

20.3: Photo-aligned Ferroelectric Liquid Crystal Display with Memorized Gray Scale

E. P. Pozhidaev, V. G. Chigrinov, Li Xihua, H. S. Kwok

The Hong Kong University of Science and Technology, Clear Water Bay, Kowloon, Hong Kong

ABSTRACT

The new concept of the passive matrix ferroelectric liquid crystal display (FLCD) with a memorized grey scale is proposed. The physical origin of the gray scale in ferroelectric liquid crystal display is considered. The criterion of reliable bistability is derived dependent on FLC hysteretic behavior in electric field. A new approach for multiplex electronic addressing of the FLCD grey scale is given. A passively addressed 64×64 FLCD based on the photo-alignment technique is developed. New applications of passively addressed FLCD with a memorized grey scale are discussed.

1. Introduction

The gray scale of passively addressed FLCD can be obtained only if FLC possesses a high spontaneous polarization $P_s > 50 \text{ nC/cm}^2$ [1, 2], when ferroelectric domains appear, being one of the possible reasons for a gray scale. Generally, any kind of spatial non-uniformity of helix free FLC's [3] with a high P_s can be principally considered as a base for the gray scale. On the contrary, at high P_s depolarizing field appears in FLC cells, suppressing the bistability, if aligning layers are thick enough [4]. Therefore, extremely thin aligning layers are necessary condition for the development of passively addressed FLCD with a gray scale. One can even remove one of aligning layers, enabling the best quality of the FLC layer photo-alignment [5,6]. However, in this case the asymmetry of the FLC anchoring energy at the boundaries can create problems with the steadiness of bistable FLC switching, which is necessary condition of the FLCD multiplex addressing. This problem is considered in our work. A principle of multiplex addressing of FLCD's with the gray scale at fixed frame time will be also discussed.

2. Experimental

Asymmetric boundary conditions were used for modeling and manufacturing of the FLCD [5,6]. At this approach only one ITO surface of FLC cells was covered with a photo-aligning substance -

azobenzene sulfuric dye SD-1 layer [5,6], while another one was simply washed in N,N-dimethylformamide (DMF) and covered with 5,2 μm calibrated spacers. The azo-dye solution was spin-coated onto ITO electrode and dried at 155°C. A polarized UV light was achieved by using a super-high pressure Hg lamp, an interference filter at 365 nm and a polarizing filter. The light with intensity of 6 mW/cm² and wavelength of 365 nm was irradiated normally onto SD-1 layers. The FLC FLC-497 (from P. N. Lebedev Physical Institute of Russian Academy of Sciences) was injected into the cells in an isotropic phase by a capillary action at $T=85^\circ\text{C}$. This FLC possess the spontaneous polarization $P_s = 95 \text{ nC/cm}^2$ and the tilt angle $\theta = 27^\circ$ at $T=23^\circ\text{C}$, the phase transition sequence is as followed: $\text{Cr} \xrightarrow{4^\circ\text{C}} \text{C}^* \xrightarrow{57^\circ\text{C}} \text{A}^* \xrightarrow{76^\circ\text{C}} \text{Is}$. The helix pitch of the FLC tends to infinity in all the bulk due to compensation by two chiral dopants with the same signs of the spontaneous polarization but opposite signs of their handedness [3]. Electrooptical measurements were carried out using an ordinary electrooptical set-up based on He-Ne laser, Hewlett Packard Infinum oscilloscope and rotating table for adjusting of angular position of FLC cells placed between crossed polarizers. A programmed generator was used for experimental simulations of the multiplex operation.

Measurements of the anchoring energy of the FLC with aligning surfaces were carried out according to a method proposed in [7]. The idea is based on measurements of static hysteresis loops of FLC cells. "Static" means here the frequency interval $10^{-3} \div 10^{-2} \text{ Hz}$, where there is no dependence of the voltage coercivity V_c on the applied voltage frequency. The voltage coercivity can be defined as

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

where V_+ and V_- are the switching voltage thresholds at positive and negative voltage correspondingly [7] (Fig.1). A shift V_{sh} of the hysteresis loop center regarding zero voltage, which usually takes place in FLC cells, can be evaluated as (Fig.1):

$$V_{sh} = \frac{1}{2} (V_+ - V_-) \quad (2)$$

It is very important point in our analyses of the steadiness of FLC bistable switching, because if

$$V_{sh} \geq \frac{1}{2} V_c \quad (3),$$

the bistability does not exist (Fig.1).

