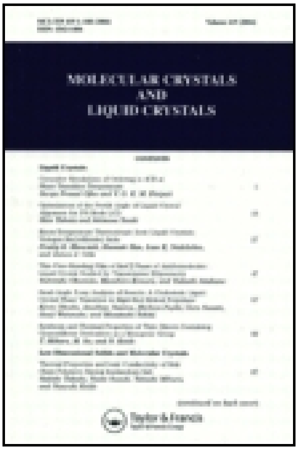

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Herbert De Vleeschouwer [a], Fatiha Bougrioua [a], Rob Van Asselt [b], Alwin Verschueren [b], Stefaan Vermael [a] & Herman Pauwels [a]

[a] University of Gent, Department of Electronics and Information Systems (ELIS), Sint-Pietersnieuwstraat 41, B-9000, Gent, Belgium

[b] Philips Electronics BV, Prof. Holstlaan 4, 5656 AA, Eindhoven, The Netherlands

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Asymmetrical Properties of Reflective LCD'S

HERBERT DE VLEESCHOUWER[a], FATIHA BOUGRIOUA[a], ROB VAN ASSELT[b], ALWIN VERSCHUEREN[b], STEFAAN VERMAEL[a] and HERMAN PAUWELS[a]

[a]*University of Gent, Department of Electronics and Information Systems (ELIS), Sint-Pietersnieuwstraat 41, B-9000 Gent, Belgium and* [b]*Philips Electronics BV, Prof. Holstlaan 4, 5656 AA Eindhoven, The Netherlands*

In this paper we present results concerning reflective LCD's with different alignment layer types. We made thought-out interpretations of the asymmetrical reflectance and current responses. The asymmetry is the result of an internal voltage. In our measurements, we distinguish alignment layers, which introduce mobile ions in the LC bulk and other alignment layers, which have a layer of trapped ions at the interface with LC.

Keywords: reflective LCD's; ion transport; electrooptical behaviour

INTRODUCTION

The reflective cell in Figure 1 has two different electrodes, a transparent one (ITO) and a reflective one (Al). The aluminium electrode is the grounded electrode. Experiments show different reflectance and current responses for positive and negative applied voltages [1].

The difference in work function $\Delta\phi=\phi_i-\phi_a$ between the electrodes causes an internal voltage (built-in voltage) to be present in the liquid

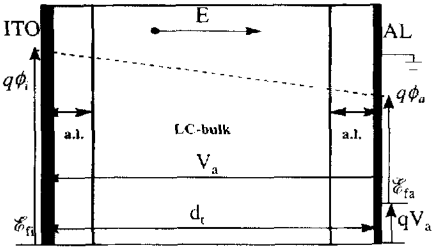


FIGURE 1 Influence of the difference in work function; E_f is the fermi level, a.l. the aligment layers, d_t the cell gap, V_a the applied voltage.

crystal even when no external voltage is applied. If the liquid crystal and the alignment layers (a.l.) are perfect insulators (with zero conductivity), the electric field caused by both the applied voltage V_a and by the difference in work function in the LC-bulk can be written as:

$$E_{lcd} = \frac{(V_a - \Delta\phi)}{d_{lcd}(1 + 2.C_{lcd} / C_{al})} \qquad (1)$$

C_{lcd} and C_{al} are the capacitances per square meter of the bulk and an alignment layer respectively. d_{lcd} is the thickness.

The ionic impurities in a real display contribute to the electrical field in the LC-bulk. Two species of ions can be considered: slow ions and fast ions. The slow ions are separated over a long time; they are too slow to respond to an external voltage during the measurement. This slow ion separation might have been introduced during the fabrication process. Their influence is revealed by image sticking measurements [2]. The fast ions (with a higher mobility) are directly involved in the ion current measurement (short-term effects). When applying an external voltage, the part of V_{ion} due to the fast ions can vary with time:

$$E = \frac{(V_a - \Delta\phi + V_{ion}^{slow} + V_{ion}^{fast}(t))}{d_t(1 + 2C_{lcd} / C_{al})} \qquad (2)$$

The sum $V_{asym} = (-\Delta\phi + V_{ion}^{slow})$ constitutes then the asymmetrical voltage which remains constant whatever the applied voltage features.

The presence of the asymmetrical voltage and the fast ion content are taken into account when we investigate our reflective cells.

PROTOTYPE CELLS AND MEASUREMENT CYCLE

We have performed measurements on reflective prototype cells (Table 1). Each cell has two pixels L and S and has a 60 degrees twist. The used liquid crystal is a fluorinated mixture for first minimum AM-devices with a very high resistivity. (L)ong and (S)hort stand for the length of the pixel ITO electrodes, the Al electrode is in common.

Cell nr.	a.l. material	a.l. thickness (nm)	Cell gap (μm)	Asymmetry pixel L (V)	Asymmetry pixel S (V)
G1B	SE5291	140	2.0	-0.71	-0.71
G2B	SE5291	140	3.5	-0.72	-0.35
G3B	SE5291	140	5.6	-0.91	-0.53
G4A	AL3046	100	2.0	-0.87	-0.86
G5A	AL3046	100	3.5	-0.36	-0.58
G6A	AL3046	100	5.6	-0.86	-0.54
G7A	AL3046	18	3.5	-0.67	-0.64
G8A	AL3046	43	3.5	-0.71	-0.53

TABLE 1: Parameters of the Philips-cells: alignment layer materials, thickness', cell gap and the asymmetrical voltage of L and S.

