Studies on Flickering in Low Frequency Driven Fringe-Field Switching (FFS) Liquid Crystal Display

Han Sol Choi[1], Jin Hyun Kim[1], Hyeong Gyun Ham[1], Young Jin Lim[1], Jae Myeong Lee[1], Heui Seok Jin[1], Ramesh Manda[1], Min Su Kim[2], Deng-Ke Yang[2] and Seung Hee Lee[1,*]

[1] Applied Materials Institute for BIN Convergence,
Department of BIN Fusion Technology and Department of Polymer Nano Science and Technology,
Chonbuk National University, Jeonju, Jeonbuk 561-756, Korea
[2] Liquid Crystal Institute, Kent State University, Kent, OH 44242, USA

Abstract

Recently, the driving scheme of a fringe-field switching (FFS) liquid crystal display varies for the best of required performance. Although low-frequency driving can effectively give rise to reduce power consumption in portable displays, proper controlling of liquid crystal director in direct current is challenging. Particularly, under different polarity of applied electric fields, the transmittance difference along the location of electrodes becomes significant, hence giving rise to an image flickering issue. Here, we investigate how physical properties of a bulk liquid crystalline medium are involved to locally modulate the transmitting light, numerically and experimentally.

Author Keywords

fringe-field switching; low frequency; flicker; flexoelectric effect

1. Objective and Background

Recently, fringe-field switching (FFS) liquid crystal displays (LCDs) are widely used in high-resolution displays and even become a standard driving method. Nevertheless, improvement of electro-optic performance of the FFS-LCDs is still continuing [1-6]. Among the remaining works for better performance, power consumption of LCDs would be particularly important to portable displays under limited battery performance, which can be governed by a simple formula $P = fCV^2$, where f is the driving frequency, C is capacitance of a panel and V is an applied voltage to the panel. When displaying text, especially, f can be lowered further down because each thin-film transistor (TFT) has sufficient time interval to being operated. However, besides the proper chance to improve the device performance, an image flickering is given rise due to transmittance difference up on the polarity of applied electric fields [7]. Considering liquid crystalline medium in the DC field dynamics of the FFS mode, one may come up with flexoelectric effect (FFE) proposed in 1969 by R. B. Meyer [8]. The FFE is a phenomenon that the distortion of the LC director and the electric polarization are coupled so that the polar axis of nematic LC is accompanied with splay and/or bend deformations. The polarization induced by FFE is given , $\vec{P_f} = \mathbf{e_{11}}\vec{n}(\nabla\cdot\vec{n}) + \mathbf{e_{33}}\,(\nabla\cdot\vec{n})\times\vec{n}$, where $\vec{n}$ is the unit vector of the LC orientation, e_{11} and e_{33} are splay and bend flexoelectric coefficients, respectively [9-12]. Under an applied electric field to the FFS mode, the electrode structure causes strong fringe electric fields and thus the field induces splay and bend deformations as schematically shown in Fig. 1(a). Therefore, the net polarization may exist in LC layer (see Fig. 1(b)). In this paper, we demonstrate a simulated result that the transmittance, according to the electric field polarity, deviates by the variation of e_{11} and e_{33}, and also depends on the magnitude and sign of dielectric constant and elastic constant of LC, and driving frequency.

2. Results

In order to check the influence of e_{11} and e_{33} in the FFS mode, we simulate the transmittance difference between positive and negative frame by a commercially available simulator (LCD Master, Shintech). Physical properties of LC were selected, such as birefringence Δn = 0.1079 (at 589.3 nm), elastic constants K_{11} (splay) = 12.5 pN, K_{22} (twist) =6.5 pN, and K_{33} (bend) = 13.0 pN. The boundary conditions were assumed, such as cell gap = 4 μm, electrode width w= 3μm and the distance between pixel electrodes l = 4.5 μm, the thickness of passivation layer by 0.29 μm, LC pretilt angles at both surfaces by 1º, initial optic axis of LC director by 80º to the in-plane vector component of the applied electric field and strong anchoring of LC to the surface. The light source was defined by D65. The birefringence of LC was tuned to yield a retardation value of 0.40 μm at 550 nm.