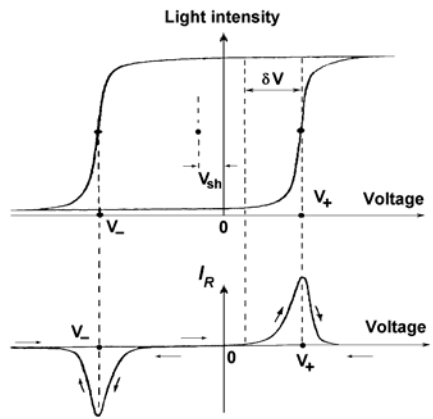


Figure 1. Top - a typical hysteresis loop of 6µm FLC-497 based cell (aligning layer thickness is 12 nm, the frequency is 0.02Hz) exhibiting a shift of the hysteresis loop center; bottom – a typical polarization reversal current of the cell.

3. Results and discussion

3.1 Criteria of bistable FLC switching

For evaluations of the bistability steadiness of display cells both in static and dynamic cases we propose now a new criterion:

$$S_b = (\frac{1}{2} V_c - |V_{sh}|) / \delta V \quad (4)$$

The parameter δV in (4) indicates a region inside the hysteresis loop, where the light intensity at the output of FLC cell depends on applied voltage, or the polarization reversal current is non-zero also (Fig. 1, bottom). Generally, one can evaluate the bistability steadiness even without any electrooptical measurements of hysteresis loops, simply measuring the polarization reversal current diagrams (compare top and bottom curves of Fig.1). The perfect FLC bistable switching takes place, if $S_b \geq 1$. In this case both dark and bright saturation levels of the light transmission obtained at applied voltage $V > V_+$ and $V < V_-$ can be memorized at zero voltage (Fig.1). If $S_b < 0$ then the hysteresis loop is completely located in positive or negative region of the voltage and perfect mono-stable operation of display cells occurs, i.e. FLC cell can memorize only one fixed light transmission level after the voltage is switched off. This case is completely inappropriate for passive multiplex addressing of FLC. An intermediate region $0 \leq S_b < 1$ corresponds to continuous transition from perfect bistability to perfect mono-stability of FLC display cells. The steady FLC bistable switching with $S_b \geq 1$ (unlimited

memory time) does not exist within the whole temperature region of smectic C* phase of the FLC because of strong temperature T dependence of $S_b(T)$. For example, the 6µm FLC-497 based cell with asymmetric boundary conditions manifests the temperature region with $S_b \geq 1$ at $T \leq 35^\circ C$, but at $51^\circ C \leq T \leq 56^\circ C$ the perfect mono-stability takes place because $S_b \leq 0$ (Fig.2).

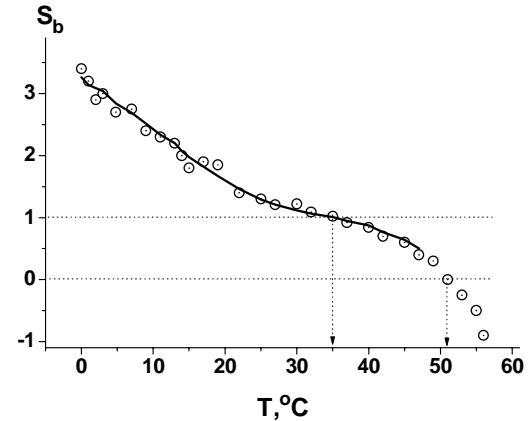


Figure 2. Temperature dependence of the bistability parameter S_b measured for the 6µm FLC-497 based cell at asymmetric boundary conditions, SD-1 layer thickness is 9nm, the frequency of triangular voltage $f=0.005Hz$, the voltage amplitude $\pm 3.0 V$.

Our evaluations of the temperature dependence of the bistability steadiness according to the criterion S_b have been confirmed by direct observations of bistable and mono-stable electrooptical responses in the corresponding temperature regions.

3.2 Optical manifestations and probable origin of ferroelectric domains modulation by the electric field

The FLC gray scale appears due to the so called ferroelectric domains existed in FLC cell with a high spontaneous polarization [8] (Fig.3).

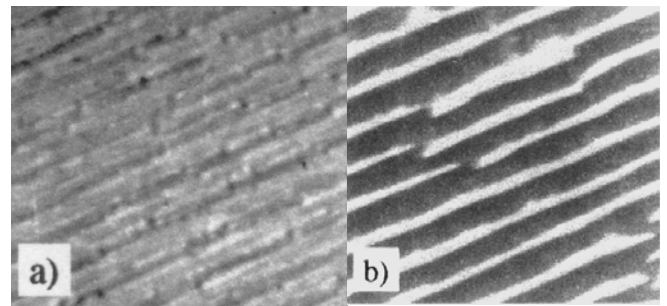


Figure 3. a) a 40×40µm size micro-photo of ferroelectric domains typical texture before the driving voltage application; b) the same area but the texture is memorized after application of the driving voltage [8].

