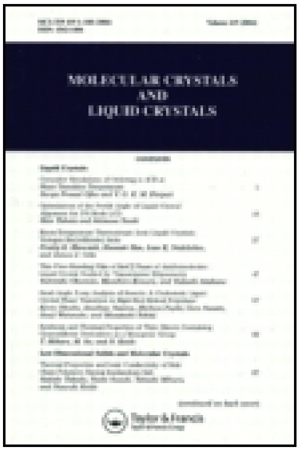

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Mechanism of Grayscale Generation in Antiferro-Electric Liquid Crystal Displays

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MECHANISM OF GRAYSCALE GENERATION IN ANTIFERRO-ELECTRIC LIQUID CRYSTAL DISPLAYS

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Abstract The statistical origin of grayscales showed by surface-stabilized antiferroelectric liquid crystal cells has been tested. Long-term stable microdomains have been detected, thus supporting the statistical mechanism. However, the relaxation time required for these microdomains to stabilize at room temperature is fairly large for current materials under actual working conditions. Therefore, a combined time-modulation/relaxation mechanism is proposed for video-rate grayscales in AFLC displays.

INTRODUCTION

Surface-stabilized ferroelectric liquid crystals[1] have attracted interest from both the basic and the practical point of view. The intrisic bistability of these devices leads in principle to displays featuring unlimited multiplexability on passive matrices. Development of ferroelectric liquid crystal displays[2] as an alternative to active-matrix nematic displays, however, has been delayed for a number of reasons, the lack of an intrinsic grayscale not being the least important.

The intrinsic grayscale demonstrated by antiferroelectric liquid crystal (AFLC) cells[3] could overcome this problem. Surface-stabilized AFLCs are not bistable; yet simple, multiplex-compatible, addressing waveforms containing DC levels along the frametime can be designed for AFLC displays[4]. Electrically-induced phase transitions from antiferroelectric to ferroelectric phase are employed in these displays. It is customary to choose the antiferroelectric phase as dark state, and the two opposite ferroelectric phases as clear states alternatively, so that DC signals are compensated every two cycles. Under these circumstances, short voltage pulses (selection pulses) give rise to gray levels that can be detected in the AFLC hysteresis cycle either as incomplete antiferroelectric→ferroelectric electrically-induced switching or as partial ferroelectric→antiferroelectric relaxation. In both cases, if a DC signal (bias voltage) is applied to the cell after the selection pulse, the gray level (i.e., the partial optical transmission) is maintained along the frametime (typically 1/25 - 1/30 s in video-rate displays). In this work, the formation and stability of AFLC gray levels in multiplexed displays has been investigated.

PROBLEM FORMULATION

Microscopic inspection[5] of AFLC cells with gray levels reveals a large number of clear and dark microdomains. These are small enough for the naked eye to see homogeneous gray areas. The presence of microdomains supports the statistical origin of AFLC gray levels: different cell regions, whose manufacturing parameters are not exactly the same, show different V-t curves and thus different switching voltages for a given set of experimental conditions. A recently published model[6] demonstrated that small fabrication variations (i.e., within manufacturing tolerances) may induce this behavior in AFLCs.

If a photodetector is coupled to the microscope, a time variation of the optical transmission is found. The bias voltage level of the addressing waveform (which is constant as dictated by

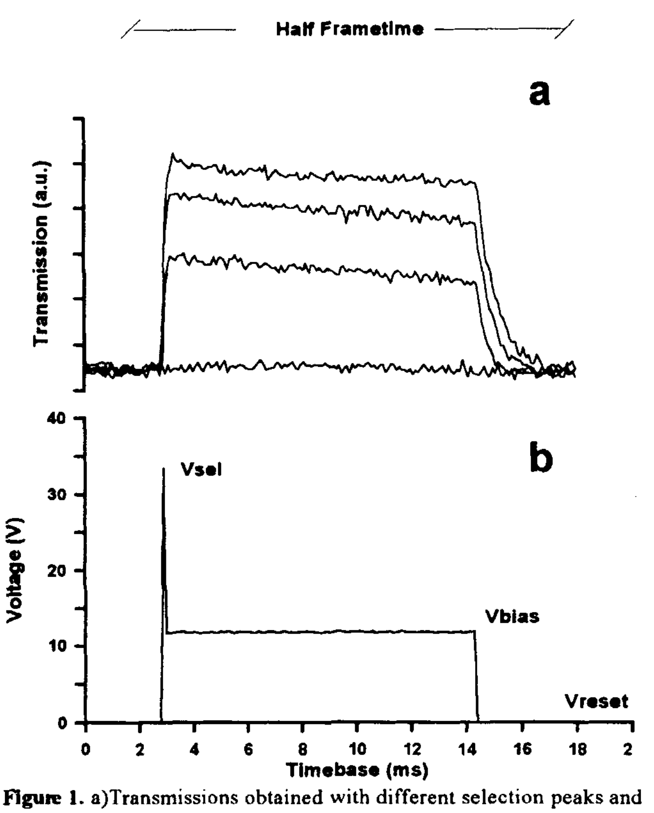

Figure 1. a)Transmissions obtained with different selection peaks and same bias voltage.b)Typical waveform for multiplexed AFLC displays.

