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Optical and electrooptical properties of homeoplanar layers of cholesteric liquid crystals

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Optical and electrooptical properties of homeoplanar layers of cholesteric liquid crystals

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A wedge shaped layer of a cholesteric liquid crystal, with the director surface orientations first planar and the other homeotropic, shows two distinctive textures depending on the relation between the local thickness, d, and the equilibrium pitch, P_0. If $d/P_0 < 1$, the texture does not show any domains; the director distribution is reminiscent of a corkscrew. If $d/P_0 > 1$, there are linear periodic domains. The domain direction rotates as the thickness of the layer increases. The voltage dependence of light transmission of the homeoplanar cholesteric layer placed between crossed polarizers is less pronounced and more linear than the corresponding dependence for the twisted nematic effect.

A flat TV-screen based on a liquid crystal layer combined with an active matrix of thin film transistors or diodes requires a material with a weak, linear dependence of the optical response on the electric field. This material may also be used for optical attenuators and for liquid crystal photosensor structures. Recently, homeoplanar layers of cholesteric liquid crystals have been reported [1] to offer such a possibility. This work presents a detailed investigation of these layers. We have discovered some new properties of such structures and we have compared the electrooptical effects in them with those in twisted nematic layers.

The main structure parameter for cholesteric phases is the equilibrium pitch of the helix. The distribution of the director (the preferred direction of the long molecular axes) in a liquid crystal layer depends on the relation between the layer thickness, d, the equilibrium pitch, P_0, and the director surface alignment. If the director on both boundaries is parallel to the substrate, the well-known Grandjean texture results. When an electric field above a certain threshold is applied along the helical axis, electrohydrodynamic [2] or electric field induced [3] instabilities occur in each Grandjean zone. It has been shown, theoretically and experimentally [3], that in zones having a low number instabilities arise as stripe domains while in high number zones as two dimensional domains. The possibility of a stripe domain appearance must be taken into account in super twist nematic effects [4], which have a very steep dependence of the optical response to the electric field. If the director at both boundaries is perpendicular to the substrates, confocal textures result. The optical and electrooptical properties of the confocal textures have been investigated as a function of the layer thickness and the equilibrium pitch [5].

To fabricate the homeoplanar layer we have used the following boundary conditions: at the first boundary the director is parallel to the substrate (homogeneous orientation), while at the other it is perpendicular (homeotropic orientation). To fabricate homogeneous director surface alignment we have used the conventional method of unidirectional rubbing of a thin polymer (polyvinyl alcohol) coated glass surface. This method resulted in a low tilt bias angle ($<2°$) and a high surface anchoring energy. Homeotropic director surface alignment is achieved by coating the glass surface with a surfactant. The tilt bias angle on the homeotropic surface was more than 80°. If an appropriate combination of rubbed polymer substrate and surfactant was used [6], the tilt bias angle on this surface was less than 80° and instead of a homeoplanar texture the Grandjean texture resulted.

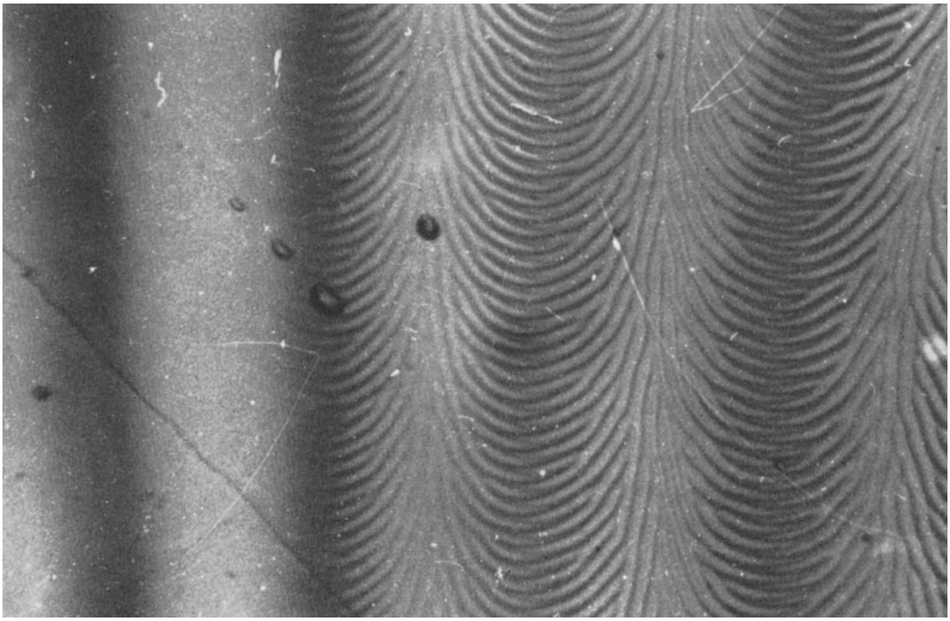

Figure 1. Textures of a homeoplanar wedge-shaped liquid crystal layer (crossed polarizers). The local layer thickness varies from 3 μm (left) to 35 μm (right). The equilibrium pitch, P_0, is 20 μm.

Two distinctive textures of the homeoplanar layer were observed depending on the relation between the local thickness, d, of the layer and the equilibrium pitch, P_0, of the cholesteric helix (see figure 1).

