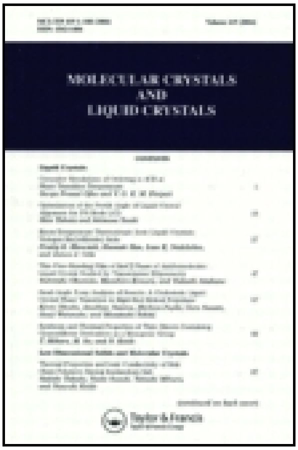

Molecular Crystals and Liquid Crystals Science and Technology. Section A. Molecular Crystals and Liquid Crystals

Control of the Electro-Optic Bistability of Some Ferroelectric Liquid Crystals Useful for Binary Phase Optical Modulators

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Control of the Electro-Optic Bistability of Some Ferroelectric Liquid Crystals Useful for Binary Phase Optical Modulators

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We report measurements on the bistability of the electrooptic response of a commercially available material (CS2005) and an experimental liquid crystal material (CDRR8) based on an organosiloxane structure. Both materials have a first order transition to the SmC* phase. CS2005 gave the normal monostable behaviour with layers tilted with respect to the rubbing direction. However, the second material, CDRR8, exhibited true bistability and at the same time its smectic layers were found to lie perpendicularly to the rubbing direction. We were able to control the bistable behaviour of the CDRR8 material by means of layer rotation using asymmetrical triangular pulses. As expected the sample shows a monostable response each time the layers are rotated so that one of the two switched states approaches the rubbing direction.

Keywords: Smectic C* phase; high tilt angle; bistability; Phase Modulation; Organosiloxanes; Spatial Light Modulators

INTRODUCTION

Liquid crystal spatial light modulators (SLMs) capable of phase modulation are increasingly important in a number of areas such as adaptive optics [1], image processing [2], and optical switches [3]. Surface stabilised ferroelectric liquid crystals are particularly well suited to binary phase modulators [4] and can give fast, polarisation insensitive, switching [5]. Optimally efficient phase modulation is obtained with tilt angles of 45 degrees and therefore materials with high tilt angles in such cases are needed. Of particular interest is achieving bistability in the transfer characteristics of electrooptic effects employing materials that exhibit high tilt angles. This can be important in the addressing of large arrays of pixels, especially when phase holograms are used for signal routing where patterns must be displayed over long periods of time without change. Special care has to be taken in order to maintain a net average dc field of zero across the pixels.

Among the ferroelectric liquid crystals only the ones exhibiting the SmC* phase through a first order transition from the nematic or directly from the isotropic phase are capable of giving tilt angles close to 45°. Patel and Goodby [6] showed that FLCs with a first order phase transition form layers in the SmC* phase that tilt away from the rubbing direction in an angle equal to the tilt angle of the material. Further studies [7] revealed that this is the main reason that this kind of materials exhibits monostable electrooptical behaviour, since in only one of the two switched states the molecular axis coincides with the rubbing direction. However, Myojin et. al. [8] were able to align a N*→SmC* liquid crystal confined in a cell where both surfaces were covered with rubbed polymer in a such a way that the layer normal coincided with the rubbing direction, by applying a triangular AC field, but no report on the bistability has been given.

MATERIALS

Measurements performed on a commercially available high tilt angle material (CS2005) [9] and an experimental mixture (CDRR8) [10] based on organosiloxane end groups [11]. Organosiloxane materials are good candidates for FLC phase modulator devices because of their low viscosity, due to their low molar mass. The phase sequence for the two materials is:

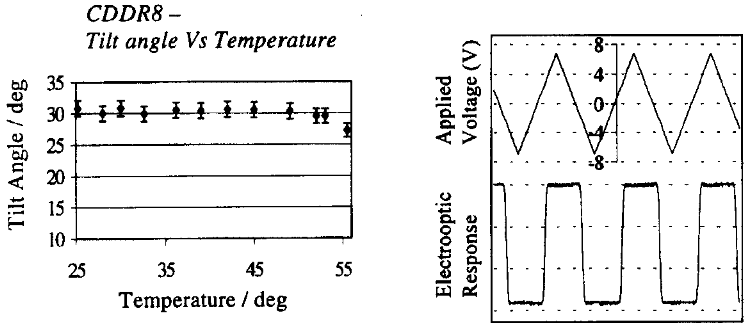
$$\text{CS2005: Cr} \xrightarrow{-19\ ^\circ\text{C}} \text{SmC*} \xrightarrow{65\ ^\circ\text{C}} \text{N*} \xrightarrow{73\ ^\circ\text{C}} \text{Iso}$$

