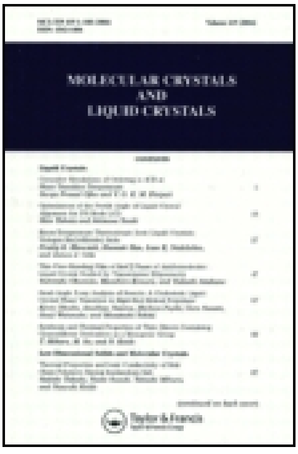

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Reflective SLMs Based on Antiferroelectric and V-shape Liquid Crystals

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Surface-stabilized antiferroelectric liquid crystals (AFLCs) and V-shape smectics share the spontaneous generation of intermediate transmission states, i.e. analogue grayscale. On the other hand, liquid crystal on silicon (LCOS) appears to be a promising alternative to thin-film transistors (TFTs) in the preparation of reflective microdisplays and spatial light modulators (SLMs). The feasibility of preparing LCOS SLMs using AFLC and V-shaped LCs has been analyzed. A comparative study of a number of AFLC and V-shape materials as candidates for LCOS SLMs has been carried out. Test cells below 1 μm have been prepared using an ITO-coated transparent glass plate and an aluminized silicon back plate mimicking the actual LCOS device. AFLC waveforms compatible to low-voltage operation of the silicon backplane have been demonstrated. V-shape waveforms have been designed and demonstrated as well. The results show that both LC families may be employed in this specific application. Dynamic behavior, with frame rates over 200 Hz, is especially remarkable.

Keywords: Antiferroelectric; V-shape; waveform; grayscale; silicon backplane

INTRODUCTION

Surface stabilized chiral smectics showing ferroelectricity have attracted attention for their potential use in applications such as passive-matrix displays [1]. Some of these phases show multiplexable analogue grayscale and can be driven by external electric signals achieving bistable or multistable optical transmission levels. From the practical point of view, the most interesting ones are the antiferroelectric (AFLC) phases, and the formerly called thresholdless antiferroelectrics [2], presently known as V-shape response chiral smectics for their characteristic electrooptic response to low frequency AC signals [3].

These materials may be interesting for active matrix applications as well. Indeed, their natural in-plane switching [4] and fast electrooptic response are attractive even when their bistability or multistability are not strictly required for multiplexing. The use of specific waveforms for AFLC addressing in active matrix environments has been demonstrated [5]. The main drawback for their actual utilization is their comparatively high switching voltage, about 15-25 V typically (Figure 1). This value is too high to be achievable by active matrices derived from standard electronics.

It is important to realize, however, that the dynamic range of the AFLC grayscale runs over 3-4 V typically, i.e., within the limits imposed by the electronics. It could be possible, therefore, to employ these materials on active matrices provided that the high-voltage pulses could be confined to the counter electrode, whereas the low-voltage pulses containing the grayscale information are provided by the active matrix itself. The combined action of both pulses may then provide the required voltage for multiplexing the display.

These ideas have been tested out over active matrices based on silicon backplanes.

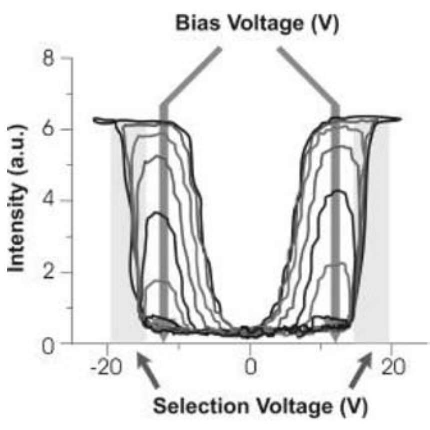

FIGURE 1. Typical electrooptic response of AFLC cells at low frequency, showing the ranges for switching voltage and grayscale.

Liquid crystal on silicon (LCOS) cells are reflective devices that may compete with thin-film-transistor displays in projection applications. Being manufactured in standard microelectronic facilities using standard silicon wafers, LCOS are a cost-effective alternative to transmissive spatial light modulators (SLM) [6]. Their use in projection is curtailed by the poor quality of reflective color in LCs, which effectively reduces their field of application to projectors featuring three SLMs for independent management of RGB signals.