(*a*) $d/P_0 < 1$. The texture does not show any domains. The projection of the director on the normal to the layer varies from 0 to 1. The twist angle goes from 0° to (d/P_0) 360°. Such director distribution is reminiscent of a corkscrew. It is worth emphasizing, that the helix pitch, P_0, of this structure assumes the equilibrium value only and does not depend on the local thickness of the layer, unlike the Grandjean texture. The homeoplanar layer has the following optical properties. If $\Delta n P_0 \gg \lambda$ (where $\Delta n = n_{\|} - n_{\perp}$ is the birefringence and λ is the wavelength of the light) the waveguide propagation of the light takes place analogously to the Mauguin limit in the twisted structure. The polarization rotates up to the angle which is proportional to the thickness of the liquid crystal layer. Therefore, a series of dark equidistant strips (see figure 1) between crossed polarizers corresponds to the local thicknesses with the angle of the polarization rotation equal to k 180°, where k is an integer.

Although we realize that the actual optical properties are significantly more complex, we have made these explanations very simple with the purpose to understand them better. Their complete explanation requires cumbersome computation of the director distribution in a homeoplanar layer. We hope to publish the accurate results of such calculations separately.

(*b*) $d/P_0 > 1$ (see figure 1). There are linear periodic domains with the period $L \approx (4\text{–}5)P_0$. The structure of the domains is defined by the periodic bend of the cholesteric axis near the homeotropic surface. The direction of the domains rotates smoothly when the thickness of the layer increases and changes to the opposite one when the difference between the thicknesses of the layer equals $P_0/2$. The direction of the rotation of the domain coincides with the helix sense. These observations give a new method for the determination of the helix sense and its pitch.

The peculiarity of the wedge shaped homeoplanar layer of the cholesteric phase is the absence of the Grandjean zones. As a consequence, the cholesteric pitch keeps its equilibrium value at any thickness of the layer. Therefore a homeoplanar layer with a small cholesteric pitch has the homogeneous colour of the selected reflection from

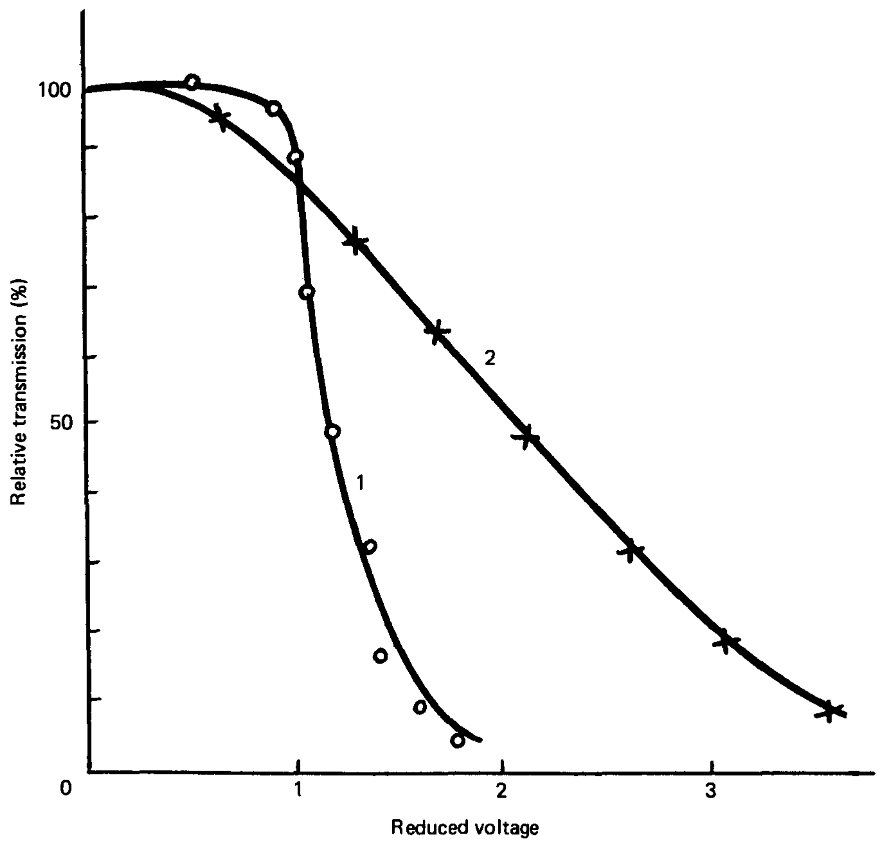

Figure 2. Comparison of transmittance-voltage curves for a conventional 90° twisted nematic display (1) and an electrooptic effect in the homeoplanar cholesteric layer (a corkscrew-effect) (2).

the surface, contrary to the colour of the Grandjean texture which changes within each zone. As a result the homogeneous colour of homeoplanar layers of cholesteric may be used for selected mirrors [7]. Another peculiarity of a homeoplanar layer of a cholesteric phase with a positive dielectric anisotropy is a weak, linear voltage dependence of light transmission when such a layer is placed between crossed or parallel polarizers. This dependence is weaker than the corresponding dependence of the twisted nematic effect. A comparison of these two electrooptic effects is shown in figure 2.

Finally, we have observed unusual properties of homeoplanar cholestic layers. We have shown that the electrooptic effect in them may be used for a flat TV-screen based on liquid crystals and an active matrix of thin film transistors.

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