Prior to any other measurement, compensating the AM discharging curve with a DC voltage delivered the asymmetrical voltage (Table 1). The typical measurement cycle performed on the cells is as follows: first, the L-pixel is measured, then the S-pixel. On each pixel, a quick compensation method experiment is performed. The pixel is addressed with a square wave of 7Vpp at 10Hz, which is sufficient to see reasonable reflectance changes. Simultaneously, the optical asymmetry is compensated with an additional DC (DC-intern). After this measurement, the reflectance curves at 100Hz and 10Hz are measured (RV curves). The curve at 100 Hz is important because the display might use this frequency. The curve at 10 Hz is interesting to monitor the ion motion during each voltage pulse. A third measurement is performed giving the continuous positive and negative reflectance curves when a staircase voltage train is applied (continuous RV curves). Its advantage is the complete fast ion separation present in the cell. The voltage shift ΔV between the positive and negative RV-curves at 50% of the reflectance at 0V constitutes the optical asymmetry. At last, the internal DC is re-measured to check its possible variation due to the whole measurement cycle. (DC-intern after).

The resemblance between the charge results (Table 1) and the optical results proofs their close relationship. The absolute charge results are a bit higher but this might be due to time in between (two weeks).

All the reflective cells have a negative optical asymmetry ΔV. This corresponds with the idea that the main contribution to the asymmetry is coming from the negative difference in work function between the aluminium and the ITO [1].

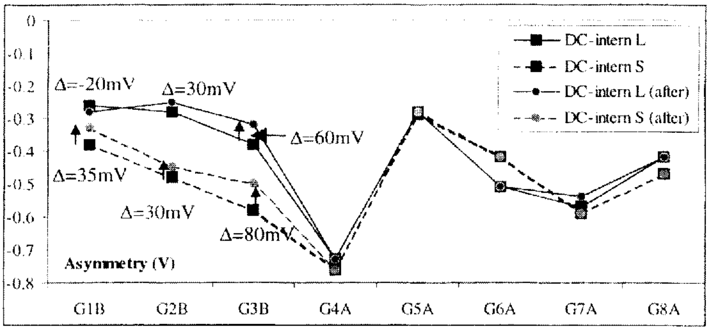


FIGURE 2 Measured asymmetrical voltages for all pixels with the decharging technique (Charge S, L) and the internal DC for S and L before and after the measurements.

PERTURBATION BY THE MEASUREMENT CYCLE

Three cells of Table 1 have an asymmetrical voltage, which is influenced by the measurement cycle (Figure 2). Effectively, over the measurement cycle, the DC-intern lowers in absolute value 30mV up to 80 mV for five of the six pixels of these cells (G1BL, G2BS, G2BL, G3BS, and G3BL). Their common point is the alignment layer SE5291. The ten pixels of the 5 other cells, with alignment layer AL3046, are not influenced by the measurements. This leads to a very important conclusion: the measurement cycle influences the optical asymmetry depending on the used a.l.

The explanation of the decrease is that each measurement in the cycle ends with a negative voltage. At that moment the fast ions are completely separated with negative ions next to the aluminium and the positive ones next to the ITO (Figure 3). After several measurements in the cycle, some of the ions remain stuck on the alignment layer (they become slow). They partially compensate the asymmetrical voltage. That's why the final measured asymmetrical voltage, DC-intern (after), is lower than the initial one, DC-int. The short-circuit period before each measurement step can not completely remove this ion separation. Moreover, the time scale by which this additional ion separation is partially removed during the short-circuit period is proportional to the release time and the transit-time ($t_{tran}=d^2/\mu V$). So, the effect is expected to be stronger for thicker cells. This is confirmed by the experimental results (Δ-values on Figure 2). After the measurement cycle, when a symmetrical 10 Hz Square Wave voltage is applied, the previous effect disappears within one hour. The cell asymmetry returns to its initial value V_{asym}.

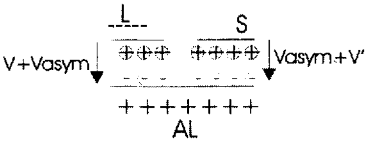
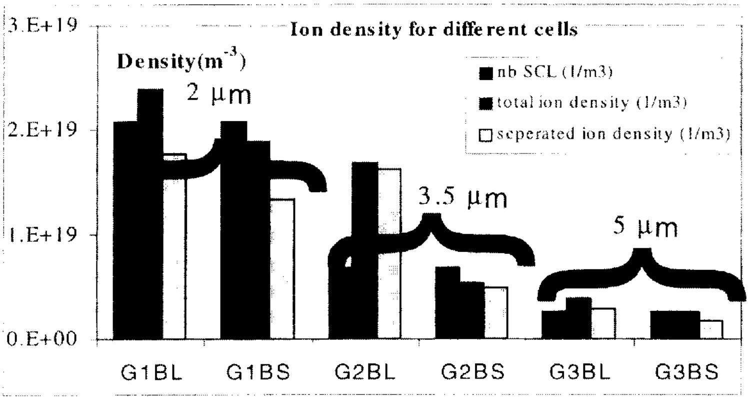


FIGURE 3 Influence on the ion content of the measurement cycle.

