Surface Anchoring and Chevron Structure in Ferroelectric Liquid Crystals

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Abstract

Applying a sufficiently high electric field to a ferroelectric smectic-C liquid crystal deforms the so-called chevron structure into one in which the layers are flat. This transition happens in three different ways depending on the type of liquid crystal phase. In all three cases, the flattening has been believed to begin from the middle of the smectic layers. We show that a previously proposed model can predict the possibility of forming a new type of partially flattened layer in which the flattening begins at the edges of the layer. This interesting behavior takes place when the surface anchoring is strong.

Keywords: ferroelectric; liquid crystal; anchoring; chevron

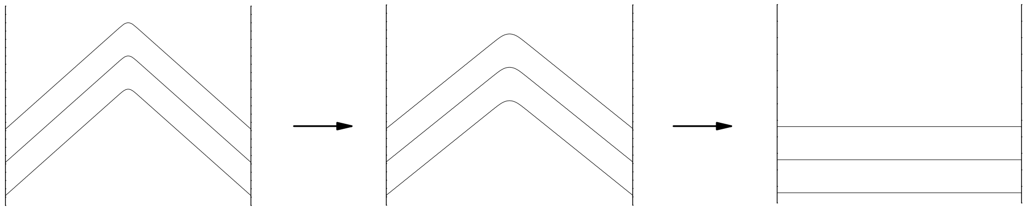
INTRODUCTION

"Chevronning" is a phenomenon that occurs when a ferroelectric liquid crystal in a device with planar anchoring is cooled from a smectic-A phase to a smectic-C phase. It describes a transition from the so-called bookshelf geometry (a geometry in which the smectic layers lie in planes containing the substrate normal) to a state in which each layer is in a V-shaped structure [1]. The mechanism responsible for this phenomenon arises from the presence of constraints on the motion of the liquid crystal molecules in contact with the substrates. These are to some extent pinned to the positions they occupied in the SmA phase. As a consequence, unless defects are formed in the layer structure, the number of layers remains the same, and if the volume of liquid crystal within the device is also constant, the volume of each layer must remain unchanged.

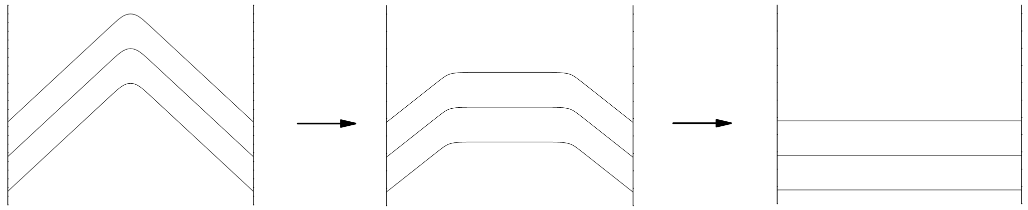
Applying an electric field to a ferroelectric liquid crystal restores the bookshelf geometry [2–5], but the way in which this happens depends on the type of phase and material involved. In some materials [4, 6], application of an electric field to the SmC^* phase causes a gradual growth of the bookshelf component within a layer at the expense of the chevron structure. This proceeds until finally a fully bookshelf geometry is reached. On the other hand, the transformation to a bookshelf structure in the antiferroelectric phase occurs at a well-defined field with a sharp transition. In these same materials, layer structure associated with the intermediate phases (also known as ferrielectric or SmC^*_{FI1} and SmC^*_{FI2}) also deforms at fields greater than a distinct threshold, though in this case the chevron curves just above the transition, before a completely bookshelf geometry is reached. We refer to these three behaviors as 'flatten', 'snap', and 'bend' respectively.

