Gray Scale Generation and Stabilization in Photo-aligned Ferroelectric Liquid Crystal

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ABSTRACT

Intrinsic gray scales generation and stabilization in photo-aligned ferroelectric liquid crystal display (FLCD) have been proposed. The frequency dependence of the FLC hysteresis loop is discussed for steady bistable switching under passive addressing. The dependence of transmission on the amplitude of switching pulse is discussed for the criterion of memorized gray scale generation and stabilization. Based on this, passive 160X160 multiplex addressing photo-aligned 5μm reflective FLCD with high contrast and four memorized gray scale levels is developed and demonstrated.

INTRODUCTION

Surface-stabilized ferroelectric liquid crystal (SSFLC) [1] has attracted great interest with regard to passive matrix displays due to its memory effect, wide viewing angles and fast response time. However, the generation of the gray scale was always an issue [2]. Common surface stabilized FLC structure with a bistable switching can memorize black and white states, but cannot provide an intrinsic gray scale.

Recently, our group has already demonstrated high uniformity of the FLC layer obtained by a photo-alignment technique using a kind of azo-dye SD-1 [3-5], which chemical structure is shown in Fig. 1.Domain texture can be observed after switching off the applied voltage for the FLC cell with very thin SD-1 alignment layer, which is the reason of gray scale generation [3]. We demonstrated the gray scale by changing the frame time {4,5}, but this method cannot be used in real displays because of the requirement of a fixed frame time. Then, we proposed a kind of a modified Seiko-standard multiplexing scheme to generate memorized gray scales for our passive matrix FLCD [6]. As pulse width modulation (PWM) method is employed, very fast driver is needed for more gray scales. Furthermore, it is not clear how to stabilize and reproduce the gray scales for passive multiplex driving of FLCD, which should be more concerned about.

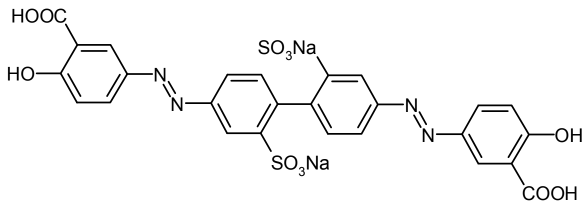


Fig. 1 Structure of azo-dye SD1

In this paper, we will discuss and investigate the principle of generating and stabilizing gray scales under passive matrix addressing. Based on this, passive 160X160 multiplex addressing photo-aligned 5 μ m reflective FLCD with high contrast and four memorized gray scale levels is demonstrated, which shows the gray scales can be highly reproduced and stabilized.

Experimental

Fig. 2 shows the schematic diagram of our FLC cell. The two glass substrates with Indium Tin Oxide (ITO) were covered with 0.4% SD-1 in N,N-dimethyl formamide (DMF). After spin coating, both substrates were baked at 155^0C on the hot plate to remove DMF solvent. Polarized UV light was produced by a super-high pressure Hg lamp, an interference filter at 365nm and a polarizing filter. The light with an intensity of 2.3 mW/cm^2 was used in experiment. The two substrates were illuminated under polarized light to get parallel alignment. After assembled with spacers, FLC mixture was injected into the empty cell. Finally, the cell was slowly cooled down to room temperature and FLC phase was transformed from SmA to SmC*. The FLC material was FLC-514 from P. N. Lebedev Physical Institute in Moscow. This FLC has a spontaneous polarization of P_s~100nC/cm^2 and a tilt angle of $\Theta=26^0$ at $T=23^0$C. The phase transition sequence was as follows:

SmC*->$^{71°C}$->SmA->$^{85°C}$->Is.

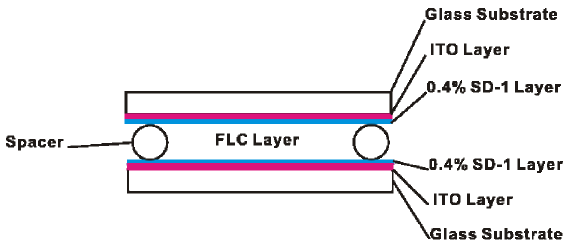


Fig. 2 Schematic diagram of photo-aligned FLC cell.

