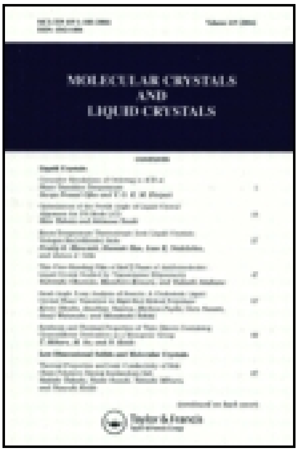

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José Luis Gayo [a] , José Manuel Otón [a] , Xabier Quintana [a] , Virginia Urruchi [a] , Cinzia Toscano [a] [b] & Noureddine Bennis [a]
[a] Dpt. Tecnología Fotónica, ETSI Telecommunicación, Universidad Politécnica, Ciudad Universitaria, Madrid, E-28040, Spain
[b] INFM Unitá di Napoli and Dip. Di Scienze Fisiche, Univ. di Napoli Federico II, via Cintia Monte S., Angelo, I-80126, Italy

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JOSÉ LUIS GAYO, JOSÉ MANUEL OTÓN, XABIER QUINTANA, VIRGINIA URRUCHI, CINZIA TOSCANO[a] and NOUREDDINE BENNIS

Dpt. Tecnología Fotónica, ETSI Telecommunicación, Universidad Politécnica, Ciudad Universitaria, E-28040 Madrid, Spain and
[a]*Permanent address: INFM Unità di Napoli and Dip. Di Scienze Fisiche, Univ. di Napoli Federico II, via Cintia Monte S. Angelo, I-80126, Italy*

A new manufacturing procedure producing asymmetric hysteresis curves in surface-stabilized antiferroelectric liquid crystal cells has been developed. It is based on the use of dissimilar surface conditionings on either side of the cell. The central relaxed AFLC state is not located at zero volts. The AF→F transitions on either side, consequently, are not produced at the same switching voltage. This behavior opens the possibility of driving the cell with several new modes, allowing some interesting effects such as video-rate multiplexed analogue grayscale with simple bipolar pulses, and long-term multistability.

Keywords Antiferroelectric liquid crystal; asymmetric hysteresis; analogue grayscale.

INTRODUCTION

Surface stabilized antiferroelectric liquid crystals (AFLCs) [1] may be of practical interest for their fast electrooptical response along with their intrinsic analogue grayscale –if stabilized with a constant DC holding voltage (*bias voltage*). These two properties together are highly

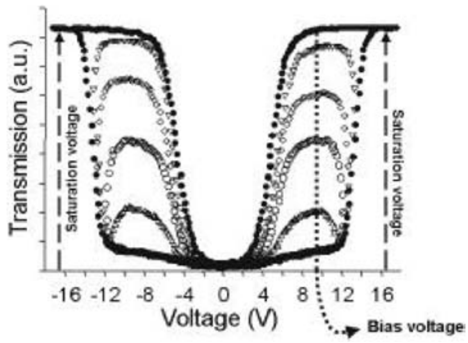

FIGURE 1. Electrooptical response of an AFLC cell driven with an AC 1 Hz triangular wave. The different gray levels obtained by varying the wave amplitude can be stabilized with the same DC bias voltage.

appropriate for a number of applications ranging from direct-view and projection displays –where their multistability can be exploited in passive matrix devices– to photonic devices requiring analogue variations of phase and/or polarization.

When an AFLC test cell is properly oriented between crossed polarizers, and a low frequency triangular AC signal is applied, a typical symmetric double hysteresis loop (Figure 1) is obtained as optical output. The symmetry reflects the electrically induced antiferroelectric-ferroelectric phase transition (AF→F), which is achieved by increasing the applied voltage either on the positive or on the negative side of the wave.

If the amplitude of the AC signal is reduced, intermediate gray levels are observed. This intrinsic grayscale has been considered a suitable alternative for multiplexed addressing of passive matrix displays [2]. Indeed, any gray level can be maintained using the same bias voltage. Addressing waveforms, moreover, easily avoid ionic effects [3] for they can be made symmetric by selecting gray levels at the positive and negative lobes alternatively. The resulting waveform is automatically DC-compensated. The symmetric double optical hysteresis loop, therefore, may be advantageous in principle, for it allows the design of DC-compensated driving waveforms. Details on symmetric driving of AFLC cells have been published elsewhere [4].

In practice, however, the advantages are less evident. Bias voltage contributes to contrast reduction in AFLC cells due to the pretransitional effect. On the other hand, manufacturing tolerances produce optical responses not entirely symmetric, which in turn induce flickering if symmetric addressing waveforms are employed [5].