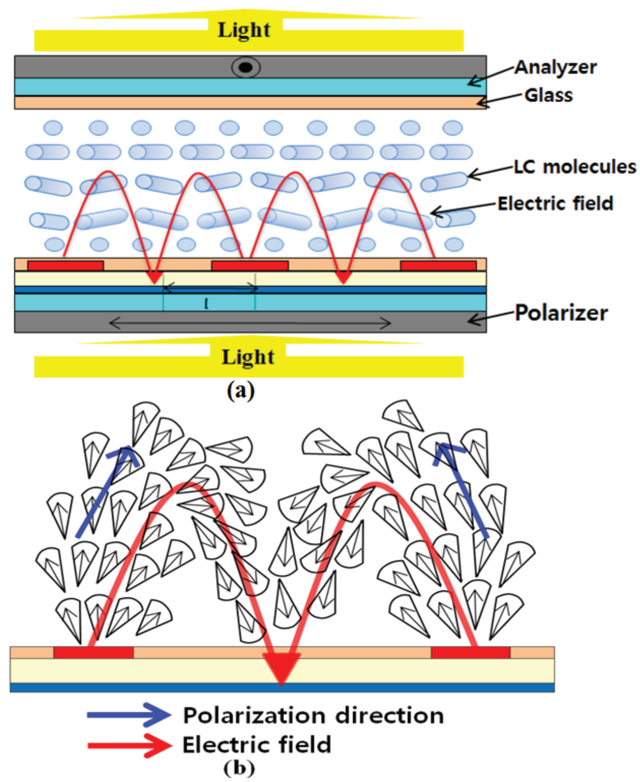

Figure 1. Schematic representation of flexoelectric effect in FFS mode. (a) LC director profile under the applied (fringe) electric field. (b) An example configuration of LC director and the resultant net polarization.

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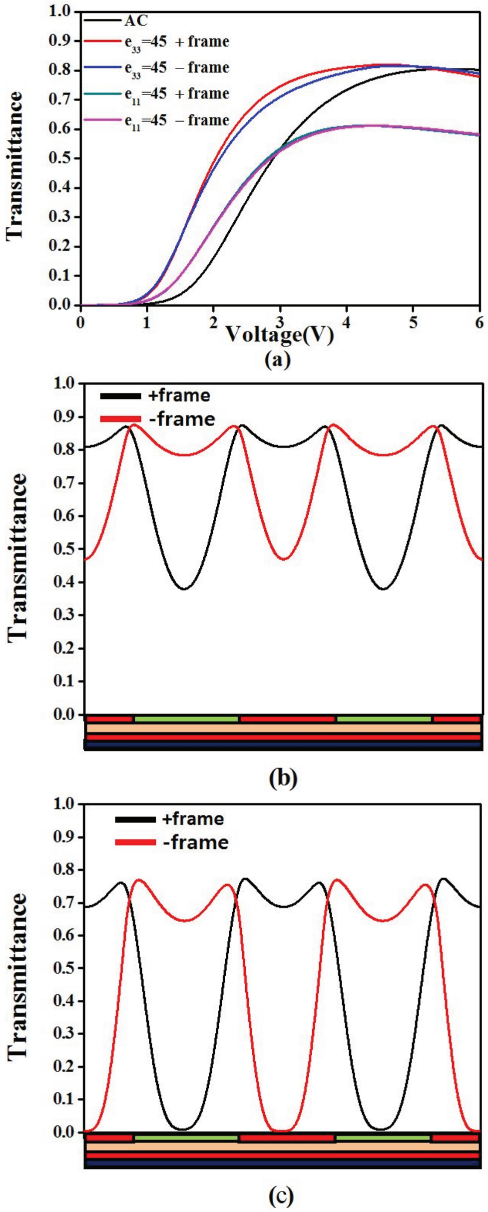

Figure 2. (a) *V-T* curves calculated with e_{33} = e_{11} = 45 pC/m in each driving frame and with e_{33} = e_{11} = 0 in an AC field. (b) Calculated transmittance at e_{33} = 45 pC/m with (±) 2.9V and (c) at e_{11}= 45 pC/m with (±) 2.7V.