Associating LCOS with either antiferroelectric or V-shape LCs can be advantageous for their remarkably short switching time and may be applied to the design of devices with sequential, rather than parallel, colors. If the full display can be effectively multiplexed at three times the frequency of the desired image rate, then sequential color may be employed. In this paper, frame rates over 200 Hz have been demonstrated. Therefore, the possibility of using sequential color in 60 Hz video applications has been achieved.

EXPERIMENTAL

Cells were prepared using standard procedures. The materials were homogeneously aligned with a cured and rubbed spin-coated polymer. Best results were obtained in most cases with Nylon-6. Polished unpixelized and pixelized silicon samples were metallized with aluminum using thermal evaporation. 0.8 im cells were assembled with one side made of aluminized silicon, and the other side made of ITO-coated polished glass. Cells were filled with a number of AFLC and V-shape commercial materials (CS-4000, CS-4001) and experimental mixtures.

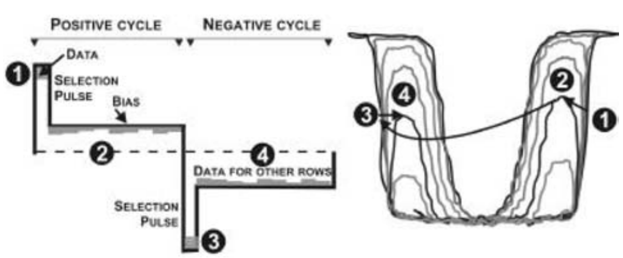

FIGURE 2. Basic waveform for AFLC driving. Data are included onto the selection pulse; a holding voltage, called bias, is applied during the remaining part of the frame to stabilize the chosen gray level.

The characterization system consists of a polarizing microscope with a positioning system and a programmable hot plate where the sample is placed. A programmable arbitrary waveform generator and fast amplifier is used to drive the LC cell. The wave shape is drawn in a PC connected to the system via GPIB. The light output from the cell is collected into a bunch of optical fibers and brought to a photomultiplier, whose electric response is acquired by a digital oscilloscope. Finally, the stored response is sent from the oscilloscope back to the PC, which in turn may modify the programmed waveform accordingly.

WAVEFORM DESIGN FOR AFLC

Design of waveforms for LCOS AFLC devices has been based on previous multiplexable waveforms for passive and active matrices. Summarizing, the waveform must contain a selection pulse and a holding region (bias) to stabilize the gray levels. The simplest multiplexable waveform having these is shown in Figure 2. A selection pulse ❶ is followed by a bias region with constant voltage ❷. The gray level data are included in the selection, while the bias voltage is a common voltage that stabilizes any gray level. Therefore, the waveform

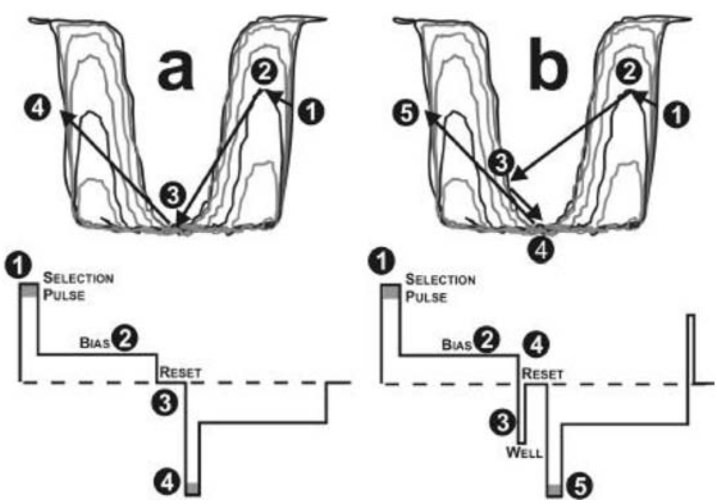

FIGURE 3. Working waveforms based on relaxation for passive displays. a) Simple relaxation. b) Forced relaxation.

can be multiplexed. Then the cycle is repeated over the negative lobe of the hysteresis curve, so that the waveform becomes naturally DC-stabilized.

