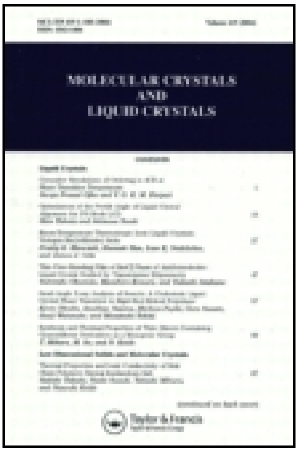

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S. J. Elston [a] & J. R. Sambles [a]

[a] Thin Film and Interface Group, Department of Physics, University of Exeter, Stocker Road, Exeter, EX4 4QL, England

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Examination of Near Surface Alignment in Tilted Smectic Liquid Crystal Filled Cells

S. J. ELSTON AND J. R. SAMBLES

Thin Film and Interface Group, Department of Physics, University of Exeter, Stocker Road, Exeter, EX4 4QL England

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The structure of the near surface director profile in a tilted smectic liquid crystal cell is of interest to the understanding of surface alignment. Here this is investigated for low and high surface tilt SiO alignments using the technique of evanescent field polarization conversion. Comparison between the observed conversion and that predicted theoretically allows the near surface structure to be probed. For low surface tilt a boundary layer is found over which reorientation to the surface alignment direction takes place. For high tilt alignment the liquid crystal surface has large twist angles, with only a very thin layer of reorganization to the surface alignment direction still present.

INTRODUCTION

The precise nature of the alignment in cells filled with tilted smectic liquid crystal materials has been a problem under investigation since Clark and Lagerwall[1] produced the first working bi-stable ferroelectric liquid crystal (FLC) device in 1980. Since then there has been substantial development of the model for the structure present within a cell. The originally proposed 'bookshelf' structure with the smectic layers perpendicular to the cell surfaces,[1] first evolved to the 'bookshelf' model plus surface pre-tilt,[2] proposed in order to explain the less than cone angle extinction states seen in a real cell. A further proposal was then made that the smectic layering could bend, producing a structure with curved layers and uniform rotation of the director around the smectic cone.[3] Many of these and other proposals were however eliminated when in 1987 Rieker discovered, using X-ray techniques, that the structure present in a cell was a 'chevron' structure, with tilted layers and a kink in the middle of the cell.[4] (A similar structure had previously been observed in 1979 by Pelzl,[5] but its significance was not then realized.) This chevron structure arises from the shrinkage of the smectic layer thickness when the tilted smectic *C* phase forms out of the untilted smectic *A* phase. Such a structure has serious implications for the director profile in a cell — for example the possibility of the existence of half-splayed states.[6,7] In its simplest form for a uniaxial model of the system, the chevron structure leads to a uniform optic tensor structure in the cell, as seen using optic mode excitation,[8] and illustrated in Figure 1. However this simple structure is inconsistent with observations of a conventional cell, for which complete ex-

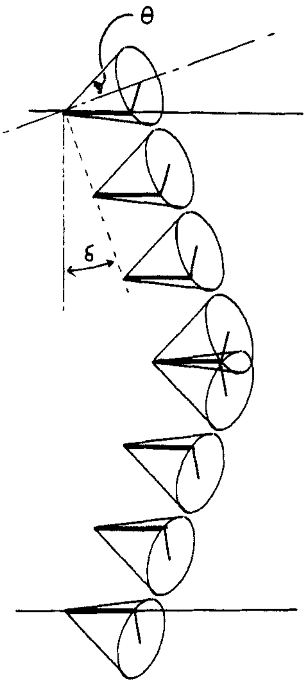

FIGURE 1 Schematic illustration of the structure present in a 'chevron' cell. In this the smectic layers are tilted from the cell surface normal by an angle δ which is less than the smectic cone angle θ. This leads to a uniform structure with a surface twist angle equal to the bulk twist angle, and should give perfect extinction states between crossed polaroids.