In this work, a different manufacturing protocol has been followed to achieve asymmetric optical responses, i.e., hysteresis loops not centered on the 0V position. This allows exploring the behavior of these materials upon non-symmetric addressing.

EXPERIMENTAL

Asymmetric cells are prepared by dissimilar surface anchoring on the cell plates. One of the surfaces is conditioned with a cured and rubbed spin-coated polymer such as Nylon-6; in the opposite side, an unstoichiometric oxide such as silicon monoxide or tungsten trioxide is deposited by thermal evaporation or sputtering. The plates were placed at highly tilted orientation (75°) from the source, so that deposition occurred at almost grazing incidence. 1.8 ìm unpixelized cells were assembled with these plates. Finally, cells were filled with commercial mixture CS-4001 (Chisso) in a vacuum chamber with a programmable temperature stage. Further manufacturing details are included in [6].

The evaporated or sputtered oxide, traps positive charges during the growing of the layer [7]. When an appropriated polarity DC voltage (or very low frequency voltage) is applied to the cell, some of these charges, those that are next to electrode, are compensated with electrons arising from the external field. Electrons are temporally trapped, unless an opposite DC field is applied. This produces an internal field inside the cell in absence of external applied voltage that shifts the electrooptical response curve. When exciting the cell with a triangular low frequency waveform, a displacement of the hysteresis curve is observed (Figure 2).

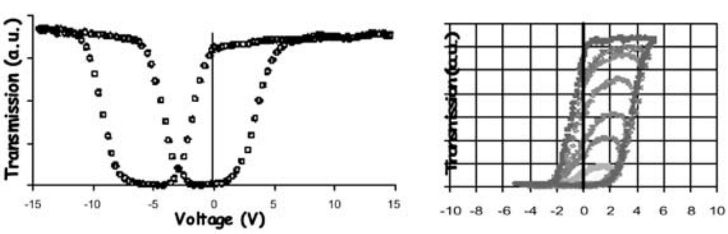

FIGURE 2. Shifting of the hysteresis curve. Left, shifted hysteresis. Right, shifting allows inducing gray levels in one lobe while the other remains unswitched.

If a saturating voltage is applied (Figure 2, left), a shifted asymmetric double hysteresis curve appear. For non saturating triangular waveforms, intermediate gray levels are achieved (right). In this case, the grayscale may display just in one lobe, while the other lobe remains unswitched. This situation is maintained while the running voltage is higher than the switching voltage of one lobe and lower than the switching voltage of the opposite lobe. The cell behaves as if a DC signal were superimposed to the external waveform [8].

The actual magnitude of induced shift depends on the manufacturing conditions of the deposited layers. Its effect on the electrooptic response depends on the switching characteristics of the liquid crystal, specially the switching threshold voltage. Indeed, the same shift may produce different effects on different materials, as the 0V position becomes closer to the bias voltage required for gray level stabilization.

Low or moderate shifts (e.g., 1 V) are fairly stable: once the cell is properly activated, the value remains constant upon further electric cycles or short circuits. The asymmetry and the contrast are reproducible over the cell area. Higher shifts show drifts upon electric cycles, as the presence of ions becomes more relevant. A comprehensive experimental study and modeling of the internal trapping processes and the rate of electron trapping and liberation is currently under development.

RESULTS AND DISCUSSION

As a rule, asymmetric multiplexed cells show improved optical performances compared to similar symmetric samples. The pretransitional effect is somewhat alleviated by the shifted hysteresis curve, thus improving the contrast ratio. Contrast ratios over 200, unusual for antiferroelectric liquid crystals with symmetric alignment layers, have been obtained in some cases.

A number of applications have been identified for this asymmetric response. The range of these applications chiefly depends on the hysteresis induced shift:

- If low shift samples are employed, then a constant DC bias voltage is still required for the gray levels to stabilize. The bias voltage will be indeed lower than the corresponding voltage for symmetric addressing modes, yet the waveform will be simply derived from the corresponding symmetric waveform. An example is given below.

- If a higher voltage shift is achieved, then the bias voltage and the 0 V position may coincide. In this particular case, a multistable sample, able to stabilize any gray level without power supply, would be achieved.
- Yet a third possibility arises for low shift samples: if a sample requiring bias to stabilize gray levels is driven by a waveform with no bias, unstable gray levels are obtained. These levels may be useful in some applications, as shown below.