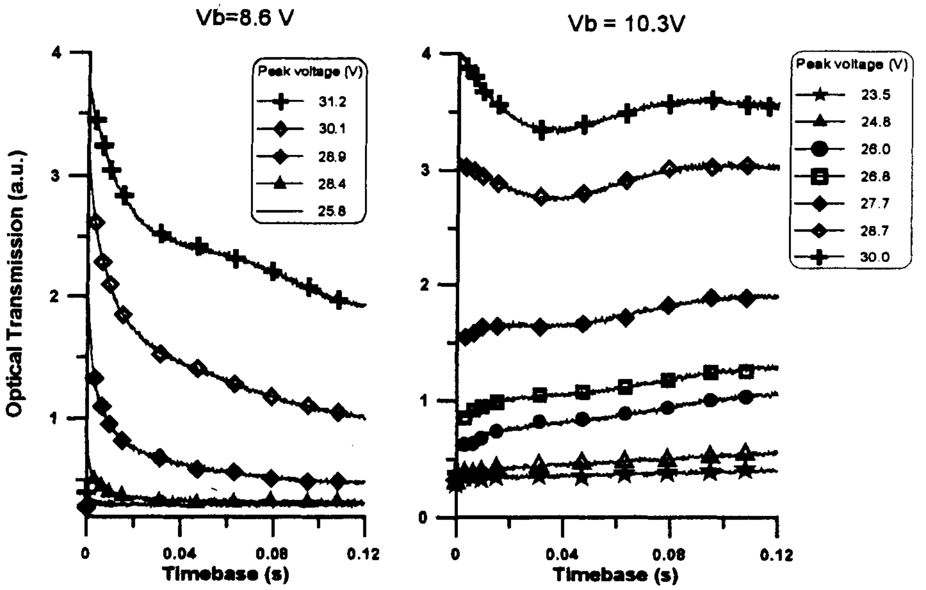

Figure 2. Examples of uncompensated bias. Note that timescale is too large for video rate signals.

the multiplexed working mode) is usually chosen so that constant optical transmission is obtained. However, it is not possible to achieve constant optical transmission for all the gray levels using the same bias voltage (Figure 1). In practice, bias voltage is adjusted for intermediate gray levels, as display flickering[7] is then minimized. No stable intermediate transmissions are achieved in this time span (30-40 ms) with actual devices. A search for bias levels producing long-term stabilized intermediate transmissions has been carried out. If a single bias level is able to stabilize any intermediate transmission, this would support the statistical model of AFLC grayscale, as microdomains could be taken as independent from each other. Otherwise the statistical model would have to be rejected.

EXPERIMENTAL

Test cells (1.7 μm thickness) filled with the AFLC commercial mixture CS-4001 (Chisso) were used. Low-pretilt PIQ polyimide was used as surface conditioning. Cells were placed in a hot stage (Mettler FP-80) on the plate of a Nikon POL 2 polarizing microscope. Working temperature was 35°C for all the experiments. An optical fiber bundle was adapted to the microscope output, and the emerging light

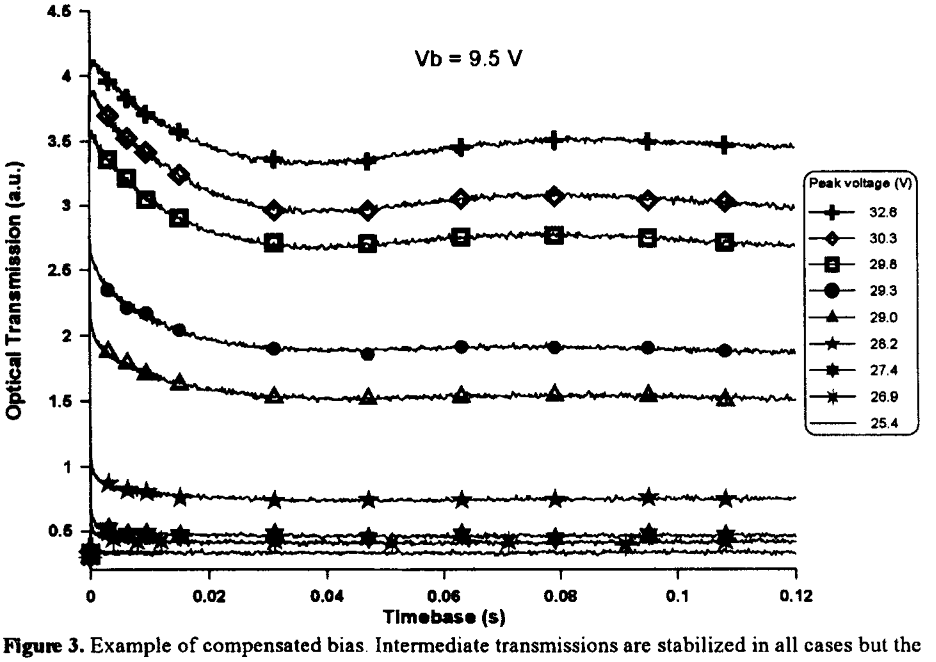

Figure 3. Example of compensated bias. Intermediate transmissions are stabilized in all cases but the lightest grays.

