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# Alignment of Surface Stabilized Ferroelectric Liquid Crystal Cell on Obliquely Evaporated Silicon Monoxide Film

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An alignment method for obtaining uniform surface stabilized ferroelectric liquid crystal (SSFLC) cell is presented. The uniform alignment is realized by ultrathin (< 80Å) silicon monoxide (SiO) film evaporated at 80° and the treatment of A. C. electric field. The alignment effects of ultrathin SiO film, thick SiO film(> 1000Å) both evaporated at 80°C and the SiO film evaporated at 60° on the FLC are described. The layer direction of FLC cell with ultrathin SiO film at 80° is perpendicular to that with thick film at the same deposition angle. The advantage of the ultrathin film is that the SSFLC cell aligned by it can be easily treated to perform perfect bistability, excellent contrast and fast switching speed. An possible orientation mechanism on surface of oblique evaporation film is discussed.

*Keywords:* Ferroelectric liquid crystals; surface stabilized ferroelectric liquid crystal (SSFLC); alignment; orientation mechanism

## 1. INTRODUCTION

Ferroelectric liquid crystal has been attracting a great deal of interest because of its fast switching speed, bistability etc. [1-2]. It can be used in displays, for optical information processing and fiber communication. The realization of these applications, however, first depends on the uniform alignment of FLC. Although much effort has been devoted to developing the alignment technique of FLC since the invention of SSFLC cell [3,4],

it is still difficult to get uniform alignment of FLC (which exhibits high contrast, perfect bistability, and fast response at the same time).

The first report of the use of the evaporation of SiO to align the liquid crystal (LC) molecules was made by J. L. Janning [5]. In common, the substrates are deposited at $60^\circ \pm 2^\circ$ or $80^\circ \sim 85^\circ$ with the substrate normales for the alignment of FLC. Substrates deposited at 60° angle with the normal yield low($\sim 0^\circ$) pretilt – a result similar to that of polyimide treated substrates [6]. Because of the low pretilt angle, zig-zag defects always appear in the SSFLC cell aligned by the SiO film evaporated at 60°. Though the A.C. electric field can be used to eliminate the defects, it shows at least two shortcomings: one is that the poly-domains always appear in the cell after the treatment, another is that the zig-zag defects can usually not be removed completely. Substrates deposited at $80^\circ \sim 85^\circ$ angle of incidence give high pretilt for the FLC molecules [4, 7]. At these deposition angles zig-zag defect free alignment and reasonable good bistability could be obtained, but the contrast is poor and the switching speed is comparatively slow [4, 7].

The alignment of FLC by the very thin SiO film at deposition angle of 80° was described by D. Doroski *et al.* [8]. Using this method, they got a perfect bistability for some FLC materials, but the contrast and the switching speed were not given.

We obtained the uniform alignment of SSFLC cell by the ultrathin SiO film evaporated at $80^\circ \pm 1^\circ$. After the A. C. field treatment it exhibits high contrast, perfect bistability and fast switching speed. We observed that the alignment effect of the ultrathin SiO film at 80° is different from that of the thick SiO film evaporated at the same angle. The layer direction of FLC cell with ultrathin SiO film at 80° is perpendicular to that with thick film at the same deposition angle. On the countrary, the molecular orientation of the cell aligned by ultrathin film at 80° corresponds to that of the cell aligned by the comparatively thick film at 60°. In an attempt to understand the alignment mechanism of the ultrathin SiO film at 80° the surface topographies of obliquely evaporated SiO films (SiO film at 60°, ultrathin and thick SiO film at 80°) were observed, the pretilt angles of LC aligned by the ultrathin SiO film at 80° and the film at 60° were measured.

In this paper, the alignment effects of FLC by the SiO films evaporated at 60° and 80° are compared. For the deposition angle of 80° the different alignment effects of the thick film and of the ultrathin film are described. In addition, an possible orientation mechanism on surface of oblique evaporation film is discussed.

## EXPERIMENT

### A Sample Preparation

The SiO film was evaporated at pressure in the range of $(8 \sim 9) \times 10^{-6}$ Torr. The ITO coated glass substrates were located approximately 25 cm from the SiO source. The depositions were initiated after the temperature of the SiO-contained boat reached a steady state. An aluminum shield in cylinder shape was placed around the substrates to screen against back-scattering. The thickness of the SiO film at $60^\circ \pm 2^\circ$ varied from 1000 Å to 2500 Å. At the deposition angle of $80^\circ$ the thickness of thick SiO film was in the range of 1000 Å ~ 5000 Å and that of ultrathin film was 60 ~ 80 Å. With 1.7 μm spacer, the cell was assembled with the evaporation direction of SiO of two substrates in antiparallel arrangement. Then the FLC material was introduced into the cell under capillary action in the isotropic phase. The FLC material is SCE13, which possesses the I↔N*↔SmA↔SmC* phase sequence. After the filling process, the cell was slowly cooled ($-0.3$°C/min) down into the SmA phase and SmC* phase.