We firstly investigate dynamic transmittance change along the electrode positions according to flexoelectric coefficient of e_{11} and e_{33} from -45 pC/m to +45 pC/m. In order to understand how each e_{11} and e_{33} affects *V-T* curves in positive and negative frame, e_{11} is given to be 45 pC/m while e_{33} is fixed to zero and, vice versa, as shown in Fig. 2(a). The deviated transmittance ($|\Delta T|$ = $T_{(+)\text{frame}}$ - $T_{(-)\text{frame}}$) at e_{33} = 45 is higher than the curves at e_{11} = 45 although the curves at e_{33} = 45 look like greater performance. Particularly at 70% of transmittance (T_{70}), $|\Delta T|$ is in the range of less than 0.01 on the curves at e_{11} = 45 while it shows in the range of 0.04 on the curves at e_{33} = 45. The results indicate that the existence of e_{33} contribute to the inconsistency of *V-T* curves in opposite polarity of electric fields, while the existence of e_{11} contributes to drop the maximum transmittance ($T_{\max}$). Transmittance curves at e_{11} = 45 and e_{33} = 45 corresponding to the electrode position are shown in Fig. 2(b) and 2(c), respectively. From this result, we may deduce that the bend deformation (with e_{33} = 45) contributes more significantly to flexoelectric effect in the FFS mode.

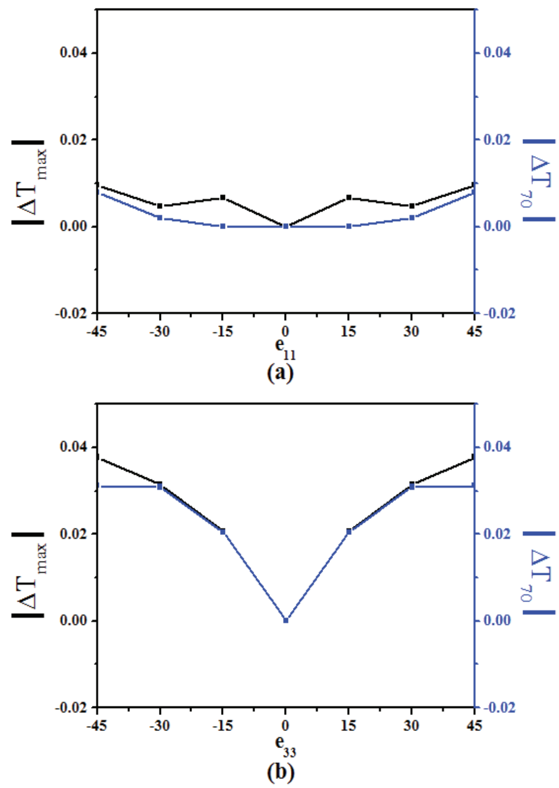

Figure 3. Summarizes /$\Delta T_{\max}$/ and ΔT_{70} with respect to the magnitude of e_{11} and e_{33}. The figures clearly show ΔT is more significantly influenced by e_{33} (Fig. 3(b)) than e_{11} (Fig. 3(a)).

Table.1. Physical properties of liquid crystals.

	$\Delta\varepsilon$	Δn	$K = (K_{11}+K_{33})/2$ [pN]
LC1	5.1	0.1088	12.6
LC2	5.1	0.1088	18.0
LC3	10.1	0.1078	18.0
LC4	10.1	0.1086	12.5
LC5	-4.4	0.1077	15.0

After numerically evaluating FEE on *V-T* curves in the FFS mode, we performed experiments to investigate the flicker behavior according to the physical properties of LC. Sample cells, with w = 3.5 μm, l = 6 μm, and cell gap d = 3.3 μm, were prepared and various LCs are injected into prepared cells with the same cell condition. A collimated and specially filtered He-Ne laser was used as a light source and transmitted light was detected by photo-detector placed behind the sample cells and connected to an oscilloscope (DPO0212, Tektronix). A square wave was applied to the cell using a function generator (AFG3022, Tektronix). We used five different types of LCs (Table 1) for comparison. LC1 and LC2 has the same dielectric anisotropy $\Delta\varepsilon$ but K =

$(K_{11}+K_{33})/2$ varies. LC3 and LC4 have the same $\Delta\varepsilon$ that is higher than that of LC1 and LC2 but K varies as of LC1 and LC2. LC5 has a negative $\Delta\varepsilon$ with moderate K value between LC1 and LC2 and Δn is similar for every LC. We firstly investigate flexoelectric contribution of dielectric anisotropy by measuring ΔT of LC1 and LC3 at T_{70} while changing the driving frequency from 120 Hz to 1 Hz as shown in Fig. 4. As the driving frequency decreases, ΔT increases; however, it becomes small in the range of 120 to 30 Hz. At low-frequency range below 30 Hz, ΔT becomes significant for high $\Delta\varepsilon$ LC (LC3) .

