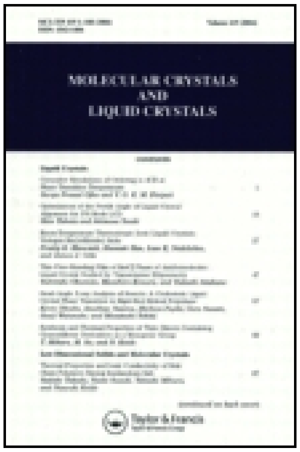

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Temperature Dependence of Nematic Anchoring Energy on Weak Surfaces of Polyimide Langmuir-Blodgett Films

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TEMPERATURE DEPENDENCE OF NEMATIC ANCHORING ENERGY ON WEAK SURFACES OF POLYIMIDE LANGMUIR-BLODGETT FILMS

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Abstract A theory for a twisted chiral nematic liquid crystal (TN) cell with weak anchoring boundaries has been developed. The anchoring energy at 4-pentyl-4′-cyano biphenyl/polyimide Langmuir-Blodgett alignment layer interfaces has been determined by measuring the saturation field of the TN cell. It is found that the anchoring energy is of the order of $10^{-6}\mathrm{J/m^2}$ and decreases with increasing temperature toward the nematic-isotropic point.

INTRODUCTION

In recent years, surface properties of nematic liquid crystals (NLCs) have become a matter of much theoretical and experimental attention.[1] In order to consider the electrooptical effect for a NLC placed between two solid walls, we must solve a problem with boundary conditions taking into account the contribution from the surface energy. The surface energy depends on orientation of the director $\underline{n}$ on both solid boundaries.[2] For a twisted NLC cell, the Rapini-Papoular (R-P) anisotropic energy density[3] for the director orientation must be extended to a more general form like Equation (1)

$$g_s = -\frac{A}{2}(\underline{n} \cdot \underline{e})^2 \tag{1}$$

where $\underline{e}$ is the "easy" direction as denoted by de Gennes,[4] and A is the anchoring energy which reflects the ability of the director to deviate from the easy direction. The unified R-P energy form given by Equation (1) has been written as a linear

*Author to whom correspondence should be addressed combination of a polar angle anchoring energy term $g_s(\theta)$ and an azimuthal angle anchoring energy term $g_s(\phi)$,[5-9] and in this way the anchoring energy A has been measured.[10-13] Although such a separation simplifies the mathematical analysis, this linear combination is not invariant with respect to rotation of the axis system. Therefore, g_s cannot be expressed as a sum of independent terms $g_s(\theta)$ and $g_s(\phi)$ and should be expressed by the two-dimensional function $g_s(\theta,\phi)$.[14] The expressions for the threshold and saturation fields have been derived from Equation (1).[15]

In this paper, a new method for determining the anchoring energy by measuring the saturation field of the TN cell with weak anchoring boundaries is proposed, and the temperature dependence of the anchoring energy for the TN cell with polyimide Langmuir-Blodgett layers is determined. It is found that the weak anchoring boundaries can be obtained by using ultra thin polyimide Langmuir-Blodgett layers.

THEORY

Let us consider a nematic layer of thickness ℓ located between the planes $X_3 = 0$ and $X_3 = \ell$ in a Cartesian coordinate system (X_1, X_2, X_3). The principal dielectric constants parallel and perpendicular to the director are denoted by $\epsilon_\parallel$ and $\epsilon_\perp$ with $\Delta\epsilon = \epsilon_\parallel - \epsilon_\perp > 0$ and the elastic constants for splay, twist and bend by K_{11}, K_{22}, K_{33}, respectively. In Reference 15, to obtain the saturation voltage (U_s), above which the director becomes completely homeotropic, the dimensionless coupling parameter was introduced as

$$\lambda = \frac{\pi K_{22}}{A\ell} \tag{2}$$

and a reduced voltage $u'' = U_s/U_0$ was also introduced, where

$$U_0 = \pi\sqrt{K_{11}/\Delta\epsilon\epsilon_0} \tag{3}$$

is the Fréedericksz threshold voltage of a homogeneous nematic layer for rigid boundary coupling (λ=0). Based on the unified R-P energy form given by Equation (1), U_s has been derived [see Equation (56) in Reference 15] as

$$\lambda\left(\frac{K_{33}}{K_{11}}\right) = \frac{\tanh(\pi Y/2)}{Y}\left[1 + \frac{\cos^2(T)}{\sinh^2(\pi Y/2)}\right] \tag{4}$$

$$Y = \sqrt{u''^2\left(\frac{K_{11}}{K_{33}}\right) - \left(\frac{2\ell K_{22}}{p_0 K_{33}}\right)^2} \tag{5}$$

$$T = \frac{\phi_t}{2} - \frac{\pi\ell K_{22}}{p_0 K_{33}} \tag{6}$$

where p_0 denotes the pitch of the material induced by a chiral dopant, ϕ_t is the twist angle. It is obvious that the anchoring energy A is determined from Equations (4), (5) and (6) by measuring U_s.

EXPERIMENTAL SETUP

The NLC used in this experiment was 4-pentyl-4'-cyano-biphenyl (5CB), which has a positive dielectric anisotropy. To produce a uniform polyimide (PI) surface on a transparent glass electrode, the Langmuir-Blodgett (LB) technique was used.[16] The thickness of PI layers was controlled by the number of the PI-LB layer. The thickness of PI-LB films was 8.4 nm. TN cells were prepared with the thickness of the NLC slab of 22.0 μm.