### B Optical Characteristics

The cooling process was examined under the polarization optical microscope. For the cell with thick SiO film evaporated at $80^\circ$ the director of FLC in the SmA phase lies parallel to the incident plane of the SiO beam. In the SmC* phase the director is tilted by an angle ($\sim 13^\circ$) to the evaporation plane. As reported in Ref. 7, the zig-zag defect free alignment was achieved. For the ultrathin SiO film evaporated at $80^\circ$ and the SiO film evaporated at $60^\circ$ the SSFLC cells behave in another manner. In the SmA phase the director of the FLC is oriented in a direction perpendicular to the incident plane of the SiO beam. Moreover, the zig-zag defects appear in the cells in the SmC* phase. We noticed that the long direction of the zig-zag defects in both cells is perpendicular to the incident direction of the SiO beams (Fig. 1). This indicates that the layer directions of the two cells are all parallel to the evaporation direction of the SiO beams. For the cell aligned by the SiO film evaporated at $60^\circ \pm 2^\circ$ this alignment effect agrees well with the results reported early [6, 7]. At the deposition angle of $80^\circ$, however, the layer direction arrangement of the SSFLC cell aligned by the ultrathin SiO film is evidently different from that of the cell aligned by the thick film (as the results of ours and of Ref. 7). With the thick film at $80^\circ$, the layer direction of the SSFLC cell is normal to the direction of the evaporation.

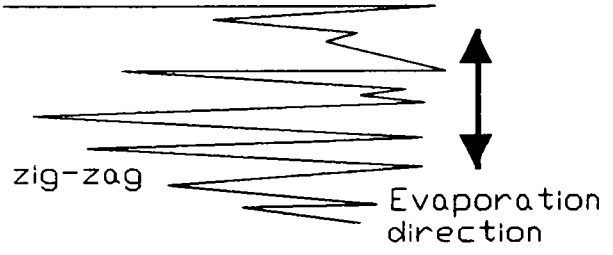



FIGURE 1 Graph of the zig-zag defects in the cell aligned by the ultrathin film evaporated at 80° and the film at the incident angle of 60°.

For eliminating the zig-zag defects the SSFLC cells with these defects were treated by an A. C. electric field (triangle wave) with low frequency (5–20Hz). After the treatment, we found that the zig-zag defects in the cell aligned by the ultrathin SiO film evaporated at 80° can be easily removed completely and do not reappear if the electric field is cut off. Nevertheless, the zig-zag defects in the cell aligned by the SiO film evapo-rated at 60° could not be dispelled completely. Furthermore, the treatment by the A. C. field made the cell aligned by the SiO film at 60° becomes poly-domains, as shown in Figure 2.

For the SSFLC cell aligned by the ultrathin SiO film we first removed all the zig-zag defects using A. C. field (triangle wave, pulse height $\pm$ 17 V, frequency 10 HZ). After the zig-zag defects were all removed, the electro-optical characteristics of the cell was measured. Figure 3 shows the response time of the cell under the rectangular electric field with the pulse height of $\pm$ 17 V. The rise time is 60 μs and the delay time of the rise is 20 μs. The decay time and the delay of the decay are 50 μs and 20 μs, respectively (the measurement was done at the temperature of $12 \pm 1$°C).

D. Doroski *et al.* defined the bistability as the ratio of the following quantities: the differences between the optical responses just before the

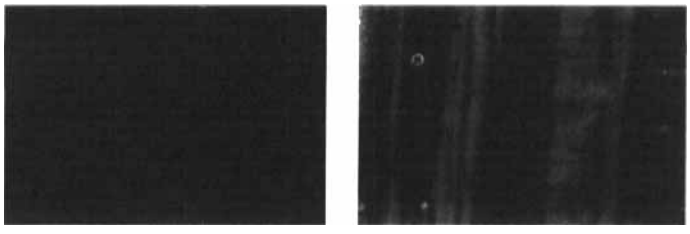


FIGURE 2 Micrographs of the cells after the treatment of A. C. electric field (a) cell aligned by the ultrathin film at 80° (b) cell aligned by the film at 60°.

