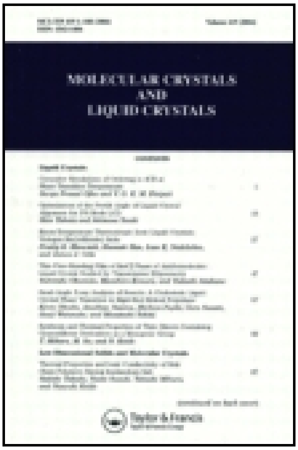

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The Cone Angle Between Relaxed States in SSFLC's—A Pure Surface Effect?

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It is found that the two ferroelectric liquid crystal mixtures ZLI-3774 and FELIX-004 give identical cone angles between the relaxed states in the SSFLC geometry on all tested surface alignment layers, but the cone angle will change with the nature of the surface. On two of the layers a number of fluids are tested, and within experimental errors all give the same cone angle irrespective of their smectic C tilt or composition.

Keywords: ferroelectric liquid crystals, surface stabilization, cone angles

I. INTRODUCTION

As originally described[1] the surface stabilized ferroelectric liquid crystal display (SSFLC) gives highest contrast when the angle between the directors in the on and off state is 45 degrees. To have this cone angle of 45 degrees a smectic C* tilt angle, of 22.5 degrees is necessary. Despite most commercial mixtures for SSFLC use being designed with a smectic tilt angle close to 22.5 degrees it is generally found that the cone angle between the two relaxed states is much lower than 45 degrees.

In a recent study[2] we found that within—a rather large—experimental error, the tilt angle between the relaxed states of two different ferroelectric mixtures were independent on the tilt of the fluids themselves, and did only depend on the surface used. This could have far reaching consequences for manufacturers of ferroelectric liquid crystal mixtures, as well as for the development of commercial ferroelectric liquid crystal displays. The aim of this study is thus to reduce the experimental error and to check whether our previous finding is generally true.

II. EXPERIMENTAL

Our cell preparation has been described elsewhere.[3] For this study a newly developed series of alkyl-aromatic polyimides for the alignment of surface stabilized ferroelectric liquid crystal displays[4] were used. The six polyimides are condensation products of pyromellitic anhydride and diaminoetane (P2), diaminopropane (P3), diaminobutane (P4), diaminopentane (P5) and diaminohexane (P6); and 1,4,5,8-naphthalene tetracarboxylic anhydride and diaminohexane (N10). The polyimides were printed onto the glass/ITO surface by a Nissha Angstromer giving an approximately 600 Å thick, even layer, with very few defects. The polymers were rubbed with a low rubbing pressure to avoid scratches and other induced defects in the surface. If necessary the cells were annealed after assembly to increase the degree of crystallinity of the surface. All the cells used in this study are 1.7 +/− 0.1 micron thick.

All cells were inspected under a polarizing microscope before the electro-optical measurements to ensure that they were in the virgin texture; and to record the director difference between different domains. Even with 1.7 micron thin cells and fluids of low birefringence there usually were a shift between blue and white or between black and yellow when rotating the cell under the microscope. In some cells both shifts could be seen simultaneously. No defectlines could be seen between the blue and black or white and yellow areas, respectively.

The cells were also inspected again under the microscope after the electro-optical measurements to make sure that the virgin texture had not been disrupted by the electrical pulses. At this time the cells that showed bistability usually were uniformly in one state and no director difference could thus be recorded.

