Temperature dependent electro-optical studies of liquid crystal in Fringe Field Switching (FFS), In-plane switching (IPS), and Patterned Vertical Alignment (PVA) modes

Eun Mi Jo[1], Anoop Kumar srivastava[1], Miyoung Kim[1], Sung Min Kim[1] and Seung Hee Lee[1], Seung Hoon Ji[2], Gi-Dong Lee[2]

[1]Polymer BIN Fusion Research center, Department of Polymer Nano Science and Engineering, Chonbuk National University, Chonju, Chonbuk 561-756, Korea
TEL:82-63-270-2343, E-mail: lsh1@chonbuk.ac.kr
[2]Department of Electronics Engineering, Dong-A University, Pusan 607-735, Korea

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Abstract

In this paper, electro-optical characteristic of Nematic Liquid crystal (LC) with varying temperature in different LCD modes, namely Fringe Field Switching (FFS), In-plane switching (IPS), and Patterned Vertical Alignment (PVA) modes are investigated and compared. Electro optic measurements suggest that rate of change of transmission with temperature in FFS mode was lowest and much more thermally stable as compared to IPS and PVA modes. However the electro-optical characteristic of patterned vertical alignment (PVA) mode was most affected by changing temperature. The measured threshold voltage was found to be much more thermally stable in FFS and IPS modes than that of PVA mode.

1. Introduction

In liquid crystal displays (LCDs), the physical properties of LC are important factor because the electro-optic characteristics of LCDs such as the driving voltage, transmittance, and response time strongly depend on the physical properties of the LC. Over the last ten years, the physical properties of LCs, particularly super-fluorinated LC mixtures, have been greatly improved such that the rotational viscosity of LC with a positive dielectric anisotropy decreases from over 100 to below 80 mPa·s for television applications to achieve a fast response time[1]. Also, for the high image quality, the LC with high resistivity is required, in order to prevent the image flickering problem. At present, the super-fluorinated LC mixtures show a resistivity larger than $10^{13}\,\Omega$cm[2]. For the high image quality in all viewing directions, several LCD modes such as in-plane switching (IPS)[3,4], fringe-field switching (FFS)[5,6], and multidomain vertical alignment (MVA) including patterned vertical alignment (PVA)[7,8] have been proposed and commercialized.

Temperature has great influence on the electro-optic characteristics of LCD modes. However there are very few reports on temperature dependent physical or electro-optical properties of LC[9-11]. Therefore, it is important to investigate the influence of temperature on electro-optical characteristics of LC for different LCD modes.

2. Experimental

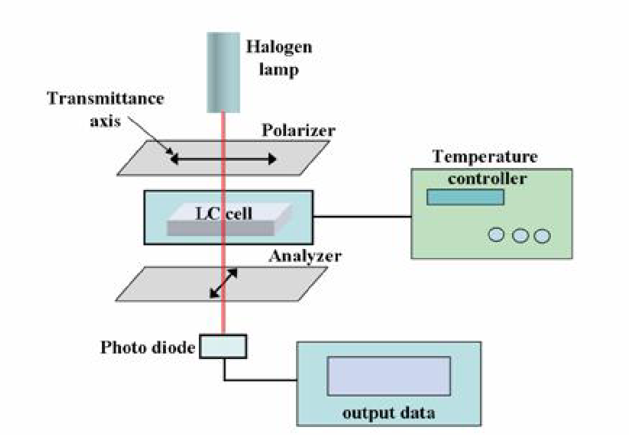

Fig. 1. The schematic of experiment setting.

Fig. 1 shows the schematic diagram for measurement of electro-optical characteristics, where cells in a temperature controlled hot stage was placed and the crossed polarizers attach between the hot stage. A halogen lamp was used as an incident light source. Transmitted light through out cells was detected by photo-diode and amount of light through out cells is shown output data. Initial state of all of LC modes is appeared to dark and when voltage is applied, the transmittance increases and show white state at certain operating voltage.