Maximum tilt angle: 43 deg

$$\text{CDRR8:}\quad \begin{array}{l}\text{Room}\\ \text{Temperature}\end{array} \xrightarrow{\qquad} \text{SmC*} \xrightarrow{57\ °\text{C}} \text{Iso}$$

Maximum tilt angle: 32 deg

The existence of the SmC* → Iso phase transition in CDRR8 is illustrated by the diagram of the apparent tilt angle versus temperature and also from the electrooptic response of the material at temperature just before the isotropic phase. These are shown in the figures 1a and 1b.



(a) (b)

FIGURE 1. a) Tilt angle Vs Temperature for the CDRR8 and b) the electrooptic response of the CDRR8 just underneath the isotropic phase.

Measurements of the apparent tilt angle of the two materials showed that saturated switching occurs for approximately 4 V/μm and 3 V/μm at 25 °C and 500 Hz driving pulse frequency for the CS2005 and the CDRR8 respectively.

EXPERIMENTAL

Measurements on four cells (two with CS2005 and two with CDRR8) were carried out using a Vickers M41 Photoplan polarising microscope.

Cells were placed between crossed polarisers and the electrooptic response was monitored using of a photodiode. The response was viewed on a HP54601A digital oscilloscope connected with a computer running a LabView code. Single and complex bipolar rectangular pulses were applied to the cells using an in-house-made pulse generator. A HP6827A bipolar amplifier amplified the output of the function generator. Figure 2 shows the two kind of asymmetrical triangular pulses that were used in order to rotate the smectic layers.

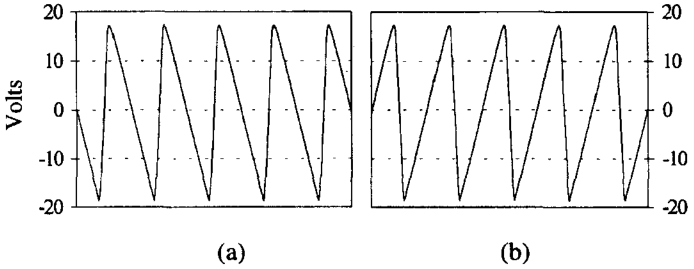


FIGURE 2. Asymmetrical triangular pulses were used in order to rotate the smectic layers. Different frequencies were used for the two materials (order of kHz). a) Negative asymmetry b) Positive asymmetry.

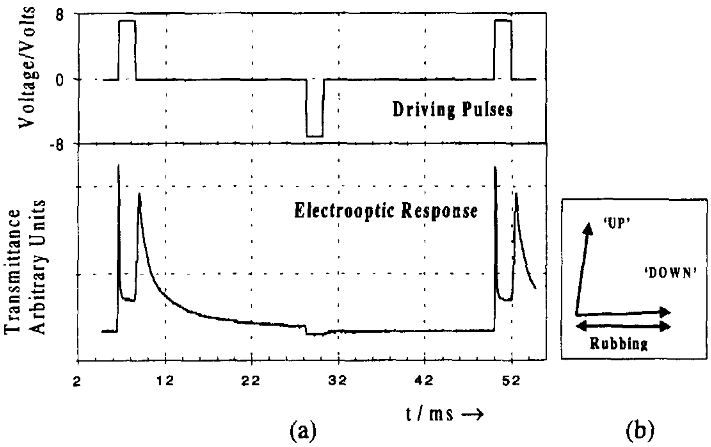
Glass spacers were used to control the thickness of the cells. Antiparallel rubbed nylon 6-6 on the ITO electrodes was used to align all the cells. A solution of 0.2% nylon 6-6 in formic acid was spun at 3000 rpm for 30 sec on each glass and then baked for 3 hours at 200 °C.

The direction of the molecules corresponding to the switched states with respect to the rubbing direction on the cell was determined by rotating the cell between the crossed polarisers and observing the point of the minimum transmittance. For the measurement of the bistability of the cells, bipolar rectangular pulses of 2ms width and ±6-8 V height were used and a period of 10-30 ms with zero field was set by the pulse generator between subsequent pulses.

RESULTS AND DISSCUSION

Normal Alignment Treatment with Symmetrical Rectangular Pulses

The electrooptic response of the CS2005 (cell thickness 2.81 μm) under a complex bipolar driving waveform can be seen in figure 3a. The pulse width and height were chosen in order to give saturated switching for both states.