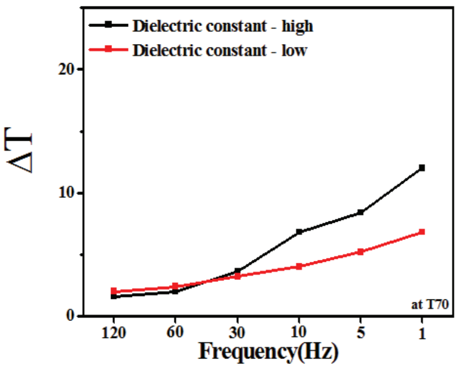

Figure 4. Measured ΔT as a function of driving frequency at different magnitude of dielectric constant at T_{70}.

Secondly, the flexoelectric contribution of elastic constants of LC is demonstrated in Fig. 5. At low-frequency driving, ΔT tends to become large for both samples with different elastic constants, but LC with low elastic constant shows more significant contribution to ΔT. (Fig. 5 also shows the consistent contribution of $\Delta\varepsilon$ to ΔT.)

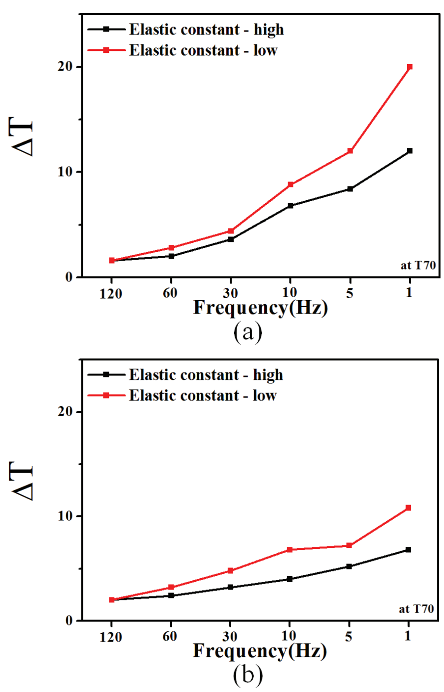

Figure 5. Measured ΔT as a function of driving frequency with different elastic constants: (a) high $\Delta\varepsilon$ (LC3 and LC4), (b) low $\Delta\varepsilon$ (LC1 and LC2).

So far, LC with positive dielectric anisotropy with various physical properties has been identified. Finally, we observe the degree of image flickering in both positive and negative dielectric anisotropy of LC: LC1 and LC5 with $\Delta\varepsilon$ = +5.1 and -4.4, respectively. Remarkably, ΔT with negative $\Delta\varepsilon$ shows extraordinarily high ΔT over the investigated driving frequencies as shown in Fig. 6(a). Quantitative evaluation for comparison between LC1 and LC5 is in the range of 0.4 to 60 over the driving frequency from 120 to 1 Hz. The dynamic response of measured transmittance corresponding to the applied voltages is shown in Fig. 6(b). Both transmittance profiles show inconsistency at low-frequency, but LC with negative dielectric anisotropy shows severe fluctuation of the profile.

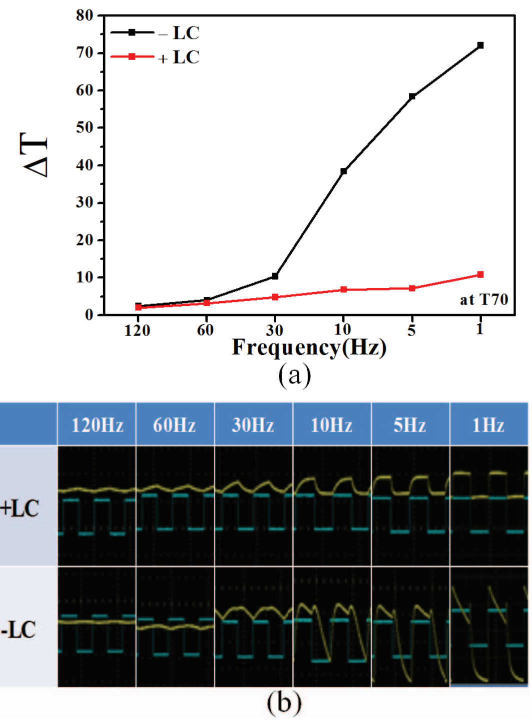

Figure 6. (a) Measured ΔT as a function of driving frequency for LC1 ($\Delta\varepsilon > 0$) and LC5 ($-\Delta\varepsilon < 0$). (b) Measured transmittance corresponding to the polarity of the field frame at different driving frequency at T_{70}.

