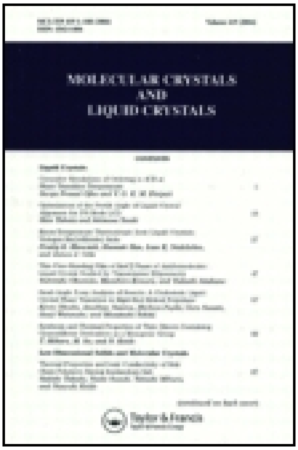

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Electrical and Optical Measurements of the Image Sticking Effect in Nematic LCD'S

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In this paper we present the results of measurements of the image sticking phenomenon. Simultaneous electric and optical measurements show that the regime leakage current and the optical transmission become asymmetric when a DC voltage is applied. In this way we can measure the change of the effective voltage over the liquid crystal. We believe this change of effective voltage is due to a DC electric field of ions which are separated by the applied DC voltage and trapped at the alignment layers.

Keywords: image sticking; leakage current; optical transmission; liquid crystal displays

INTRODUCTION

Active Matrix Liquid Crystal Displays have now deeply penetrated into the display market, but there are still some problems, like the image sticking effect. This image sticking effect is said to be due to a residual DC electric field caused by ionic particles in the liquid crystal[1]. The applied electric field separates the positive and the negative ions. An internal electric field is built up, which influences the effective voltage across the liquid crystal. The effective voltage differs from the applied voltage and this changes the optical transmission. In previous articles, we have presented a way of characterising the conduction in LCD's[2]. In this paper, we will try to characterise the image sticking effect, by applying a DC voltage, and measuring the optical transmission and the leakage current of a liquid crystal cell.

THEORY

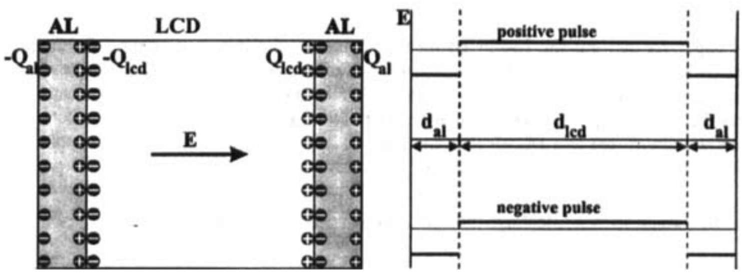

Figure 1 Schematic presentation of the distribution of ions in the liquid crystal (left) and the electric field profile (right) after applying a DC voltage.

Consider the situation shown in Figure 1. This is a schematic presentation of the situation in a cell when a DC voltage has been applied for a long time. Ions in the liquid crystal are gathered or stuck at the interface between the alignment layer and the liquid crystal. This gives rise to a surface charge Q_{lcd} at one surface and $-Q_{lcd}$ at the other. In the alignment layer there may be ionic particles which are separated by the DC electric field, causing a surface charge $-Q_{al}$ at the ITO-alignment layer interface and Q_{al} at the LC-alignment layer interface, and opposite signs at the other alignment layer. For a given voltage V over the cell, we can calculate the electric field in the alignment layer and in the liquid crystal. We find

$$E_{lcd} = \frac{VC_{al} + 2(Q_{al} - Q_{lcd})}{d_{lcd}(2C_{lcd} + C_{al})} = E_{lcd}(V) + E_{lcd}^{DC} \tag{1}$$

with C_{lcd} and C_{al} the capacitance per square meter of the liquid crystal and the alignment layer. The total internal electric field consists of a part depending on the applied voltage and a DC part. The presence of a DC component in the applied voltage is the major cause of the image sticking effect. Because of this DC electric field, positive and negative ions are separated, and will cause an internal electric field. This DC electric field adds to the average electric field in one period of the signal, and decreases the electric field in the other period, as shown in Figure 1. As the transient time of the ions which contribute to the leakage current is of the order of a few hundred milliseconds[2], the influence of these ions on the electro-optical behaviour of the LCD will disappear soon. For the effects on a much larger scale, like the image sticking effect, there are three possible explanations.