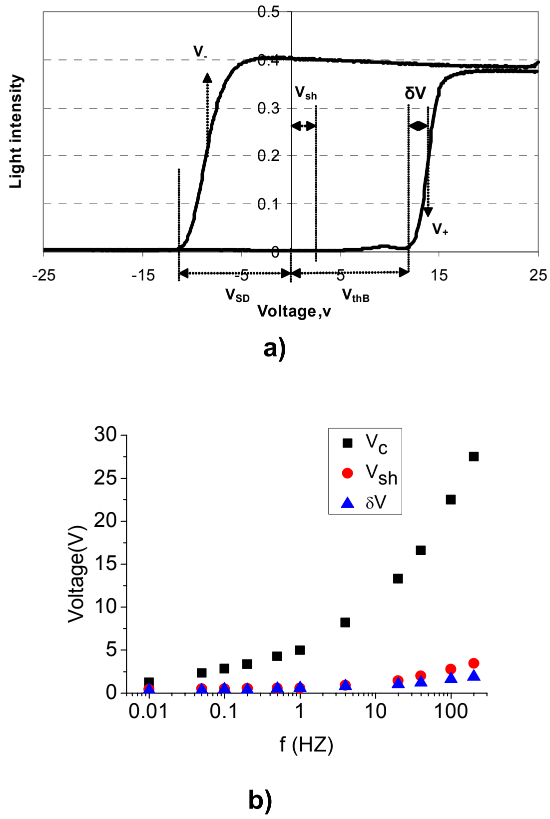


Fig.3 (a) Hysteresis loop of 5μm FLC-514 cell; frequency of triangular voltage f=100HZ, amplitude ±25V, T=23°C. (b)frequency dependences of V_c, V_{sh} and δV of 5μm FLC-514 cell.

Results and discussion

1) Bistability steadiness for photo-aligned FLC display under passive addressing

The condition of bistability steadiness is based on the shift of hysteresis loop center proposed by us [6]. The static hysteresis loop of 5μm FLC-514 sample is measured as Fig. 3(a) with triangular voltage of the frequency f=100HZ and amplitude ±25V. The voltage coercivity (the width of an FLC hysteresis loop) V_c is define as:

$$V_c = V_+ - V_- \qquad (1)$$

where V_+ and V_- are switching voltage thresholds that correspond to the peaks of the polarization reversal current at positive and negative voltages, respectively. The shift V_{sh} of the hysteresis loop center with respect to zero voltage, which usually takes place in FLC cells, can be evaluated as:

$$V_{sh} = 1/2(V_+ + V_-) \qquad (2)$$

FLC bistable switching can be steady and reliable in both static and dynamic regimes, if the parameter S_b satisfies the condition[6]:

$$S_b = \frac{0.5V_c - |V_{sh}|}{\delta V} \geq 1 \qquad (3)$$

The values of Vc, $|V_{sh}|$, and δV are all frequency dependent as illustrated in Fig3(b) at the range 10^{-2} – 10^{2} HZ for the photo-aligned 5μm FLC-514 cell. It clearly shows that the validity of above condition even at zero frequency, which automatically holds for any higher frequencies. Furthermore, in order to generate reproducible gray scale for FLCD under passive addressing, $|V_{sh}|$ should be as small as possible.

2) Principle of gray scale generation and stabilization for passive addressing FLC display

Owing to hysteresis loop for FLC, a special waveform including two pulses should be designed to generate FLC gray scale (Fig. 4).