tinction states are not seen between crossed polarizers. This indicates some non-uniformity in the optic tensor profile, since a uniform profile would show extinction when the optic axis is aligned with the polarizer or analyser. It has been shown that for a cell with low tilt alignment on SiO and filled with the BDH material SCE3 that this anomaly is explained by the existence of a thin boundary layer (of order 0.1 μm thickness) at the cell surfaces over which the structure reorientates from the bulk alignment to align in the original nematic surface alignment direction.[9] This type of thin layer has been observed by Lavers using leaky guided mode methods.[10] However Anderson[11] has shown, using transmission spectroscopy, that with a non-chiral smectic *C* material the profile is very non-uniform, varying smoothly from the surface alignment direction to the twist angle in the centre of the cell (chevron cusp). Here we seek to prove the existence of the boundary layer in a SCE3 filled cell by direct observation using evanescent polarization conversion.

EXPERIMENTAL

The evanescent field polarization conversion technique has been used before by Xue to probe the alignment of a FLC near a clean surface, with no alignment layer.[12] In that work, Xue *et al.* showed that any un-switched region of the material, where the director was not at the bulk twist angle, was very thin indeed—the constraint placed being <2 nm thick. Here we probe the polarization conversion in the reflectivity from a cell with low surface tilt SiO alignment (evaporated at 60° incident angle) for incident radiation beyond critical angle, i.e. for total internal reflection. Light is incident as p-polarized (E-field vector parallel to the plane of incidence) and the reflected intensity of s-polarized (E-field perpendicular to the plane of incidence) is monitored. Variation of the angle of incidence of the light then allows the penetration of the evanescent field into the liquid crystal to be varied. Twist of the optic axis out of the surface alignment direction in the region of evanescent field penetration causes p-s mixing in the light and thus a signal may be observed. Care has to be taken when observation is made of such data in order to allow for any background polarization conversion present from scattering at the SiO alignment surface, and also possibly in the prism used to couple the light into the system. This is overcome by taking polarization conversion data for the S_A phase and subtracting this from data obtained for the S_C phase. For the material used here (BDH SCE3), the mixing observed in the S_A phase is $1.3 \times 10^{-3} \pm 0.3 \times 10^{-3}$.

Polarization conversion as a function of angle of incidence (with background subtracted off) is shown in Figure 2 (as crosses). This is for the region of evanescent field penetration, with the mixing rising up to the critical angle θ_c at ~ 56.75°. As the incident angle is increased above θ_c, the mixing drops due to a decrease in the depth of penetration of the field. It is the rate of this drop off which leads to information about any boundary layer present. If the bulk twist angle (in this cell ~ 11°) extends to the surface, then the drop off will be slower with decrease in field penetration depth (increase in incident angle) than if the twist angle decreases near the surface, which will cause less mixing with decreasing penetration of the field into the liquid crystal.

The boundary layer is initially modelled using a structure which twists uniformly from the surface alignment direction out to the bulk angle over a variable thickness of t_{bl}. Polarization mixing theory is plotted on Figure 2 (continuous line and dashed lines) for varying t_{bl}—showing the evanescent mixing obtained. It is clear from this model that a boundary layer of ~ 0.2 μm ± 0.03 μm is required to fit the data. This is very interesting and consistent with guided mode data which is rather insensitive to this layer,[8] and also with transmission spectroscopy which showed it to be ~ 0.2 μm thick.[9] Thus we see that for low surface tilt SiO alignment, with this particular material, a boundary layer region exists over which the bulk alignment reorientates to the surface alignment; this is the only explanation for the rate of drop off in the polarization conversion data.

HIGH SURFACE TILT

It is even more of a question as to the nature of the near surface alignment in a high surface tilt (HST) SiO aligned cell (where the SiO is evaporated at ~ 85° to the surface normal, leading to a surface tilt of ~ 25°–30°). It had been thought that if the bookshelf type layers could be retained then it would form a simple