1.The liquid crystal contains a large number of very slow ions. These ions are too slow to contribute to the leakage current, but they will cause a large internal electric field (equation (1), with Q_{al} =0). With this assumption, the number of ions remains constant. The leakage current will become asymmetric, but the peak to peak value should remain constant.

2.The fast ions can be trapped at the surface. There is a trapping phenomenon, with a short release constant, causing the bump in the regime leakage current[3], but there is also a very strong sticking force, with a very large release constant. The ions which are strongly stuck at the surface cannot contribute to the leakage current any more, so the amplitude of the leakage current will decrease in both periods. There will also be a shift, due to the separation of ions, making the leakage current profile asymmetric.

3.Charge carriers in the alignment layers can separate, causing a DC electric field in the alignment layers, which influences the effective electric field in the liquid crystal, as can be seen from equation 1, with Q_{lcd} = 0. Time constants can be very large, because the charge carriers have to move in the solid alignment layers[4]. The concentration of ions in the alignment layer has to be extremely high to have a noticeable effect.

The internal DC electric field from the separated ions causes the total electric field in the liquid crystal to increase in one period, and to decrease in the other. The effective voltage across the cell will therefore increase, and this will result in a different optical transmission.

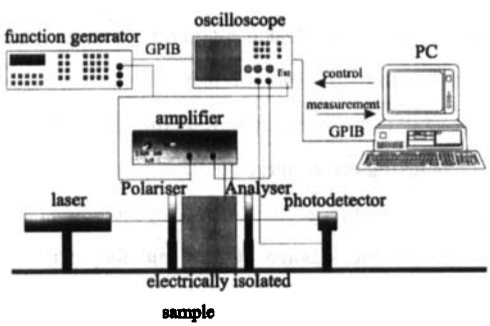

Figure 2 Measurement set-up.

EXPERIMENTS

For our experiments, we used Twisted Nematic cells with thickness of 8 μm, and filled with ZLI-4757. We used AL1254 (JSR) as alignment layers. The liquid crystal has a high threshold voltage, suitable for sub-threshold leakage current. Because the cell was not matched, we operated it in the 'normally dark' mode. The threshold voltage of the cell is 5.3 V. The measurement set-up is shown in Figure 2.

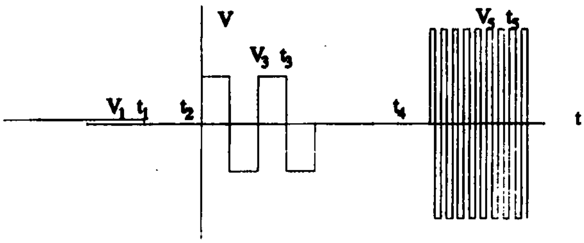

Figure 3 Applied waveform.

The waveform, used for the image sticking measurements is shown in Figure 3. The leakage current is amplified using a low noise current amplifier, developed in our group[5]. For the optical measurements, we use a He-Ne laser, for the ease of use. The transmission is measured by a photodetector. First a DC voltage with amplitude V_1 and duration t_1 is applied. This DC voltage causes the fast as well as the slow ions to move towards the alignment layers. Then the cell is short-circuited for a period t_2, which is taken smaller than the time t_1. The slow ions are almost not influenced by this short-circuit, but the fast ions are distributed almost homogeneously. The internal electric field from the slow ions can cause a deviation from this homogeneous distribution, and this deviation may become important for the leakage current measurements. After the short circuit, a number of alternating pulses are applied, with amplitude V_3, and pulse width t_3. The first of these pulses corresponds to the transient measurement, the subsequent pulses give rise to regime measurements. The voltage V_3 is chosen below the steady state threshold voltage, in order to have no effects from the switching current.

Then, for a short time t_4, the cell is short circuited again, before the optical measurements start, to eliminate the influence of the leakage current measurement. The fast ions are again distributed more or less homogeneously. For the optical measurements, we apply a square wave with amplitude V_5 and pulse width t_5, simulating the signals in a real device. The total duration of this square wave is not too short, because of the slow response time of the liquid crystal. After the optical measurements the cycle starts again. In this way we can see the evolution in time of the leakage current and optical transmission.