The usual interpretation of the experimental data leads us to the layer shapes shown in Fig. 1. This, however, is not the only possible interpretation of the experimental results. In the case of 'bend' deformation, for example, it is known from the experiments that in each layer there is a large bookshelf component ($\delta = 0$), for intermediate electric fields, but the exact position of the flattened area cannot be determined experimentally. In other words, the flat region could begin to grow from the middle of the sample or from the boundaries or both. The interesting case of three flat areas, one in the middle and the others at the boundaries, is shown in Fig. 2. The question now is to ask what are the physical conditions under which this kind of flattening happens? Our investigation shows that the answer lies in the strength of the surface anchoring of the liquid crystal molecules to the substrate.

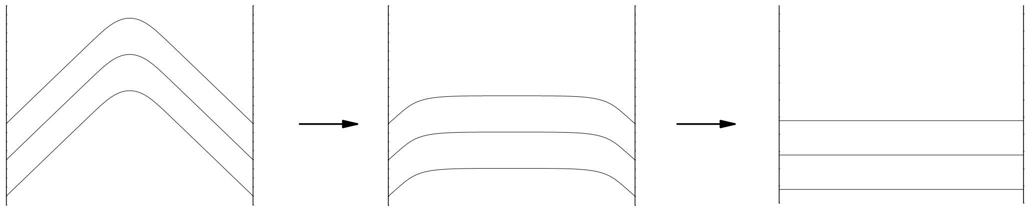
To provide a theoretical explanation for the three different classes of deformation behavior, we turn to a previously proposed model [7]. The results of that study suggested that a parameter related to the layer compression modulus was the crucial factor in determining the way in which the bookshelf-chevron transition occurs. In this Letter we use the same model to show that the interesting flattening behavior shown in Fig. 2 occurs when the anchoring strength is large.



(a) Snap



(b) Flatten



(c) Bend

FIG. 1: *The figure shows 'flatten', 'snap', and 'bend' transitions according to one possible interpretation of the experimental data.*

MINIMIZING THE FREE ENERGY

We study a cell of thickness L containing a ferroelectric liquid crystal by introducing a free energy [7] that can be expressed in terms of three angles : the angle δ between substrate and layer normal, the angle θ between layer normal and director $\mathbf{n}$, and the azimuthal angle ϕ, as illustrated in Fig. 3. The layers are assumed to deform in only one direction, which is chosen to be the z direction. We choose the x axis to be perpendicular to the boundary

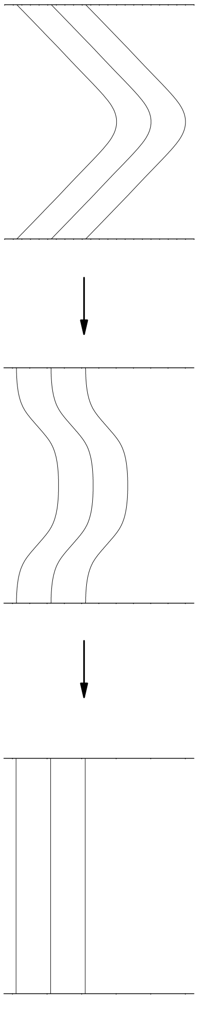


FIG. 2: *Proposed alternative pattern of layer deformation.*

plates, which are located at $x = \pm L/2$. The layer displacement and the three angles are assumed to be functions only of x.

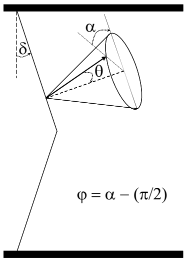


FIG. 3: *The three angles that specify the orientation of the director.*

The contributions to the free energy and the numerical values of the relevant parameters have been discussed previously [7]. We choose the same values for the parameters except for the anchoring strength, which is chosen to range from our previous choice, $w_0 = 0.005$, to $w = 1000w_0 = 5$. The dimensionless free energy per unit length can be written in terms of the appropriate dimensionless units as