The electrically modulated structure of ferroelectric domains, between two crossed polarizers is characterized by a regular structure of black and white stripes elongated along smectic planes of the FLC with the period, which is almost equal to ferroelectric domains period (compare Fig. 3a and Fig. 3b). Bright stripes indicate spatial regions, where the FLC director is completely switched and memorized, while black stripes correspond to absolutely non-switched regions.

Sharp boundaries occur between black and white regions illustrating the fact that the FLC director possesses only two steady positions. Thus any intermediate states between “black” and “white” states cannot be memorized. The apparent light transmission of the structure shown in Fig. 3b is a result of a spatial averaging of “black” and “white” areas light transmission inside the light aperture, which is much larger than the structure period. The gray scale appears as a result of this averaging, therefore one can discuss multistability of the light transmission levels only. Memorization of all generated gray scale levels for unlimited time is possible and confirmed in our experiments.

3.3 Principles of multiplexing driving voltage development

A driving voltage pulse sequence to provide the gray scale of passively addressed FLCD has been developed taking into account the two basic concepts. These are well-known Seiko-standard multiplexing scheme, which provides binary multiplexing mode of passively addressed FLC displays, and the pulse width modulation (PWM) technique used e.g. for the gray scale of STN displays [9]. A proposed modification of the Seiko-standard multiplexing scheme relates to the column voltage shape and polarity, while the row voltage shape is the same as for classic Seiko-standard addressing. Instead of a pair of “negative-positive” row voltage pulses the modified pair of the same total duration can be generated (Fig.4). Only time interval τ (Fig.4) can be changed and additionally, polarity of the pulses can be reversed. A rate of pulse width modulation can be defined as τ/T . Figure 4 summarizes our approach. The variation of τ/T parameter inside an interval $0 \leq \tau/T \leq 1$ provides the gray scale generation. At $\tau/T = 0$ (the column pulse in left bottom corner) the binary mode takes place. Relative intensity of gray levels vs τ/T parameter measured at multiplex driving for FLC 497 photo-aligned display cell with the FLC layer thickness $5,2\mu\text{m}$, $T=25^\circ\text{C}$ and the driving

voltage parameters: $V_{\text{row}} = \pm 20\text{V}$, $V_{\text{col}} = \pm 10\text{V}$ are also shown in Fig.5.

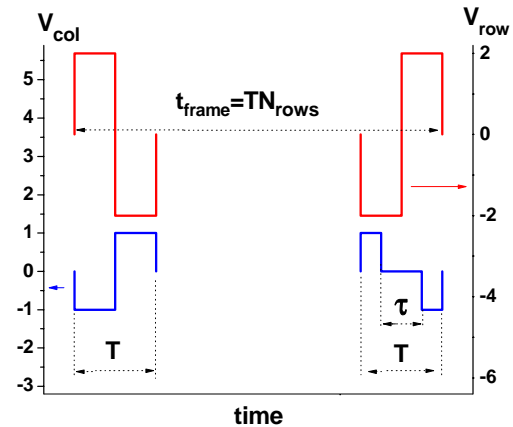


Figure 4. Modified Seiko-addressing scheme for FLC display.

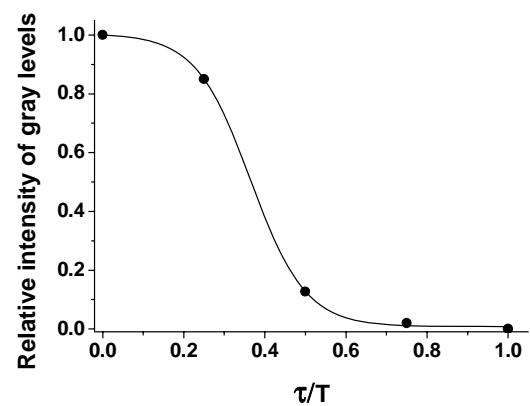


Figure 5. Gray levels in FLC cell obtained by the addressing scheme shown in Fig.4.

3.4 Potential applications

The main potential of applications is memorizing of images possessing gray scale levels for unlimited time after the driving voltage switching off. A simple display device based on 64×64 and $33 \times 33 \text{mm}^2$ photo-aligned FLC display matrix was made according to principles discussed above to illustrate this idea (Fig.6). As seen from Fig. 6 below any gray scale can be memorized. The display matrix has dimensions of $33 \times 33 \text{mm}^2$, and the FLC layer thickness is $(5.2 \pm 0.2) \mu\text{m}$. The display device operates with the frame frequency 30 Hz (at $V_{\text{row}} = \pm 18\text{V}$, $V_{\text{col}} = \pm 9\text{V}$, $T=23^\circ\text{C}$) generating a continuous gray scale, which can be memorized for more than 10 days after the driving voltage is switched off.