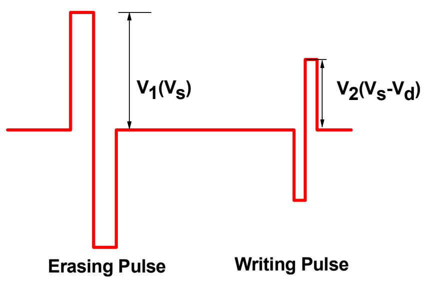


Fig. 4 Driving waveform for gray scale generation of FLCD: varying the amplitude of writing pulse with fixed duration time

First pulse is erasing one, which has large enough amplitude (V_s) and duration time to change the state of FLC to “dark” (or “bright”). Second pulse is writing one, which is used for gray scale generation. The amplitude (V_r) is changing for analog gray scale generation while the duration time (T) is fixed.

Fig. 5 shows the dependence of the transmission of 5 μm FLC 514 cell on the amplitude of the writing pulse, when the duration time is fixed (1ms). During the measurement, the erasing pulse forces all the FLC molecules to the dark state.

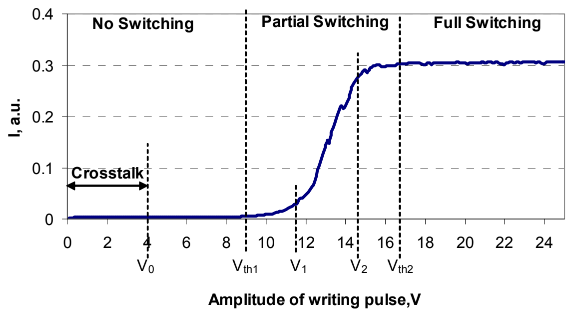


Fig.5 Dependence of transmission of 5μm FLC 514 cell varying the amplitude of selecting pulse with fixed duration time (1ms).

When the amplitude of the writing pulse V_{wr} is smaller than a threshold value $V_{wr} < V_{th} = V_{th1}$ (Fig.5), no switching is observed and FLC will keep its initial (dark) state. Taking into account of multiplex driving for FLC display, the worst case of crosstalk is two random data pulses with opposite polarity adjacent near each other. In this case, they are equal to a pulse with the twice duration time. So, if we want to make sure that the random crosstalk cannot switch the state of FLC under any circumstances, the data pulse must satisfy the condition of $V_d<(1/2)V_{th1}$ (4V in Fig.5) to stabilize the gray level with crosstalk under passive multiplex driving of FLCD. As the electrical field increases larger than V_{th1}, the directors of FLC molecules start to flip into the opposite allowed orientation. In the regime of $V_1<V_{wr}<V_2$ (V_1=12V and V_2=14.5V in Fig.5), the transmission of FLCD will be approximately proportional to the amplitude, which means the domain area is proportional to the amplitude of writing pulse V_{wr}. Therefore, it is possible to address any gray scale level through varying V_{wr} in principle. As the amplitude of writing pulse increases large enough, all FLC molecules are switched to the opposite allowed direction and the state of FLC is bright no matter how large of amplitude V_{wr}>V2th (V_{2th}=16V in our experiment).

3) Investigation of Gray Scale Stability under passive matrix addressing

Fig.6 is the driving waveform for gray scale stability investigation of FLC cell under passive matrix addressing. The multiplex ratio for simulation is 60:1, which means 59 crosstalk pulses following the writing pulse. It is interesting that how ferroelectric domains can be stabilized and gray scale can be reproduced in practice, which should be highly concerned for passive addressing FLC display.

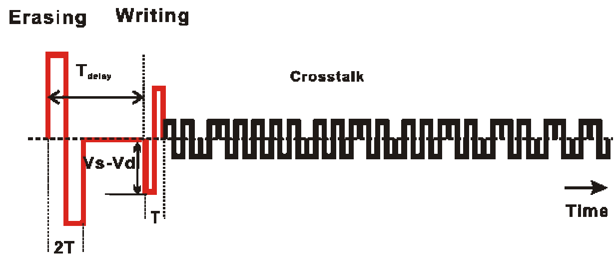


Fig.6 Driving waveform for investigating gray scale stability of FLC cell with a multiplex ratio 60:1

Taking into account Transmission vs. Voltage (TVC) response of 5μm FLC cell without crosstalk (Fig.5), the amplitude of 13V and the duration of 1ms can let the transmittance of FLC cell to 50% of maximum value. So, we can select 13V and 2ms pulse for erasing while 1ms for writing pulses in experiments (Fig.6). For crosstalk pulse, the amplitude is varied and the duration time is fixed as the same as writing pulse (1ms). This simulation condition is totally the same like the performance of every pixel in FLCD under passive matrix addressing. The erasing and writing pulses is corresponding to the row driving waveform, while crosstalk is the column driving waveform with multiplex ratio of 60:1.