$$
\begin{aligned}
f &= \gamma\left(\int_{-1/2}^{1/2}\left[1-\exp[-c(\cos\delta-\cos\theta)^2]\right]dX\right)^2 \\
&+ \int_{-1/2}^{1/2}\Big[-\exp[-c(\cos\theta-0.95)^2] \\
&+ (1/320)\Big(\delta'^2(2-\sin^2\theta\cos^2\phi)+\phi'^2\sin^2\theta+\theta'^2 \\
&- 2\phi'\delta'\sin\theta\cos\theta\cos\phi\ -2\delta'\theta'\sin\phi\Big) \\
&- (E/E_0)^2\cos\delta\cos\phi\Big]\,dX \\
&- w(\sin\delta\sin\theta\sin\phi+\cos\theta\cos\delta)^2_{X=1/2}
\end{aligned}
$$

with $X = x/L$, $\delta' = d\delta/dX$, $\theta' = d\theta/dX$, and $\phi' = d\phi/dX$. Here E/E_0 is the scaled electric field, c is a constant chosen to be 2000, and w, as mentioned before, is the anchoring strength. The parameter γ, which is proportional to the layer compression modulus, is the most important factor in determining the flattening behavior, and measures the relative strength of the two competing effects, expressed in the first and second terms in the free energy. The first term favors a value of δ equal to θ, while the second tends to keep θ equal to the preferred tilt angle θ_0 in the smectic-C^* material. In our calculations $\cos\theta_0$ is chosen to be 0.95.

Calculations were performed for different values of γ, E/E_0, and w. The 'snap', 'flatten', and 'bend' types of transition are shown in Fig. 4 for the case of strong anchoring. In the case of weak anchoring, flattening begins from the middle of the sample, whereas strong anchoring forces the layers to flatten also at the ends. As can be seen from the free energy expression, the anchoring energy is minimized if, at the boundaries, we have either $\phi = \pi/2$ and $\theta = \delta$, or $\phi = \theta = \delta = 0$. Since the azimuthal angle ϕ is equal to zero throughout the cell at high electric fields, the anchoring term favors δ and θ to vanish at the boundaries of the sample. This, however, greatly increases the elastic energy, and so δ and θ do not vanish at the boundaries unless the anchoring is very strong.

Strong anchoring also affects the transition point in the case of intermediate γ. As illustrated in Fig. 4(b), the transition field ($E/E_0 = 4.8$) is smaller when $w = 5$ than it is in the case of weak anchoring. Large w, however, does not significantly change the electric field at which the deformation takes place when γ is very large or very small compared to unity. This can be explained by the fact that when $\gamma = 1$, the two previously mentioned competing effects are comparable, and so a third factor (surface anchoring) can affect the transition field.

CONCLUSIONS

A new possible route has been proposed by which the chevron layer structure of a ferroelectric liquid crystal may transform into a bookshelf geometry. Because the current x-ray methods used to analyze experimentally the shape of a smectic layer cannot distinguish between the newly proposed structure and the form traditionally assumed, it will require some new techniques to determine whether the new structure is realized in existing devices.

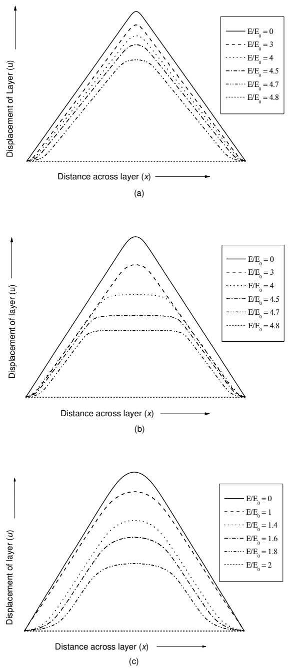


FIG. 4: *The way in which the chevron shape transforms under the influence of an electric field is shown for (a)* $\gamma = 10$*, (b)* $\gamma = 1$*, and (c)* $\gamma = 0.1$*. In all cases* $w = 5$*. The arbitrary scale for the dimensionless layer displacement* u *has been exaggerated relative to the scale for the distance* x *across the layer in order to show more clearly the difference between the 'snap', 'flatten', and 'bend' types of transition.*

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