3. Conclusion

We numerically and experimentally investigated the contribution of physical properties of bulk liquid crystalline medium to the flexoelectric effect in fringe-field switching liquid crystal display. In numerical simulation, we found higher flexoelectric contribution to transmittance with bend deformation of liquid crystals than that with splay deformation. In experiment, when the magnitude of dielectric anisotropy is low and elastic constant of LC is high, image flickering is reduced. The result seems reasonable to be associated with the degree of splay and bend deformation, which couples with electric field polarity. Unusual finding is reported, which is yet vague. In general, the flexoelectric contribution of negative dielectric anisotropy is known to reduce image flickering; however, our finding shows reduced flickering with positive one, which is highly required to further investigation for possible fabrication cost reduction in an industrial market.

4. Acknowledgments

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5. References

[1] S.H. Lee, S.L. Lee, and H.Y. Kim, "Electro-optic characteristics and switching principle of a nematic liquid crystal cell controlled by fringe-field switching." Applied physics letters **73**(20), 2881-2883 (1998).

[2] I.H. Yu, I.S. Song, J.Y. Lee, & S.H. Lee & T.Y. Eom, "Analysis of light efficiency in homogeneously aligned nematic liquid crystal display with interdigital electrodes." Journal of the Korean Physical Society **35**, S1111-S1114 (1999).

[3] S.H. Hong, I.C. Park, H.Y. Kim, & S.H. Lee, "Electro-optic characteristic of fringe-field switching mode depending on rubbing direction." Japanese Journal of Applied Physics **39**, L527 (2000).

[4] S.H. Jung, H.Y. Kim, S.H. Song, J.H. Kim, S.H. Nam, & S.H. Lee, "Analysis of optimal phase retardation of a fringe field-driven homogeneously aligned nematic liquid crystal cell." Japanese journal of applied physics **43**(3R), 1028 (2004).

[5] I.H. Yu, I.S. Song, J.Y. Lee, & S.H. Lee, "Intensifying the density of a horizontal electric field to improve light efficiency in a fringe-field switching liquid crystal display." Journal of Physics D: Applied Physics **39**(11), 2367 (2006).

[6] S.H. Jung, H.Y Kim, M. H. Lee, J.M. Rhee, & S.H. Lee, "Cell gap-dependent transmission characteristics of a fringe-electric field-driven homogeneously aligned liquid crystal cell, for a liquid crystal with negative dielectric anisotropy." Liquid crystals **32**(2), 267-275 (2005).

[7] H. Chen, F. Peng, M. Hu & S.T. Wu, "Flexoelectric effect and human eye perception on the image flickering of a liquid crystal display." Liquid Crystals **42**(12), 1730-1737 (2015).

[8] Meyer, R.B. "Piezoelectric effects in liquid crystals." Physical Review Letters **22**(18), 918 (1969).

[9] C. Kischka, S.J. Elston & E.P. Raynes, "Measurement of the Sum ($e_1 + e_3$) of the Flexoelectric Coefficients e_1 and e_3 of Nematic Liquid Crystals using a Hybrid Aligned Nematic (HAN) cell." Molecular Crystals and Liquid Crystals **494**(1), 93-100 (2008).

[10] F. Castles, S.C. Green, D. J. Gardiner, S.M. Morris, & H. J. Coles, "Flexoelectric coefficient measurements in the nematic liquid crystal phase of 5CB." AIP Advances **2**(2), 022137 (2012).

[11] R.A. Ewings, C. Kischka, L. A. Parry-Jones & S.J. Elstion, "Measurement of the difference in flexoelectric coefficients of nematic liquid crystals using a twisted nematic geometry." Physical Review E **73**(1), 011713 (2006).

[12] T. Takahashi, S. Hashidate, H. Nishijou, M. Usui, M. Kimura & T. Akahane, "Novel measurement method for flexoelectric coefficients of nematic liquid crystals." Japanese journal of applied physics **37**(4R), 1865 (1998).