STUDY OF CELLS G1B, G2B AND G3B.

V_{asym} can prevent the creation of a fast ion homogeneous distribution during the 10 seconds of short-circuit which precedes the ion current and reflectance measurements [5-6]. This creates the measured asymmetrical currents. The total fast ion density in the liquid crystal as well as the separated ion density (Figure 4) can be determined with the measurement setup [3] and the methods described in previous papers [1-4]. The separated ion density is the amount of ions one should completely separate to get the same ionic voltage across the liquid crystal bulk as the real ionic distributions. The Space Charge Limit (SCL) is the amount of ions one should completely separate to annihilate the applied voltage in an AM or S/H drive ($SCL=C_{lc}V$) and indicates whether the ion concentration is significant enough to influence the electrical field.

Cells G1B, G2B and G3B have the same cell characteristics except for the cell gap d_t. The ion concentration is more or less reversibly proportional to d_t. This means that the ion content is independent from the lc and originates thus from the a.l., which all have the same thickness. This surface contamination can be determined as $3e^{13}/m^2$.



It is also interesting to note that the fast ion concentration of pixel L is always bigger than the concentration of cell S. Pixel L has a higher asymmetry than S, which suggests that fewer slow ions are present in L to compensate for the work function difference.

STUDY OF CELLS G5A, G8A, G7A

The cell parameters of cells G5, G8 and G7 respectively show that only the a.l. thickness is becoming thinner (TABLE 1). The small current indicates that the ion content is extremely low which means that no surface contamination of the lc-bulk takes place.

The reflectance results of Figure 5 exhibit a decreasing voltage asymmetry (in absolute value) for an increasing a.l. gap. ΔV at 10 Hz is very comparable to the ΔV Continu where a complete ion separation is present. So, the conduction process is almost finished at 10 Hz. The measured curves at 100 Hz show that the liquid crystal didn't have enough time to respond to each voltage pulse ($T_{period/2}<T_{response}$); the measured asymmetry is then less important. The values of the internal voltage are studied because these are the best estimates of the asymmetrical voltage.

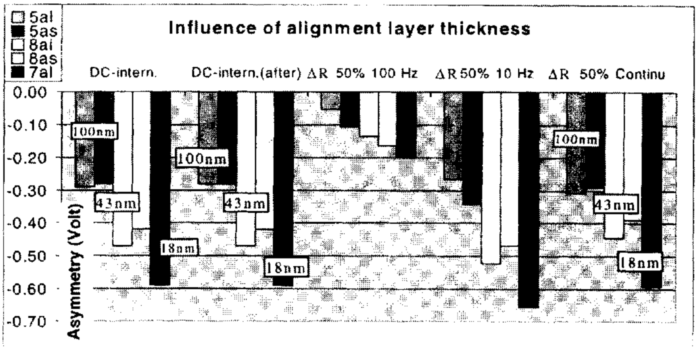


FIGURE 5 Influence of the alignment layer thickness on the asymmetry.

The a.l. capacitance of cell 5 is higher than the one of cell 8 and this one is higher than the one of cell 7. Two immobile ion layers with the same charge density but with opposite charges, completely separated by the LC bulk, would create an asymmetrical voltage given by:

$$V_{asym} = -\Delta\phi + 2.\frac{Q_{lcd}}{(C_{al} + 2.C_{lcd})} \approx -\Delta\phi + 2.d_{al}.Q_{lcd} / (\varepsilon_0 \varepsilon_r) \qquad (2)$$

This equation shows that the asymmetry increases with d_{al} as was measured. A linear regression technique gives a work function difference of $\Delta\phi$=0.62V and an acceptable ion separation of $Q_{lcd}=6e^{14}/m^2$. This work function is intermediate to values found in literature in the order of 0.25-0.4V [7,8] and measured values in the order of 1V.

CONCLUSIONS.

We developed and explained a measurement cycle, which allows determining the influence of the work function difference, slow and fast ion content on the asymmetry in the display. We used it to investigate our liquid crystal prototype cells.

We see that the influence of the measurement on the cells can not be ignored and its importance depends on the alignment layer and on the bulk thickness. Closer verification showed that alignment layer SE5291 gives rises to a surface contamination of the bulk during the fabrication process. The ion density is reverse proportional to the cell thickness.

AL3046 gives no fast ion contamination of our mixture but shows that slow ion separation takes place at the interface alignment layer-bulk, which decreases the absolute electrooptical asymmetry caused by the work function difference. This decrease is proportional to the alignment layer thickness as can be expected from theory. However its low fast ion content taken into account, the measured asymmetry is still higher than for the first alignment layer.

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