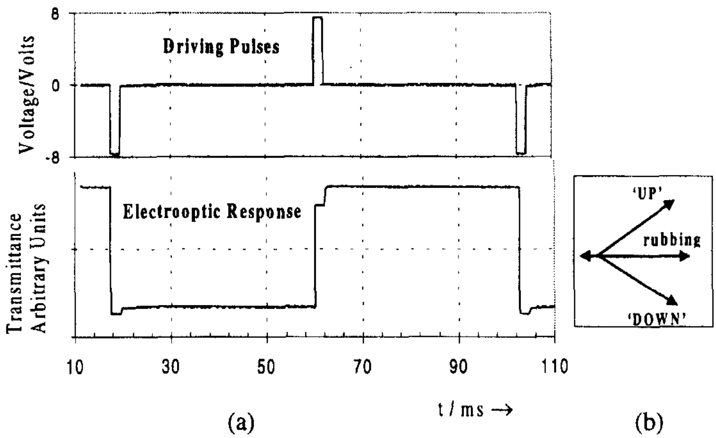


(a) (b)

FIGURE 3. a) The bistability response of the CS2005 (cell thickness 2.81μm). b) The two switched states with respect to the rubbing direction. The 'UP' state is unstable. The 'DOWN' is stable.

The sample clearly showed monostable behaviour. As was expected the smectic layer normals are tilted away from the rubbing direction. The switched state, which coincides with the rubbing direction ('down' state in the figure), is the stable state (see figure 3b). If the cell is switched to the 'up' state (by a positive pulse) and the field is taken away then the molecules relax back to the 'down' state. As can be seen from the diagram the complete relaxation process takes place within about 20 ms, which however is much longer than the switching time from the 'down' to 'up' state which is less than 1 ms.

Figure 4a shows the electrooptic response that was obtained with the CDRR8 cell (thickness 1.80 μm), using the same kind of pulses. Surprisingly, the sample showed excellent bistable behaviour. Calculation of the orientation of the two switched states also gave the unusual result of layers oriented perpendicular to the rubbing direction (see figure 4b) (we make the assumption that the layer normal intersects the two switched states, thus we assume symmetrical switching around the cone).

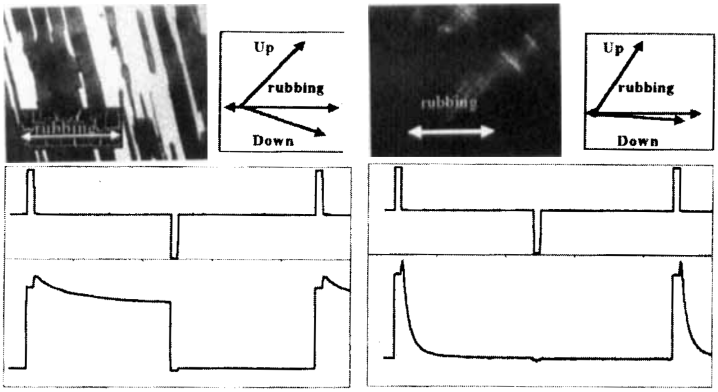


(a) (b)

FIGURE 4. a) The bistability response of CDRR8 (cell thickness 1.8 μm). b) The two switched states with respect to the rubbing direction. Both states are stable.

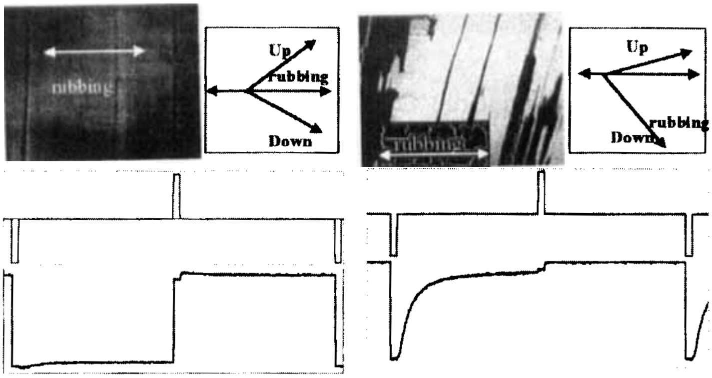
Treatment with Asymmetrical Triangular Waves

In order to investigate the 'odd' behaviour of the CDRR8 in terms of layer orientation and bistability, asymmetrical pulses of the type shown in figure 2 were applied to the cell containing CDRR8 in an attempt to induce layer reorientation. Treatment with either positive or negative asymmetric fields was performed in the following manner: The asymmetric pulses were applied for periods of duration of 10s (typically). During the intervals between these periods, the treatment field was removed and the layer orientation and cell bistability recorded as is shown in Figures 5 and 6.