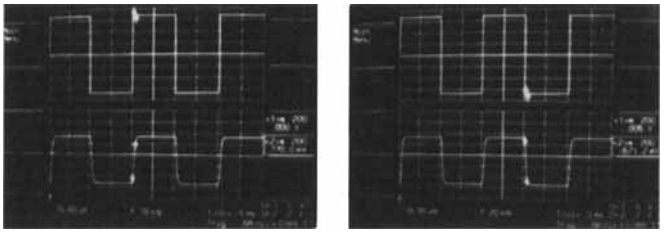


FIGURE 3 Photographs of the electro-optical characteristics of the cell aligned by the ultrathin film. Upper and below lines correspond to the electric field applied to the cell and the optical transimission of the cell, respectively.

positive pulse and the optical responses just before the negative pulse to the difference between the extreme optical responses during the positive and negative voltage pulses [8]. According to this definition, the cell aligned by ultrathin film at 80° exhibits 100% bistability (See Fig. 4), which agrees well with the result in Ref. 8. Moreover, the contrast of the cell was measured. It is higher than 100:1.

The apparent tilt angle is defined as a half of the angle difference between the two extinction positions. Apparent tilt angles in a "switched" state were measured under the application of 17 $V_{o\text{-}p}$, 10 Hz rectangular pulse to the cell; a "memory" state was measured under no electric field subsequent to 17 $V_{o\text{-}p}$, 1ms bipolar pulse application. In both situations, the apparent angles were nearly 22°, which is nearly the same as the molecular tilt angle of FLC (SCE13, tilt angle $\theta = 22.5°$ at 12°C). This means that not only the cell has an perfect memory but also the smectic layers in the cell have been made to stand approximately perpendicular to the substrate surface.

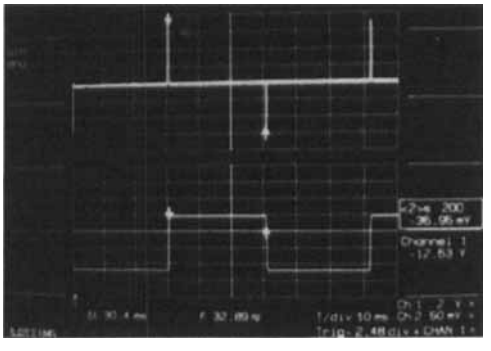
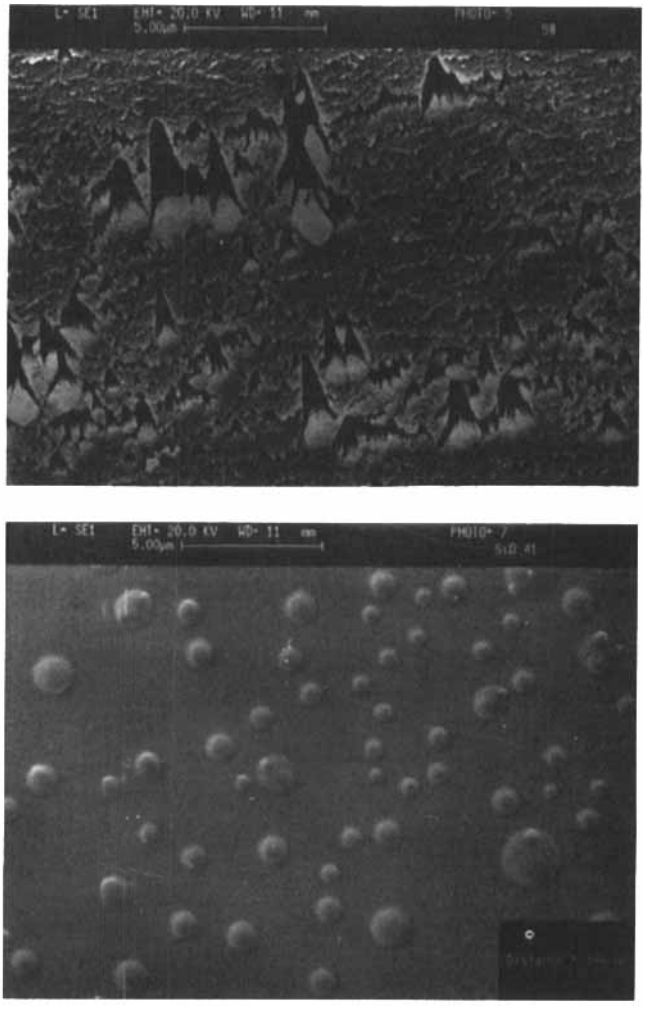


FIGURE 4 Photographs of the electro-optical characteristics of the cell aligned by the ultrathin film. Upper are below lines correspond to the bipolar electric field applied to the cell and the optical transimission of the cell, respectively.