For the measurement of the cone angle the cell was placed between a pair of crossed polarizers and switched to one of the two relaxed states. After short circuiting the cell it was rotated between the polarizers and the transmission versus the orientation of the cell was recorded. The axis of rotation coincided with the center of the light ray. The cell was then switched to the other relaxed state without removing it from the rotating stage and the procedure was repeated. To check whether the cell was truly bistable the rotating stage was set to its initial setting after each of the two series of measurements. If one of these readings differed from the originals the cell was not regarded as bistable. The phase difference between the two sine curves is the cone angle between the two relaxed states. In nearly all the cases the experimental points were within one degree from the ideal sine curve. However with cells that should be nominally equal, made from the same coated glass plates, or even measured over different areas of the same cell, there were much larger random variations. Heating the cell above the clearing point of the liquid crystals and cooling down again did not alter the cone angle when measuring over the same area. The cone angle measured depends on the degree of crystallinity of the sample.[5] The difficulty in reproducing cone angles is connected with the problem of having the same degree of crystallinity over large surfaces. Annealing the polymers did not alter the maximum cone angle found for a given polymer, but reduced the random variations between different cells. Other methods for coating the cells did usually lead to more defects in the alignment, and less reproducible values for the cone angle, but again the same maximum angle could be achieved.

The reported values are the highest that could be obtained. These were always found with at least two different cells for a given surface/fluid combination. For polymers P2, P4 and P6 these values agree with the one obtained by rotating the cell under a polarizing microscope and finding the angle between maximum extinction for different domains. For the others the values are different as will be discussed later.

III. RESULTS AND DISCUSSION

a. Comparison of two methods to determine the cone angle

Looking at SSFLC's under a polarizing microscope and measuring the angle between the director in different domains is often taken as a quick way of measuring the cone angle. We did this together with the more time consuming procedure of determining the phase shift between the two relaxed states. The relations between the two methods are shown for a large number of cells in Figure 1.

Along the x-axis is the cone angle between different domains found by turning the cell under a microscope to get minimum transmission. Along the y-axis is the

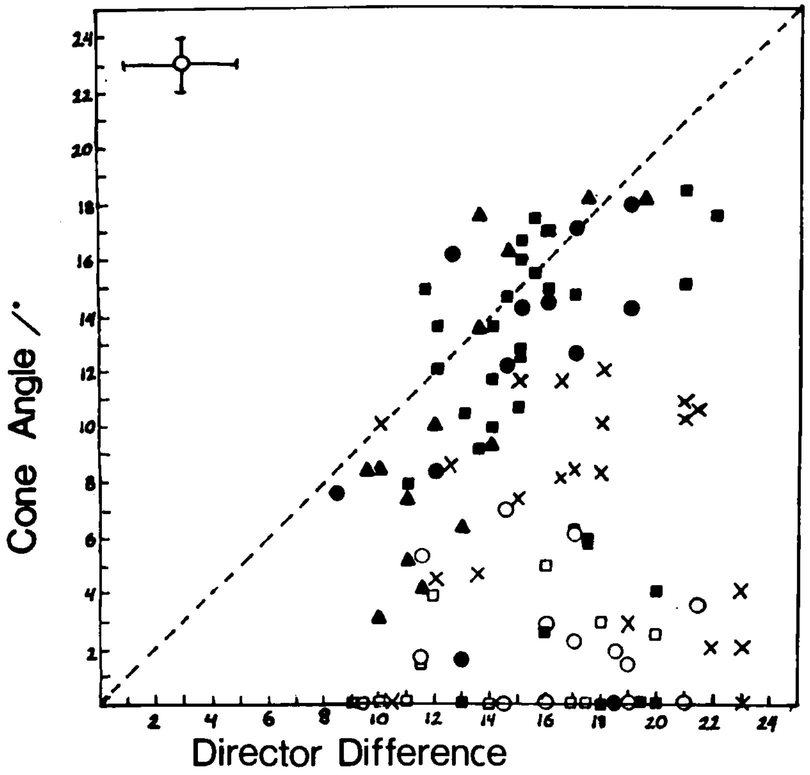

FIGURE 1 The abscissa gives the angle between the director of neighboring domains in the cell, while the ordinate gives the cone angle for the same area. The cross in the upper left corner gives typical errors. ● = P2, ○ = P3, ■ = P4, □ = P5, ▲ = P6, × = N10. For the three crystalline surfaces P2, P4 and P6 the values obtained with the two methods are similar. For the more amorphous polymers the cone angles are always less than the director change between neighboring domains.

cone angle for the same cell found by turning the cell between two crossed polarizers and finding the phase shift between the two resulting sine curves.