Fig.7 shows the TVC response of the same 5μm Photo-aligned FLC cell using the simulation waveform as in Fig.6. The erasing pulse is 13V and 2ms, while 1ms duration is used for writing pulse and crosstalk pulse. The transmittance of FLC cell is measured when changing the amplitude of writing pulse under different crosstalk (1V, 3V, 5V). It clearly shows that smaller crosstalk affects the gray scale levels less. However, for the real passive driving scheme, the gray scale levels are generated by varying the column driving voltage. At the same time, the amplitude of writing pulse is the

the fixed as the erasing one for row driving (13V). In this case, smaller column driving voltage means the range of addressing voltage ($V_{wr}=V_{row}- V_{colomn}$) is narrower. The number of gray scale addressing will be decreased. From Fig.7, 3V is reasonable for column driving. Under this driving waveform, the amplitude range for addressing gray scale will be from 10V to 16V, which as much as possible gray scale levels can be generated.

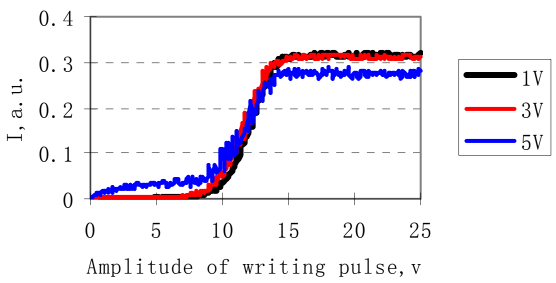
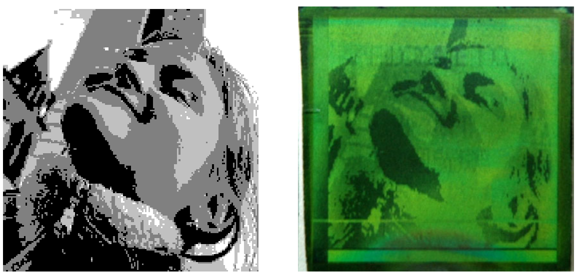


Fig.7 Gray scale stability for 5µm photo-aligned FLC cell under driving waveform (Fig.6) with different crosstalk of 1V, 3V, 5V

4) Demonstration of 160X160 passive matrix addressing FLC display with four memorized gray scales

Based on the investigation and discussion above, 160×160 passive matrix addressing FLC display (the size of about 48mm×44mm) was demonstrated. Fig.8 shows the original and the same Image on our bistable reflective FLCD with 4 memorized grey scale levels. The dark state is fixed here as a basic one, while the gray levels depend on the writing voltage with a fixed duration time.



a) b)

Fig.8 (a) the original image (b) the same Image on reflective 5µm photo-aligned 160X160 FLCD with 4 memorized grey scale levels.

Owing to a birefringence for 5µm cell gap, the nonselected and selected states are green and dark for our FLC display, which is green background in the image. The images can be saved for infinitive time without any power supply.

Conclusion

In this paper, principles and methods for gray scale generation and stabilization of photoaligned bistable FLC display are investigated and discussed both in theory and experiments. 160×160 passive matrix addressed bistable 5um FLC display is demonstrated at the first time. Images can be saved for very long time without any power supply. We believed, our result is a breakthrough for bistable FLC display with low power consumption, which is the best solution for watches, PDA or e-papers in the future.

Acknowledgements

The research was supported by ITF grant ITS/111/03, RGC grant HKUST 6149/04E and DAG05/06.EG14.

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