## DISCUSSION AND CONCLUSION

In order to understand the mechanism of the alignment of the obliquely evaporated SiO films, the surface topographies of the thick ($\sim 3500$ Å) and the ultrathin ($60 \sim 80$ Å) SiO films both evaporated at 80° as well as the SiO film evaporated at 60° ($\sim 2000$ Å) were observed by a scanning electron microscope (SEM). Their SEM photographs are shown in Figure 5. The



(a)

(b)

FIGURE 5 SEM photographs of obliquely evaporated SiO surfaces. Photograph (a), (b) and (c) correspond to the thick film at 80°, ultrathin film at 80° and the film at 60°, respectively.

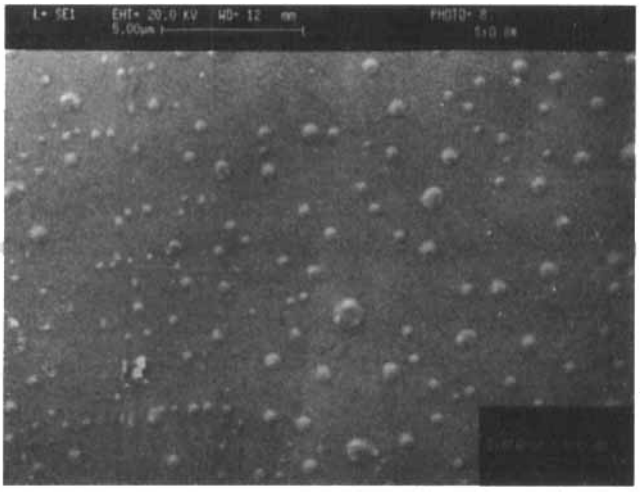



FIGURE 5 (Continued).

direction of the incidence of the SEM electron beam is normal to the substrate surfaces coated by SiO.

From Figure 5(a) very steep columnar structures are seen on the thick SiO film evaporated at 80°. This columnar structure is arranged in rowlike order. The rows are, on the average, perpendicular to the plane of the incidence of SiO beam. On the contrary, the surface topography of the ultrathin film at the same angle is much flattened and featureless (Fig. 5(b)). This topography is similar to that of the SiO film at 60° (Fig. 5(c)), except that the average dimension of the bumps of the ultrathin film at 80° is larger than that of the comparatively thick film at 60°. Attempting to observe the anisotropic features of the ultrathin film at 80° and/or of the film at 60°, we tilted these two samples by an angle (from 0 to 50° while each step = 10°) to the incident electron beam, but the resulting SEM photographs are similar to that shown Figure 5. In addition, we have noted that the SEM photograph of the film at 60° presented here looks like that of Ref. 9, where the photograph corresponds to the 1000 Å $SiO_2$ film evaporated at 60°.

The surface topography and its effect on the molecular orientation of the obliquely evaporated SiO film have been investigated by many authors [9–16]. Based on the observation by transmission electron microscope (TEM) and the calculation by the elastic energy model, the model of the surface topography of the obliquely evaporated SiO film and the molecular orientation on it have been suggested explicitly in Ref. 10, as depicted in Figure 6. In this model, the obliquely evaporated SiO film is composed of a

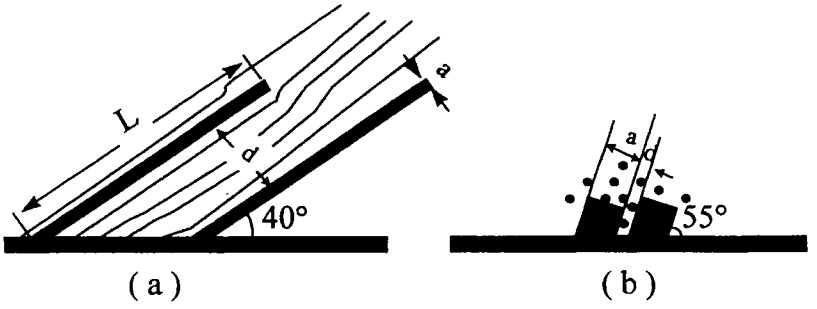



FIGURE 6 Surface topographies of and NLC molecular orientations on obliquely evaporated SiO films. (a) and (b) correspond to the films (thickness > 300 Å) evaporated at 80° and at 60°, respectively.