Six different polymers are used as alignment layers, and a number of different ferroelectric mixtures have been tested on each surface. The cell thicknesses are 1.7 +/−0.1 microns. All the cells are in the virgin texture.[6] Cells having 0 degree cone angles are not bistable even though they might have domains with different director orientations.

From this scatter plot a few conclusions can be drawn.

1. It seems that the value found between different domains under a microscope is the upper limit for the value found when rotating the cell between crossed polarizers.

2. The three surfaces called P2, P4 and P6 which are expected to be highly crystalline, give rather similar values for the two different experimental techniques. While the remaining three surfaces which are much less crystalline, or amorphous, give much smaller values for the cone angle than for the director difference between different domains. This odd-even effect is the subject of a forthcoming study.[7]

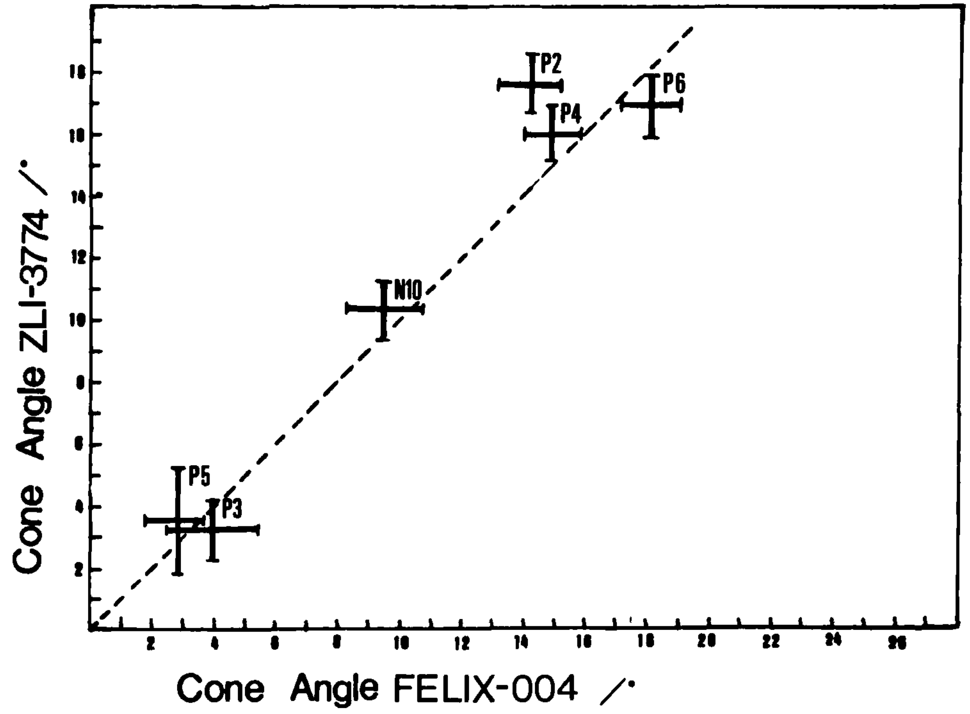

FIGURE 2 The cone angle found for ZLI-3774 plotted as a function of the cone angle found for FELIX-004. Despite a 30% difference in smectic C* tilt between the two mixtures the cone angles obtained by them are near identical for all surfaces. The codes identify the polyimides used in the different cells.