Single Lobe DC Compensated Waveform

Figure 3 shows an example of multiplexable asymmetric DC compensated waveform. In this case, only the positive lobe is used. The positive selection pulse at the beginning of the frame contains the gray level data. The wide plateau covering most of the frame is the region where bias is applied. Finally, a reset region is included: a simple negative well is used to erase the pixel and to compensate DC. Note that the negative well amplitude is lower than the switching voltage of the negative lobe; therefore, the pixel is optically turned on just by the positive selection. This is an advantage compared to symmetric waveforms. It has been shown [5] that small differences in optical response of the positive and negative lobes of symmetrically driven AFLC cells induce flickering. The problem is obviously overcome by asymmetric addressing.

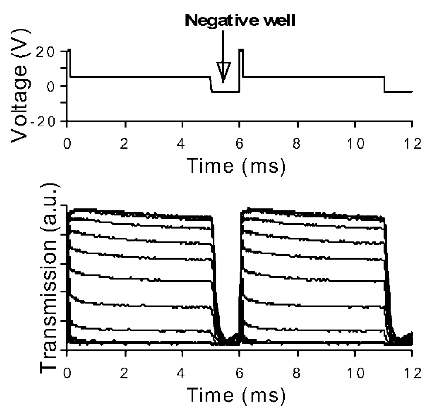

FIGURE 3. Stable multiplexable gray-scale obtained on a single lobe of the hysteresis curve. See text for details.

Asymmetric waveforms like this are applicable to video-rate frequencies. In the case shown in Figure 3, a frametime of 6 ms is used. This scheme is fast enough to allow three frames per image (18 ms) in a 60 Hz video application. These three frames could be used, for example, to supply sequential color to the display, i.e., to show sequentially R, G, and B frames at a rate high enough for the eye to integrate the whole image.

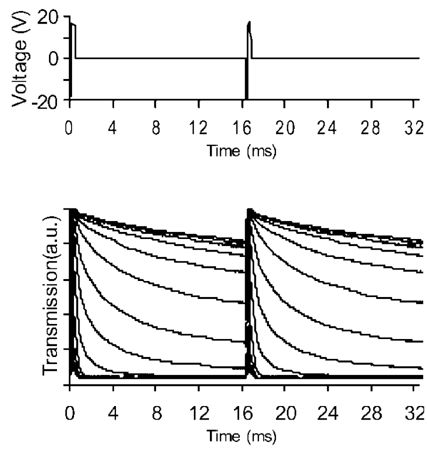

FIGURE 4. Unstabilized video-rate grayscale obtained with a simple bipolar waveform.

<u>Unstabilized Gray Levels</u>

If one lobe of the hysteresis cycle were centered at 0V, no holding voltage would be needed to stabilize gray levels, i.e., the required bias voltage would be 0 volts. A multistable gray level display would be obtained in absence of external electrical field. Although no long-term stabilization has been achieved yet, gray level decaying times of several seconds have already been recorded. This issue is currently under study. If waveforms without bias stabilization are employed with samples having lower voltage shifts, then the gray levels are not stabilized. This situation need not be disadvantageous: in video-rate applications, for example, gray levels are refreshed every few ms, and the human eye is unable to observe the decay above a certain frame rate (this is the regular working mode in standard CRT monitors, actually).

An AFLC waveform without bias is highly attractive, since electronics are dramatically simplified, thus becoming a cost-effective alternative for video applications. Figure 4 is an example of a video-rate driven asymmetric AFLC cell whose addressing waveform has been reduced to a mere bipolar wave. Gray level data are included in the bipolar pulse and are bipolar themselves, so that the waveform is DC compensated. The 16.6 ms frametime chosen for this example correspond to a 60 Hz frame rate. An excellent grayscale is obtained, even when the grey levels are clearly not stabilized.

CONCLUSIONS

An asymmetric AFLC cell may be prepared by using different anchoring in either side of the cell. One plane is covered with an unstoichiometric oxide, while the other is conditioned with a standard polymer treatment. This method leads a shift of the entire optical hysteresis response curve, what in turn allows the design of some asymmetric addressing modes. These modes are potentially useful for a number of applications, ranging from long-term multistable cells without power supply to video-rate grayscales generated with simple bipolar pulses. In either case gray levels are produced only on one lobe of the hysteresis loop, so flickering arising from low-frequency components shown by symmetric addressing modes is overcome. The decrease in switching voltage on the working lobe also contributes to an improvement of the contrast ratio.

ACKNOWLEDGEMENTS
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