This simple scheme does not work, since the electrooptical response of the AFLC material to a given voltage pulse depends on the previous state of the pixel. To avoid this undesirable memory effect, the pixel must be erased between consecutive cycles. An erasing procedure based on saturation (i.e. electrically induced AFLC→FLC phase transition) has been proposed in [7, 8], while a second procedure based on relaxation (Figure 3) has been proposed by our group [5, 9]. The advantage of the saturation procedure is that all steps are voltage-dependent; therefore, it shows in principle faster response than in the relaxation schemes. Our group has demonstrated, however, that the slow relaxation process may be substantially reduced by forcing the relaxation with a counter pulse (well pulse ❸, Figure 3b).

Adapting this waveform to active LCOS devices is not straightforward. The active matrix works at much lower voltages than the required ones for AFLC driving; on the other hand, frames over the whole display must be setup and held along a substantial fraction of the frametime; this is necessary because the image is displayed by flash pulses. As a consequence of flash lighting, the usual multiplexing procedure by sequential rows and parallel columns is no longer useful –the chance of being lighted would depend on the row position.

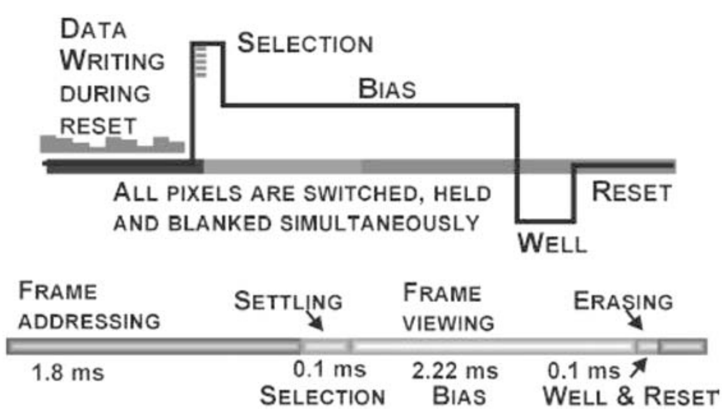

FIGURE 4. Adapted waveform for LCOS based on AFLCs. A single pulse applied to the counter electrode switches all pixels. Every pixel gets the gray level dictated by the active matrix.

Figure 4 shows the solution proposed for LCOS AFLCs [10]. The matrix is written during reset time; then a selection pulse applied to the counter electrode switches the whole display. Any given pixel "sees" the selection voltage and the voltage induced by the charge stored in the pixel. This allows every pixel to reach their corresponding gray level. A definite improvement of this waveform is given by the use of the LC relaxation "reset" time as the time the matrix needs to rewrite. In an actual case [11], a 4.5 ms frametime was needed, but the matrix writing time was about 1.8 ms (Figure 4, bottom). It was possible to save 2.22 ms for lighting by overlapping the reset time and the matrix writing. Writing data during reset is feasible because the switching voltage of AFLC materials is usually much over the voltage induced by the active matrix pixels upon charge storage. The LC behaves as if no voltage is applied and relaxes accordingly.

WAVEFORM DESIGN FOR V-SHAPE CHIRAL SMECTICS

Waveforms for LCOS V-shaped smectics show again constraints arising from the sequential lighting of the display. In the previous example, the frame time is about 5 ms. Under these conditions, the materials do not reach stable grey levels. Although this goes unnoticed to the eye, it is important that every pixel is switched in the same way at the same time, so that two pixels excited with the same voltage may