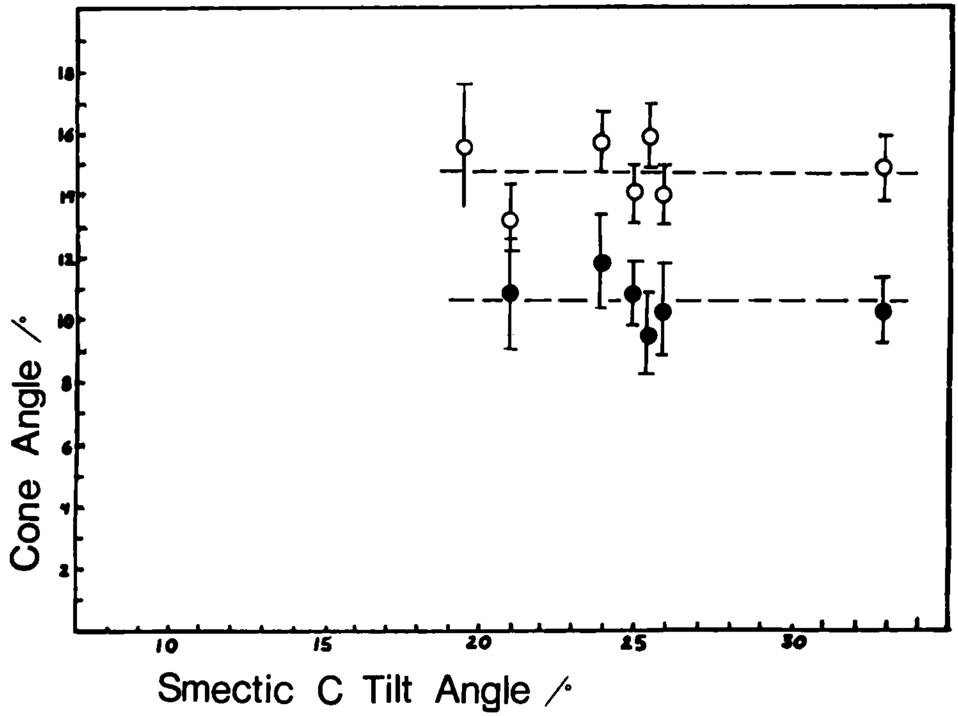

FIGURE 3 Cone angle found on surface no. P4 (open symbols) and N10 (filled symbols) as a function of smectic C* tilt of the mixtures tested.

3. If one has a good surface alignment layer microscopic observation should be a fast and reliable method for obtaining the maximum tilt for a given fluid.
4. To evaluate different surfaces the much more time consuming procedure of looking at the cell as a quarter wave plate between crossed polarizers is needed.

b. Comparison of different surfaces

Thus having found the proper technique to determine the influence of the surface on the cone angle in SSFLC's we compared the two ferroelectric room temperature mixtures FELIX-004 and ZLI-3774 in cells with six different alignment layers. The two fluids have a smectic C* layer tilt of 33 and 25.5 degrees respectively. As can be seen from Figure 2 the cone angles of the two fluids agree very well on all six surfaces, as has also been seen earlier on different nylons.[2]

c. Comparison of different ferroelectric mixtures

Surfaces P4 and N10 give examples of high and medium cone angles and these two were chosen for further inspection with additional fluids. In Figure 3 the tilt obtained for the different fluids are shown as a function of the smectic C* tilt of the mixtures. At the 95% confidence level there are no differences between the different fluids.

The polyimides used in this study have melting points around 300 centigrades. One would thus not expect the properties of these alignment layers to change much over the smectic C temperature range of the materials used in this study. If the cone angle obtained is solely a surface effect a small temperature dependence is expected for the cone angle. With the equipment we have it is only possible to run the measurements at ambient temperature, thus the temperature dependence of the cone angle has not been determined.

Recent data for the cone angle of ZLI-3775 does show a rather strong temperature dependence.[8] Both the cone angle and the layer tilt angle are changing proportionally to the smectic C tilt angle. Thus indicating that both of these properties are mostly fluid dependent. The cells used were however not truly bistable. There were one stable state and one quasistable state that relaxed to the stable one over a period of several minutes. Cells prepared with the polyimides we use in this study have on the other hand showed bistability without perceptible changes over several weeks.

CONCLUSIONS

It is found that the cone angle between the relaxed states of an SSFLC is strongly dependent on the surface polymer used, and that the properties of the ferroelectric fluid apparently only play a minor role.

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