The experimental setup for the measurement of transmittance is illustrated in Figure 1. A dc voltage was applied to the cell in the temperature range 27.0°C to 34.5°C below the clearing point of 5CB (35.3°C). The intensity of transmitted light was measured by a photodetector.

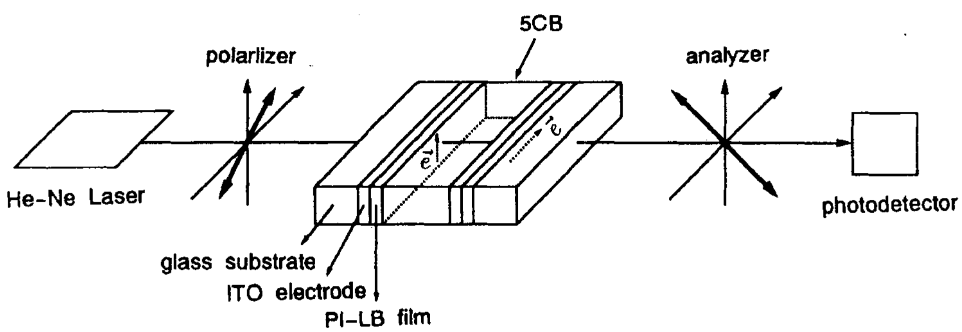

FIGURE 1 Experimental setup for transmittance measurement.

RESULTS AND DISCUSSION

Figure 2 shows the voltage dependence of the transmittance at different temperatures. Above the Fréedericksz transition voltage, the transmittance decreases with increasing applied voltage and the transmittance becomes zero at the saturation voltage.

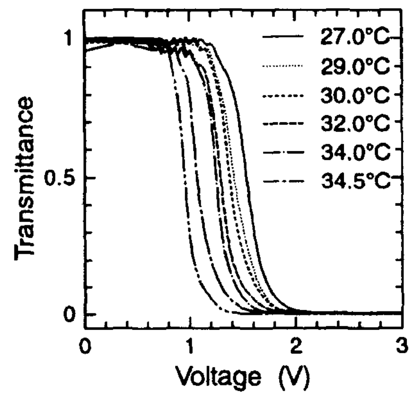

FIGURE 2 Voltage dependence of the transmittance of the 5CB/PI-LB TN cell.

Thus, the saturation voltages at different temperatures can be determined from Figure 2. The saturation voltage was also confirmed by the measurement of the optical retardation of the cell and is shown in Figure 3. As expected from Equations (4), (5) and (6), the saturation voltage decreases with decreasing anchoring energy. Figure 3 may show evidence that ultra thin PI-LB layers have weak anchoring boundaries.

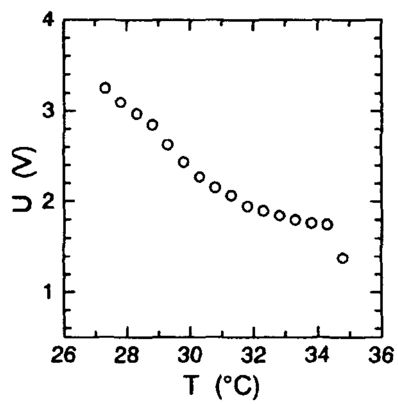

FIGURE 3 Temperature dependence of saturation voltage for the 5CB/PI-LB TN cell.

From Equations (4), (5) and (6) with $\phi_t = \pi/2$ and $p_0 \rightarrow \infty$ the following equation is obtained.

$$A = \frac{U_s K_{22}\sqrt{\Delta\epsilon\epsilon_0}}{\ell K_{11} \coth\left(U_s\sqrt{\Delta\epsilon\epsilon_0/K_{33}}\right)} \tag{7}$$

Using the value of ℓ, measured U_s, K_{11}, K_{22}, K_{33} and $\Delta\epsilon$ in literature [17,18] the anchoring energy is obtained from Equation (7). The temperature dependence of the anchoring energy of the TN cell is shown in Figure 4.

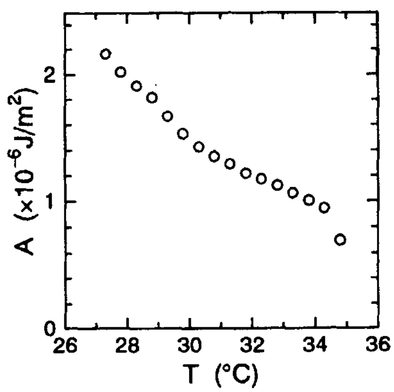

FIGURE 4 Temperature dependence of anchoring energy A for the 5CB/PI-LB TN cell.

The anchoring energy decreases with increasing temperature toward the nematic-isotropic point. Such temperature dependence is in qualitative agreement with that of the anchoring energy in strong anchoring energy boundaries.

From our measurements of the unified anchoring energy mentioned above, we should stress two findings. First, the anchoring energy is of the order of 10^{-6}J/m^2, which is much smaller than that of strong anchoring boundaries.[12] Second, PI-LB layers are therefore useful as alignment layers for weak anchoring.

CONCLUSIONS

In order to study the anchoring energy on weak anchoring energy boundaries, we have proposed a new method for calculating the anchoring energy by measuring the saturation voltage. The anchoring energy at a 5CB/PI-LB alignment layer interface has been determined for a TN cell. The measured anchoring energy is 1.9×10^{-6}J/m^2 at 28.0 °C, and the anchoring energy decreases with increasing temperature toward the nematic-isotropic point. In addition, it is shown that PI-LB are useful as weak anchoring boundaries for 5CB.

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