row like array of columns. The columns lie in the plane of the incidence and are tilted by an angle of $40 \sim 55°$ to the substrate. The rows are, on the average, perpendicular to the incident plane of the beam. At a deposition angle of 83° (Fig. 6(a)), column thickness $a = 100 \sim 150$ Å, channel width $d = 200 \sim 650$ Å and column length $L = 300 \sim 3200$ Å (the thickness is in the range of $300 \sim 3200$ Å). At this angle, the column is long, the NLC molecule is oriented along the long direction of the column and yields a high pretilt angle. At a deposition angle of 60° (Fig. 6(b)), the column thickness $a = 60 \sim 70$ Å, the channel width $d = 20 \sim 30$ Å and the column length is very short (the thickness of the film is in the range of 350–3200 Å). The NLC director lies along the channel therefore perpendicular to the incident plane of the beam and resulting in a zero pretilt. Although meeting the difficulty to explain the pretilt angle quantitatively [10–11], this model is suitable to explain the molecular orientation of NLC qualitatively and agrees well with the molecular orientation of FLC for the thick SiO film [7, 10, 12, 13]. On the other hand, theoretically, the column and channel formations are a nature occurrence of the deposition process due to self-shadowing and atomic mobility [14–16].

It is worth mentioning some of the Goodman's conclusions which draw from the experiment: 1) the channels at 60° appeared even the film thickness $\leqslant 75$ Å where the columnar growth does not appear. 2) the channel growth is prior to the development of the columnar growth 3) at 83°, the length of column increases with the increasing of the film thickness. 4) the channels of the film evaporated at 83° are wider than those at 60°.

Return to the situation concerning ours. For the thick film at 80°, the surface topography of the SiO film and the molecular arrangement are in

agreement with the model of Goodman's. The only difference is that each column is wider at the bottom than at the top in Fig. 5(a), while in Goodman's model the dimensions of the column at the bottom and at the top are the same. This difference demonstrated that Goodman's model of the surface topography is over-simplicity. At 60°, like the SEM photographs in Ref. 10, 17, the channels are not found. In Ref. 17, especially, for the same $SiO_x$ film deposited at 60° while the SEM photograph is flat and featureless, its TEM photograph shows the existence of the channels which have an average direction perpendicular to the deposition plane. Hence we believe that such channels also exist in the SiO film at 60° for our sample, although they were not observed in the SEM photograph. We attribute the failure to observe the channels to the limitation of the detecting apparatus. These channels are responsible for the alignment of the LC director. For the ultrathin film at 80° the surface topography also shows no evidence of anisotropy. Nevertheless, from the theoretical predicts of Ref. 14–16 and Goodman's conclusions 1–4) mentioned above, it seems reasonable to explain the molecular orientation on the ultrathin SiO film at 80° as following: for the ultrathin film at 80°, the channels which have an average direction perpendicular to the incident plane of the beam have existed but the column structure have not appeared because the film is too thin. Consequently, the channel is the dominant factor in the alignment of LC and the molecular arrangement is similar to that of SiO film at 60°.

In the hope of finding the difference between the ultrathin film evaporated at 80° and the film by the incident angle of 60°, the pretilt angles of the LC aligned by them were measured using the crystal-rotation method [18]. The LC material was RO-TN-570. The result shows that the pretilt angle of NLC aligned by the ultrathin SiO film at 80° is about $2.7° \pm 0.2°$, the one aligned by the film evaporated at 60° is nearly 0° (the measurement was done at the temperature of $12 \pm 1$°C). These pretilt angles are clearly smaller than that of the thick film evaporated at 80°, where the pretilt angle is typically above 25° [7]. We have noted that the NLC director lies perpendicular to the incident plane of the beam for the ultrathin film at 80°. This agrees well with the experimental result of Ref. 12.

This pretilt angle ($2.7° \pm 0.2°$) acquired by the ultrathin film evaporated at 80° is a little larger than that of the SiO film by the incident angle of 60°. The difference of the pretilt angles may explain why the uniform alignment of the SSFLC cell can be realized by the ultrathin film at 80°, but not be obtained by the SiO film at 60°.

The non-zero pretilt for the ultrathin film at 80° implies the symmetry-breaking mechanism. Is there anything of the ultrathin film at 80° different

from that of the film at 60°? Explanation of this non-zero pretilt demands a clear knowledge of the surface topography of the ultrathin film (at 80°) at first, then the physicochemical force and the elastic force between the LC and the solid surface need to be known [11, 19, 20]. For the deficiency in both aspects mentioned above, this problem remains unsolved here and needs to investigate in the future.

In summary, this paper presented a reliable method for the uniform alignment of FLC by the ultrathin SiO film evaporated at 80° and the treatment of A. C. field. The SSFLC cell made in this way exhibits high contrast, perfect bistability and fast switching speed. Due to the deficiency of the direct experimental evidence of the channel existence on the ultrathin SiO film at 80° and that on the film at 60° (from the SEM photographs), the explanations of the alignment mechanism by these films need to verify in the future.

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