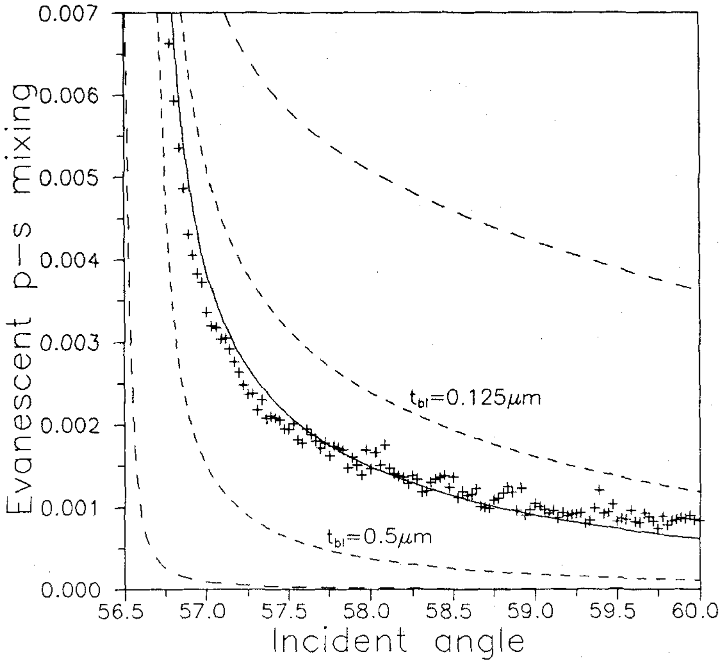

FIGURE 2 Evanescent polarization conversion observed in reflected light beyond critical angle, from a SCE3 cell aligned with low surface tilt SiO. The data are the crosses (with background removed) and the correct theory (with boundary layer thickness of 0.2 μm) is the continuous line. Also shown are theory curves for other boundary layer thicknesses (dashed lines) showing the sensitivity of the technique. The top curve has no boundary layer, with the bulk twist angle extending to the surface, while the bottom curve uses the uniformly varying profile from the surface alignment direction to the centre of the cell.[11]

structure as shown in Figure 3a. However observation by X-ray scattering has shown that the chevron structure also exists in parallel HST cells[13]; this leads to the conclusion that the structure present should be similar to that shown in Figure 3b. In this it is seen that the surface pre-twist is quite large, being nearly equal to the cone angle. Anderson[14] has shown using transmission spectroscopy techniques that the surface twist angle is greater than the twist angle in the centre of the cell, which is consistent with this model. It is clear that if this state is indeed correct then large evanescent polarization conversion should be observed due to the large optic axis twist angle near the surface. Evanescent conversion reflectivity data are shown in Figure 4 for a HST cell filled with the BDH material SCE12. This rises to a peak of ~ 66% below the critical angle, at the excitation of the first propagating guided mode in the cell. (Clearly the small background mixing ceases to be a problem with such high levels of mixing present.)

It is immediately clear that with such mixing levels there must be a large twist angle near the cell surfaces. Modelling the structure in the cell by retention of a chevron type structure in the layers as shown in Figure 3b leads to this high level of mixing, and the fit is shown by the dashed line in Figure 4. This however shows a little too much mixing at high angles, indicating the presence of a thin layer very near the cell surfaces where the twist angle is less. Incorporation of this, now

