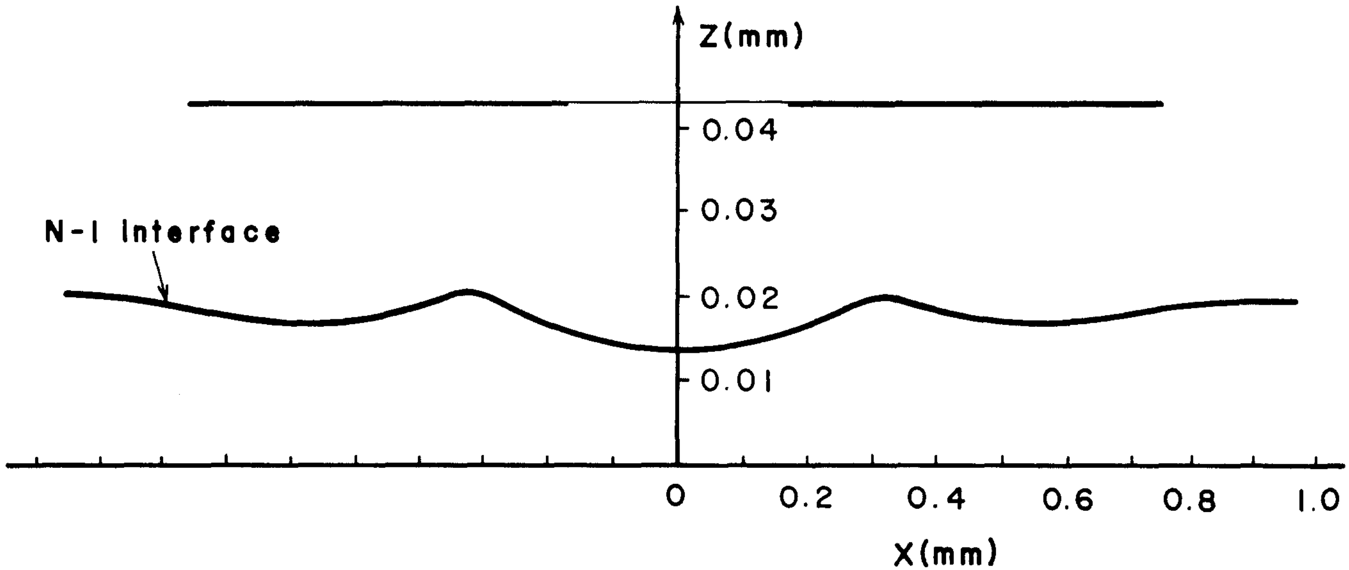

FIGURE 7 Quasi-equilibrium interface profile in a nonuniform electric field, as estimated from Figure 6(b), based on the fact that the dark band-to-dark band spacing corresponds approximately to 5 μm change in the nematic layer thickness. The center of the field-free region is located at $x = 0$. Note that the deformation is greatly exaggerated.

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