In the IPS cells, the signal and common electrodes exist only on the bottom glass substrate with an electrode width of 5 ㎛ and a distance (*l*) of 10 ㎛ between electrodes. In the contrast, the FFS cells have an electrode width of 4 ㎛ and a distance(*l*) of 5 ㎛ between electrodes that these electrodes exist same position like a IPS cells. IPS and FFS cells are composed of transparent electrodes. Due to the electrode structure, in the IPS mode, the horizontal electric field (E_y) is mainly generated between electrodes when a voltage is applied but FFS mode generated all area including on to the electrode. For an alignment layer, a homogenous alignment layer was spin-coated on the patterned electrode at bottom and top glass substrates with a thickness of 800Å. The rubbing process on both substrates was performed in the antiparallel direction to align the nematic LC with an angle of 80° with respect to E_y in the IPS cells. On the other hand, FFS cells have 83° with respect to E_y. The cell was then assembled to give to each other d = 3.5, 3.8 ㎛ in IPS cells and FFS cells respectively, where the plastic balls were used to keep d. Finally, in the IPS and FFS cell using the LC with positive dielectric anisotropy from Merck Co. ($\Delta\varepsilon$ = 7.4, Δn = 0.088 at λ = 589 nm, γ= 147 mpa·s, T_{ni} = 87℃) was used. In the PVA mode, the pixel and common electrodes are patterned alternatively, and thus an oblique field which has vertical and horizontal components is generated with the biased voltage and this applied field tilts LCs downward in four different diagonal directions. In order for LCs to tilt downward exactly in diagonal directions, the field direction of horizontal component of an oblique field should be in diagonal direction. The cell was then assembled to give to d = 4 ㎛, and using the LC with negative dielectric anisotropy from Merck Co. ($\Delta\varepsilon$ = -4, Δn = 0.077 at λ = 589 nm, γ = 136 mpa·s, T_{ni} = 75℃) was used.

3. Results and discussion

We measured the voltage-dependent transmittance in heating cycle at 10℃ intervals of temperature up to T_{ni}. The results are shown in Fig. 2. The rates of change in the threshold voltage (V_{10}) with temperature are different for different types of modes. The rate of change of V_{th} with temperature in IPS and FFS mode driven by horizontal field is smaller than that of PVA mode driven by vertical field (see Fig. 2).

The threshold voltage, V_{10} in these modes is given by

$$V_{th} = \pi l / d\sqrt{\left(K_{ii} / \varepsilon_0 |\Delta\varepsilon|\right)} \quad (1)$$

where l is a distance between electrodes and K_{ii} is the effective elastic constant. For IPS and FFS modes $K_{ii} = K_{22}$ whereas for PVA mode $K_{ii} = K_{33}$. According to equation (1), threshold voltage is proportional to $\sqrt{\left(K_{ii} / |\Delta\varepsilon|\right)}$ and in general, $K_{33} > K_{11} > K_{22}$ [14]. The elastic constant in the liquid crystal is given by

$$K_{ii} = C_{ii} V^{-7/3} S^2 \quad (2)$$

where C_{ii} is reduced elastic constant and V is the molar volume, S is order parameter[12]. Also, S can be expressed by

$$S = [1 - T / T_{ni}]^{\beta} \quad (3)$$

where β is a material parameter and for many of the liquid crystal compounds, $\beta \approx 0.25$ and T_{ni} is clearing temperature[13]. As the temperature increases, K_{ii} decrease, and it can be explained by eq. (2) and (3).

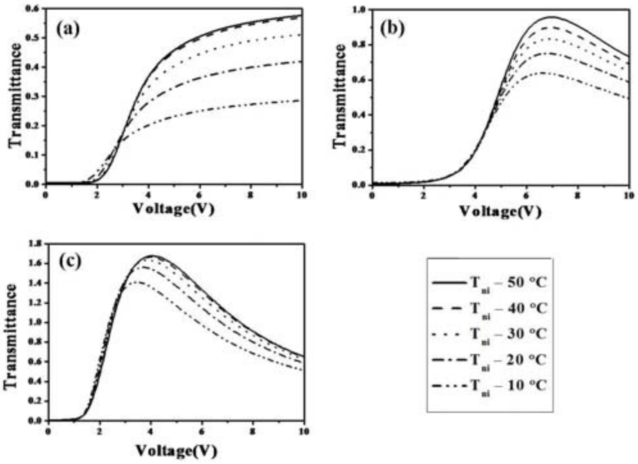

Fig. 2. Voltage dependent transmittance curve according to change of temperature: (a) PVA , (b) IPS and (c) FFS mode.