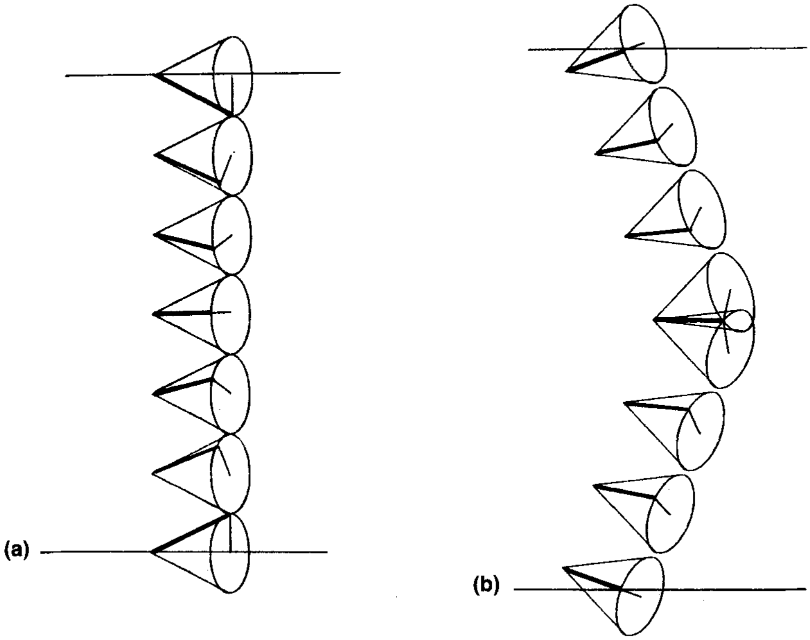

FIGURE 3 Models of the structure in a high surface tilt aligned cell. (*a*) Assuming that the smectic layers lie perpendicular to the cell surfaces, (*b*) assuming that the smectic layers form a chevron structure as shown by X-ray scattering.

modelled as a region of thickness $t_{bl} \sim 0.04$ μm over which the director returns to the nematic surface alignment direction, leads to the improved fit shown by the continuous line. This very small region was too thin to be noticed in the transmission work,[14] but is observed here. It indicates an apparent general condition that very near the surface materials realign to the surface alignment direction. Although it should be realised that for such a thin boundary layer it is very difficult to tell its exact nature, a slightly thicker region which returned to a twist angle of a few degrees (but still much less than that expected without a boundary layer) would also allow a good fit to the data. The apparent surface alignment condition is not surprising, since on a local level the difference between nematic and smectic materials is subtle.

SUMMARY

It has been seen that for low surface tilt SiO alignment of SCE3 a boundary region exists where the bulk alignment direction (observed extinction angle) reorientates to the surface alignment direction. For this material this is found to be 0.2 ± 0.03 μm thick. It should be noted that transmission work indicated the same result.[9] This may vary from material to material depending on the balance of the complicated elastic properties of tilted smectics and the surface alignment condition used,[9,10,11] and a complete study should be done to investigate this. We have also seen that

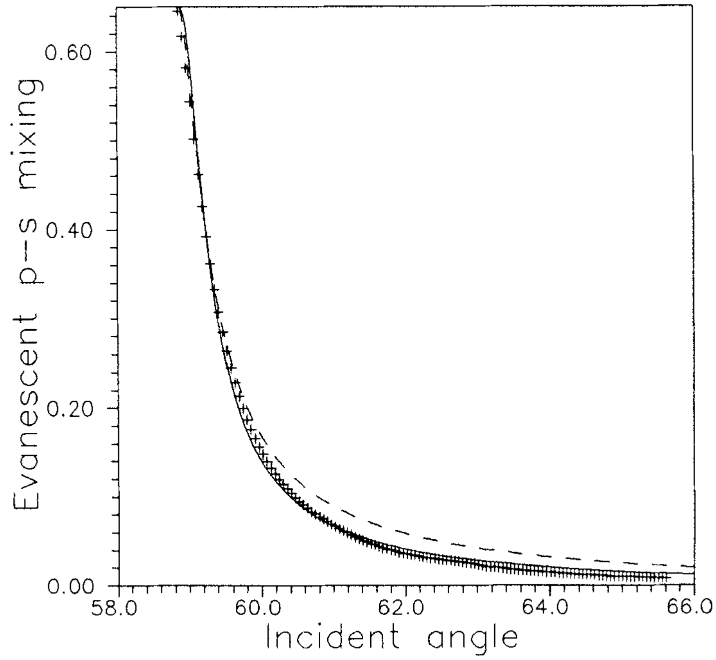

FIGURE 4 Evanescent conversion from a HST cell (filled with BDH SCE12). The data are the crosses, and the dashed line is a fit assuming the chevron structure is retained leading to a large near surface twist angle. The continuous line is an improved fit allowing for a very thin (~ 0.04 μm) boundary layer region of reorganization to the surface alignment direction.

for HST SiO surface alignment, although generally near the surface the twist angle is large, there also exists a very thin region over which the bulk alignment breaks down. This observation in both cases, that the alignment very near the surface is different from the bulk alignment, is not surprising if the nature of the material is considered. The smectic materials are only subtly different from the nematics on a molecular scale, and as this reorganization is taking place over distances of < ~ 100 molecular lengths, the formation may be quite nematic-like in the boundary layer region.

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