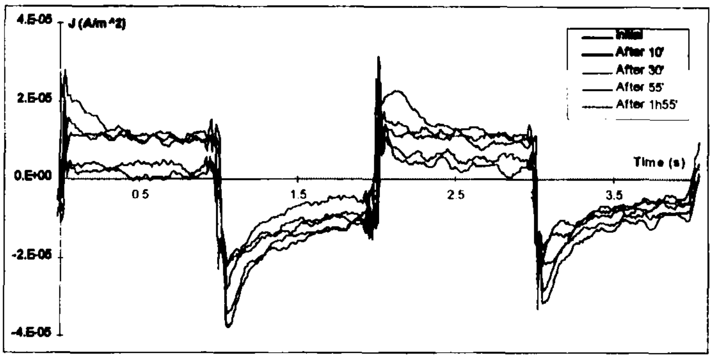

Figure 4 Leakage current profiles during the stress situation.

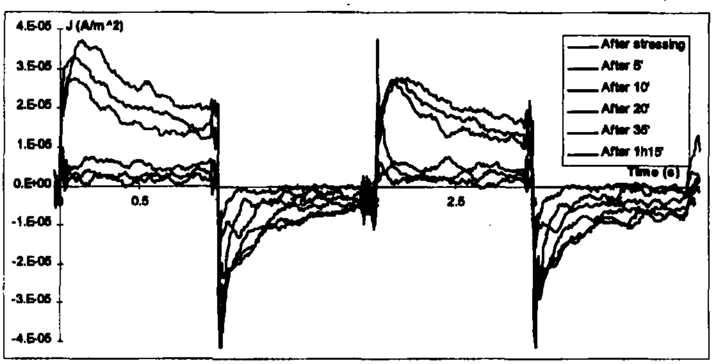

Figure 5 Leakage current profiles during recovery.

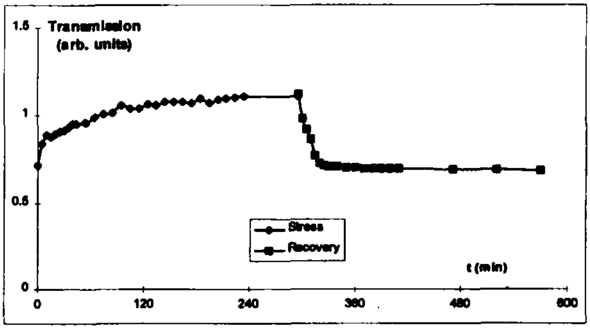

Figure 6 Average transmission during the stress and recovery processes.

Two kinds of measurements were done. First we investigated the time evolution of the electro-optical properties when a DC voltage is applied (voltage V_1 = 200 mV), which we will call stressing. We also investigated the behaviour when the cell was short circuited afterwards (voltage V_1 = 0). We will refer to this measurement with the term recovery. The leakage current profiles are shown in Figures 4 and 5. In the stress situation, the leakage current in the positive pulses decreases in time. In the negative pulses, there is an increase in the amplitude, but afterwards, the amplitude decreases again.

Also an asymmetry is introduced. This large asymmetry clearly points towards an internal DC electric field caused by the presence of a large number of slow ions, and from the decrease of the amplitude in both pulses, we can conclude that the trapping of ions at one of the surfaces, with a strong sticking force, plays an important role. On the other hand, the amplitude of the leakage current in the recovery process, increases during the first 30 minutes, which is due to the release of the trapped ions, and decreases again afterwards, as the ions can be trapped again at the opposite surface. Also the asymmetry becomes less, and after a long time, returns to the initial situation, before the stressing process. In Figure 6, the average transmission during the stress and recovery is shown. During stress, the transmission increases, because the internal DC electric field and the rms-voltage across the cell increase in time, and during recovery, the internal DC electric field, and the transmission fall back to the initial level. The time constants for the transmission are of the same order as the time constants for the change of the leakage current.

CONCLUSIONS

Our measurements show that the trapping of ions, with a strong sticking force, and the presence of a large number of very slow ions, giving rise to an asymmetric leakage current, can be related to the change of transmission of a liquid crystal cell. We have shown that the image sticking effect is caused by ion transport in the liquid crystal, and that this effect can be characterised by measuring the evolution of the leakage current.

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