was brought to a Hamamatsu H5783-01 photomultiplier connected to a 200 MHz Tektronix TDS420A digital oscilloscope. The addressing waveforms were produced by a DS345 Stanford Research arbitrary waveform generator. The whole experimental setup is controlled by a PC computer via GPIB. The computer stores the waveform into the wave generator, and reads the optical output and the applied voltage simultaneously from the oscilloscope. This process can be automatically repeated, allowing the design of thorough searches of parameter optimization.

Time for applying bias voltage in video-rate driving signals (see for example Fig. 1) is about 15-20 ms. As no stabilization was achieved, addressing signals whose bias period had been extended to 120 ms were programmed. These are signals employed in this work.

RESULTS AND DISCUSSION

Figure 2 shows two examples of uncompensated bias. In these measurements the bias voltage was kept constant, while the height of the selection peak was modified.

The lower bias voltage stabilize the darker gray levels, while the higher voltage stabilize the lighter gray levels. The remaining gray levels evolve in both cases. The final optical state is dark or clear, i.e., no stable intermediate transmissions are obtained. This means that a single phase (antiferroelectric or ferroelectric, respectively) is ultimately formed.

Figure 3 shows the best set of parameters found for this material and working conditions. Again, the bias voltage is constant, and the selection voltage is modified. Long-term stabilization is achieved for the whole range of gray levels except the highest ones, which still show slow decay. Stabilization of the lightest gray levels is preceded by an oscillation of the optical transmission; this is presently under study. Note that none of these optical features is usually observed in actual displays, since the time scale employed in this work is larger. In fact, the video-rate grayscale of these cells (corresponding to the left darker regions of figures 2 and 3) show unacceptable decays for the optimum waveform (Figure 3), while is fairly compensated for the 10.3 V bias voltage case shown in Figure 2. These results lead to several conclusions:

- Long-term stable intermediatetransmissions can be achieved by using different selection peaks with the same stabilizing bias voltage. Depending on this voltage, different grayscales are obtained (Figure 4). The statistical nature of AFLC grayscale, while not fully demonstrated, is reinforced by this fact.
- The stabilization of

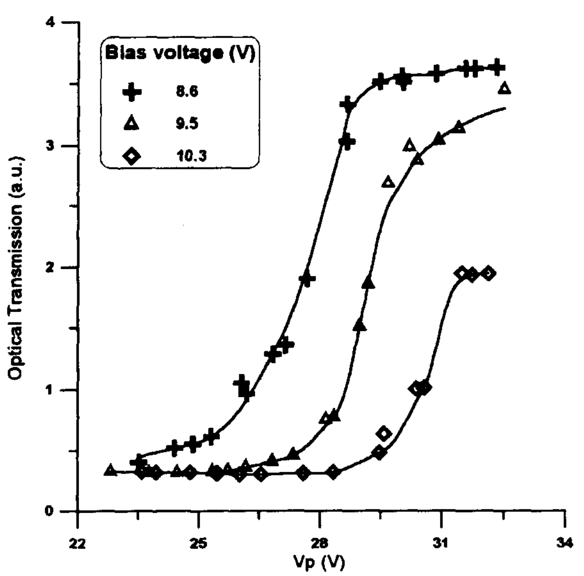

Figure 4. Grayscales obtained with compensated and uncompensated bias voltages.

intermediate optical transmissions is too slow for video applications, at least for current AFLC materials and moderate temperatures. Increasing temperature would speed up the relaxation processes; however, the resulting grayscale would be exceedingly sensible to small temperature changes. This could jeopardize the spatial homogeneity of the grayscale across the display.

Even if the stabilization were fast enough for video applications, multiplexing would introduce superimposed spurious voltage signals from the data columns on the bias level. Therefore, depending on the data contents of other display areas, the effective bias voltage would be different.

In summary, a statistical mechanism based on independent microdomains seems to be responsible of the grayscales shown by surface-stabilized AFLC cells. In actual video-rate working conditions, however, gray levels are obtained by a combined mechanism of time modulation and bias stabilization. Optimized video-rate waveforms need not be the same as optimized stabilizing waveforms, since no stable gray levels are usually achieved in actual devices.

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