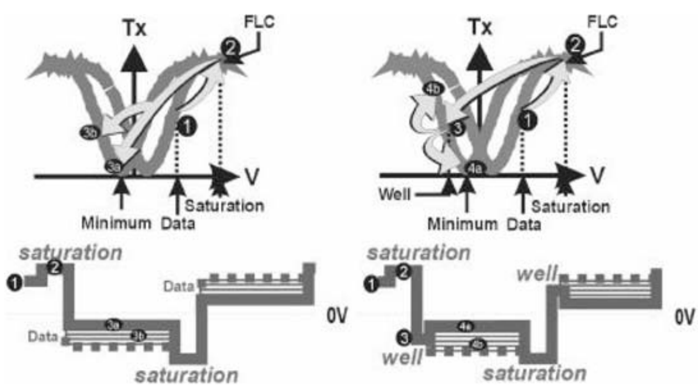

FIGURE 5. Waveform for V-shape LCOS cells. The wave takes into account the existence of V- and W responses. A well may be added after the saturation if required for speed..

reach the same gray level (regardless if stable or not). Specifically, the time elapsed between the selection pulse and the lighting period must be the same for all pixels. Note that this constraint is a direct consequence of sequential lighting (and short frametime); it does not affect backlighted direct-view V-shaped displays.

The idea is to switch all pixels at the same time, as in the previous case, after the data writing period. This could be easily accomplished in tristate AFLCs because the switching voltage effectively determines a threshold that avoids premature switching during data writing time. However, V-shape materials show thresholdless switching; therefore immediate switching upon data writing cannot be avoided. The solution proposed in this case is to saturate every pixel during the data writing time by applying a saturating voltage to the counter electrode.

Figure 5 shows the proposed solution [10]. The waveform takes into account that the V response often becomes W response if frequency or temperature are changed. Thus the waveform is designed to handle both responses in the same display. A voltage well may be optionally added to speed up the gray selection process after the relaxation.

SAMPLE CHARACTERIZATION

Figure 6 shows an example of characterization. A V-shape cell is driven by the waveform shown in the top. A 5 ms frame time is used. The writing time of the matrix is assumed to be 1 ms. During this time, the cell is saturated. Then the voltage applied to the counter electrode is turned off, and data voltages at the pixels switch the entire display. Switching and erasing times are notably small.

Note that this waveform is tailored for sequential lighting. Standard constant-backlighted displays cannot use with this waveform, since the reset saturating voltage would turn the pixel on in every frame. This would reduce the contrast to unacceptable values. However, contrast reduction does not happen in our case, as the lighting period is restricted to the region where the pixel gray levels are stabilized. In the example of Figure 6, the light is turned on approximately from the milliseconds 2 to 4, and from 6 to 8. The duty cycle is about 50%, a fairly high value that improves the display brightness.

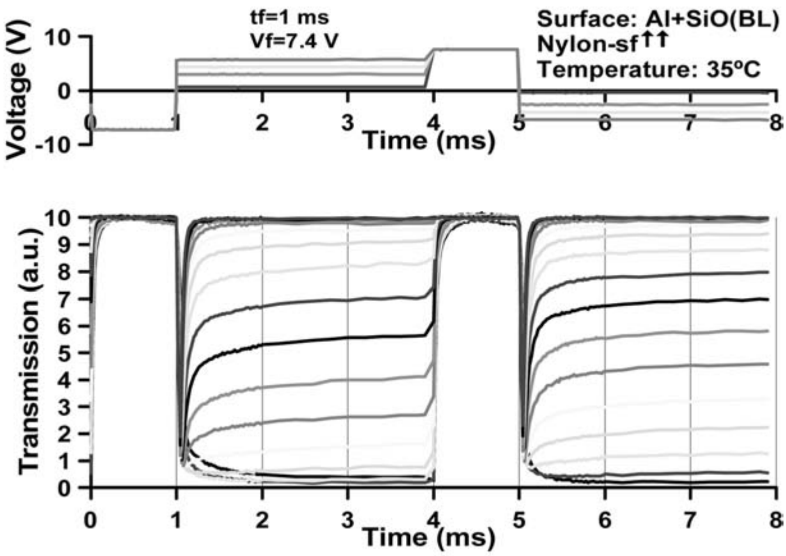

FIGURE 6. Characterization sheet of a V-shape material. The applied waveform is shown above and the electrooptical response is presented below. A 5 ms frame time has been chosen. Note the remarkable speed of the material and its associated waveform: the blanking decay time is below 100 ìs.

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