In general, the bend elastic constant (K_{33}) of LC is highly temperature dependent as compared to twist (K_{22}) elastic constants [15]. In other words, the bend elastic constant relatively much more decreases than that of twist elastic constant (K_{22}) with increasing temperature. Another physical parameter responsible for change in threshold voltage is the dielectric anisotropy of LC. The behavior of dielectric anisotropy with the change in temperature can be explained on the basis of Maier and Meier theory [16]

$$\Delta\varepsilon = \frac{Nhf}{\varepsilon_0}\left[\Delta\alpha - \frac{F}{2kT}\mu^2\left(1-3\cos^2\beta\right)\right]S \quad (4)$$

where the symbol have their usual meaning. The Maier-Meier theory predicts that the temperature dependence of $\Delta\varepsilon$ roughly follows that of the order parameter S, the 1/T factor contributing only slightly over a limited temperature interval. It is well know that order parameter decreases with increase in temperature for all LC. Hence $\Delta\varepsilon$ would also be decreased with increase in temperature for all LC.

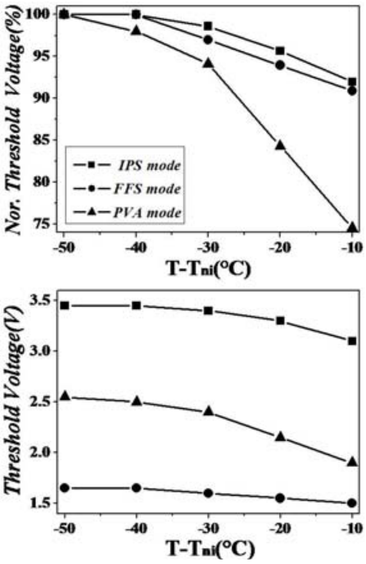

Fig. 3. The comparison of threshold voltage according to increasing the temperature.

Therefore in case of PVA cell, the ratio of $\left(K_{ii}/|\Delta\varepsilon|\right)$ and hence V_{th}, relatively much more decreases with increase in temperature than those of IPS and FFS cells because of their change in elastic constants values with varying temperatures. In other words, the threshold voltage in PVA cell is much more sensitive to the temperature than those of IPS and FFS modes.

Finally, the maximum transmittance according to climbing the temperature is shown in Fig. 4. This result also shows that IPS and FFS modes are less sensitive to the temperature than that of PVA mode. The normalized transmittance, τ/τ_0 is given by

$$\tau/\tau_0 = \sin^2 2\,\psi(V)\,\sin^2(\pi\, d\, \Delta n_{eff}(V)/\lambda) \quad (5)$$

where ψ is a voltage-dependent angle between the transmission axes of the crossed polarizers and the LC director, Δn is the effective birefringence of the LC layer dependent on voltage, and λ is the wavelength of incident light.

Transmittance in PVA cell is also found to be, highly temperature dependent than those of IPS and FFS cells and it may be due to birefringence (n_{eff}) term of eq (5).

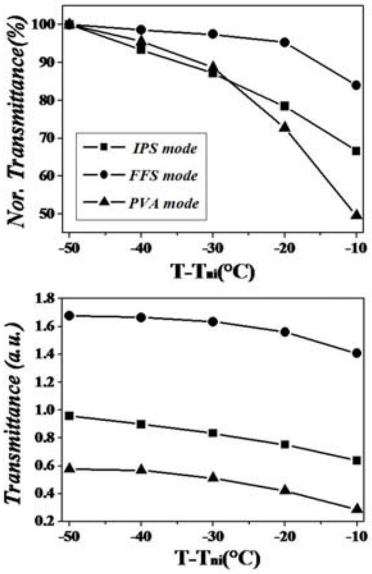

Fig. 4 The comparison of maximum transmittance according to increasing the temperature

4. Summary

In conclusion, temperature dependent electro-optical characteristics of IPS, FFS and PVA modes have been investigated. The threshold voltage in PVA cell was highly temperature dependent than those of IPS and FFS cells. It may be due to relatively larger decrease in the value of K_{33} than that of K_{22} with increase in temperatures. Maximum transmittance in PVA cell was also found to be, highly temperature dependent as compared to IPS and FFS cells.

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