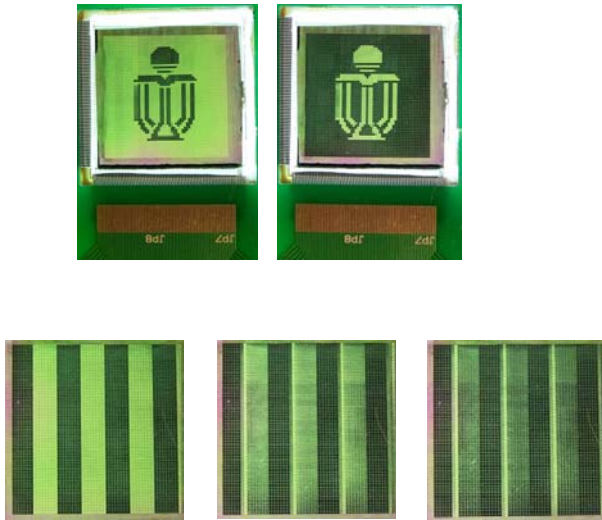


Figure 6. Top: 64×64 and 33×33mm² photo-aligned FLC display matrix. Bottom – the reference state of the 64×64 photo-aligned FLC is bright, right – the reference state is dark. Right: memorization of the gray scale in FLC display.

Actually, the row addressing time is not fixed value at fixed temperature and the steady multiplex operation in our case exists at the temperature range 25°C÷35°C. So further optimization of ferroelectric liquid crystal material is needed.

Passive matrix FLCD can compete with supertwisted nematic LCD (STN-LCD) on the market of high resolution fast responding LCD.

The row addressing time depends on the driving voltage amplitude, so the higher frame frequency in comparison with STN-LCDs is envisaged (Fig.7).

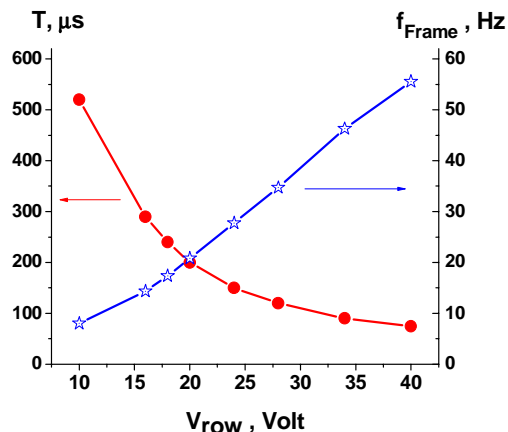


Figure 7. Row addressing time T and estimated frame frequency f_{frame} of 240×320 FLCD.

4. Conclusion

A passively addressed 64×64 ferroelectric liquid crystal display (FLCD) based on the photo-alignment technique has been developed. A new criteria for FLC bistable switching was proposed. An origin of FLC gray scale was discussed and a new way for the generation of the FLC gray scale was demonstrated. The samples of passive matrix addressed photoaligned FLC display with a memorized gray scale were shown. A possible way to produce a fast responding high resolution passive matrix FLCD was demonstrated.

5. Acknowledgements

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

6. References

1. A. L. Andreev I. N. Kompanets, E. P. Pozhidaev, *Proc. SPIE*, **2771**, 289-292, (1996).
2. E. P. Pozhidaev, A. L. Andreev, I. N. Kompanets. *Proc. of 7th Int. Conf. on FLCs*, pp. 164-165, (1999).
3. A.Z. Rabinovich, M.V. Loseva, N.I. Chernova, E.P. Pozhidaev, O.S. Petrashevich, J.S. Narkevich, *Liq. Cryst.*, **6(5)**, 533-543 (1989).
4. K. H. Yang, T. C. Chieu, *Jpn. J. Appl. Phys.*, **28**, N⁹, L1599- L1601, (1989).
5. D.D. Huang, E.P. Pozhidaev, V.G. Chigrinov, H.L. Cheung, Y.L. Ho, H.S. Kwok, *Displays*, **25**, pp.21-29 (2004).
6. D.D. Huang, E.P. Pozhidaev, V.G. Chigrinov, H.L. Cheung, Y.L. Ho, H.S. Kwok, *J. of SID*, **12**, pp.455-459 (2004).
7. E. P. Pozhidaev, V. G. Chigrinov, Yu. P. Panarin, V. P. Vorflusev, *Mol. Mat.*, **2**, 255-238, (1993).
8. L. A. Beresnev, M. Pfifherr, W. Haas, M. V. Loseva, N. I. Chernova, P. V. Adomenas, *Pisma v JETF*, **53**, pp. 170-175, (1991).
9. E. Lueder, *Liquid Crystal Displays*, (Wiley, N.Y., 2000).