(a) (b)

FIGURE 5. Bistability response, layer orientation and switched states for CDRR8 after treatment with triangular pulses of negative asymmetry after (a) 1min and (b) 2 min. After the treatment only the 'down' state is stable.



(a) (b)

FIGURE 6. Bistability response, layer orientation and switched states for CDRR8 after treatment with triangular pulses of positive asymmetry. Layers rotate clockwise (a) after 2 min the sample has become again bistable (b) further 2 min make the sample again monostable ('down' state is now unstable). See Color Plate IX at the back of this issue.

It was observed that as the layers rotate and one of the two switched states approaches the rubbing direction then this state becomes more stable than the other. The later becomes completely unstable after the layer rotational tilt exceeds approximately 20 deg. Figures 5a and 5b show the response of the cell after applying left tilted saw-tooth bipolar pulses of Vp-p=35 volts and frequency 5kHz, for 1 min and 2 min, respectively. The layers rotate anti-clockwise so that the down state approaches the rubbing direction. The rotation can be easily identified in the pictures at the top left-hand corner of figures 5a and 5b. It can be seen that the stripe lines gradually tilt away from the rubbing direction. In these figures also the electrooptic response is given for each case and the calculated switched states with respect to the rubbing direction. After the first minute (figure 5a) the bistability has been significantly degraded. Some of the areas (black in the picture) have become monostable. After the second minute of treatment (figure 5b) with the same asymmetric pulses the sample has become completely unstable. The 'down' state almost coincides with the rubbing direction and 'up' switching relaxes back to the down state within approximately 10 ms.

Applying triangular pulses with opposite asymmetry (right tilted saw-tooth) we were able to recover the bistability of the cell. By rotating the layers anticlockwise it was possible to orient the layer normal parallel to the rubbing direction (figure 6a). This can be seen by observing the stripes lines on the sample which now are pointing in the same direction as the rubbing (figure 6a – photo). It can also be seen in the same figure (figure 6a – upper right hand) that the rubbing is now bisecting the two switched states. The response of the sample at this stage is shown at the low half of the figure 6a. It is evident that excellent bistable behaviour was obtained in contrast with the cases shown in figures 5a and 5b. Further treatment with pulses of the same asymmetry rotate the layer normal away from the rubbing direction (figure 6b). Specifically, the 'up' state gets closer to the rubbing direction and the sample becomes monostable again. The white areas in the picture of the figure 5b are unstable areas (they relax back to the 'up' state).

The same does not apply in the case of CS2005. In none of the two cells with CS2005, that were examined, was it possible to rotate the layers continuously and therefore no alignment with the two switched states bisected by the rubbing direction could be obtained. Instead, after long treatment with asymmetrical triangular pulses of either polarity, the monodomain that was obtained by normal symmetrical treatment was broken into two different areas with layer normals tilting away from the rubbing direction. These results are interesting because they are indicative of some sort of de-coupling of the molecules in the case of the organosiloxane material from the alignment layers, which is not the case for CS2005. In the later case, strong coupling of the molecules with the alignment layers appears to prohibit any layer rotation even in thicker cells.

CONCLUSIONS

Qualitative measurements on the bistability behaviour of two materials with first order transition to the smectic C* phase, were presented here. It was shown that it is possible to obtain bistable behaviour, even with a material with a SmC* - Iso phase sequence, subject to whether or not it is possible to align the smectic layers so that the alignment conditions do not favour one of the two optical switched states. Furthermore, we show that when layer rotation is possible, we can selectively choose one of the two switched states to be stable, whilst the other one is unstable, by aligning it parallel to the rubbing direction. Finally, possible de-coupling of the molecules from the alignment layers due to the presence of siloxane end groups is suggested.

Acknowledgements
CDRR materials are organosiloxanes that were originally synthesised by Prof. J. Goodby's group at the School of Chemistry Hull University on the DTI Link Molecular Electronics Programme, project no. IED 2/435/30/001. The particular material used here (CDRR8) was obtained from CRL. CDRR8 is a fluorine-substituted organosiloxane.

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