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Deformed Helix Ferroelectric Display with Low Driving Voltage and Fast Response Time

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Abstract

In this paper, the electrooptical behavior of deformed helix ferroelectric(DHF) liquid crystals is described. Fast response with low driving voltage is obtained. One of remarkable properties of DHF mode is frequency dependence of the electrooptical response time, which is really exists in our case. Experimental and simulation results are provided with good accordance. Variable anchoring energy is realized in experiment with photosensitive alignment material SD1. For the purpose of evaluate the influence of anchoring energy on alignment quality in DHF mode, the measurement of anchoring coefficient of alignment layer for short helix pitch FLC is proposed. The contrast ratio of 13000 with switching time of 113 μ s is obtained at room temperature.

1. Introduction

Currently most liquid crystal displays (LCDs) apply spatial color synthesis, by using a white backlight spectrum combined with sub-pixels formed by red (R), green (G), and blue (B) color filters. The color filters only pass one-third of the light and the effective resolution is only one-third of the addressable sub-pixel resolution [1, 2]. Instead of using spatial color synthesis, a field sequential color (FSC) display applies temporal color synthesis. In an FSC display the backlight sequentially flashes R, G, and B. The LCD panel is controlled to modulate the transmission of each pixel at each field [3]. An FSC display does not need color filters and has the advantages of increased light transmission and higher spatial resolution [4]. The target response time for a field sequential color (FSC) displays should be less than 1 ms (240 Hz frame frequency) [5] to provide a high resolution, low power consumption and extended color gamut liquid crystal displays (LCD). Fast switching ferroelectric liquid crystal (FLC) displays (FLCD) is a good candidate for the new generation of FSC LCD [6], which is proved to be better in response time, than usually used nematic LC. The problems, which are usually faced in ferroelectric LCD such as quality of FLC alignment on sufficiently large surface area etc., can be effectively solved by a photo-alignment technology [7].

In the short-pitch approximation, a DHF cell is shown to be optically equivalent to a uniformly anisotropic biaxial layer where one of the optical axes is normal to the bounding surfaces [8]. For in-plane anisotropy, orientation of the optical axes and birefringence are both determined by the voltage applied across the cell and represent the parameters that govern the transmittance of normally incident light passing through crossed polarizers.

2. Experiment

The geometry of an FLC cell exhibiting the DHF effect is shown in Figure1. The polarizer on the first substrate makes an angle, β , with the helix axis (zaxis) and the analyser is crossed with respect to the polariser. The FLC layers are perpendicular to the substrates and the cell gap is much larger than the helix pitch. Electrooptical measurements were carried out using a conventional electrooptical setup based on He-Ne laser. A programmed generator was used for experimental simulating the multiplex operation.

Figure 1 Schematic drawing of the structure of deformed helix FLC cell

A sulfonic azo-dye, SD-1, is used for aligning FLC molecule in DHF configuration. One remarkable property of this azo-dye is the pure reorientation of molecular absorption oscillates perpendicular to UV light polarization without any photochemical transformations. Thus, the high photoalignment quality of FLCs onto azo-dye SD-1 layers can be achieved. For aligning DHF cells, the anchoring strength of orientation layer plays a critical role. The optimal anchoring energy is needed for high alignment quality, since helix can be unwound when anchoring strength is higher and uniformity of helix direction cannot be achieved when anchoring strength is lower.

3. Result and Discussion

When an electrical field is applied, the polarization, P_s , of the chiral smectic C phase interacts with it and the FLC director rotates around the z-axis with a cone angle of $2\theta_0$. The azimuthal angle φ of the FLC directors in a harmonic electric field $E=E_0\sin\omega t$, with E_0 much smaller than the unwinding field, E_{ib} , can be described as follows:

$$\varphi(z) = q_0 z + \frac{P_s E}{K q_0^2} \sin q_0 z \quad (1)$$

Where K is the elastic constant of FLC, and q_0 represents the helix with $q_0=2\pi/p_0$, and p_0 is the helix pitch. When the azimuthal angle $\varphi(z,t)$, of the directors of the FLC molecules are known, the rotation of the helical axis, $\Delta\alpha(E,t)$, and the effective refractive index difference, $\Delta n_{eff}(E,t)$, can be calculated as averages over the helix pitch. The cell transmittance is finally given by:

$$T = \sin^2 2(\beta \pm \Delta\alpha) \cdot \sin^2 \frac{\pi 2d\Delta n_{eff}}{\lambda} \quad (2)$$

One of remarkable properties of DHF mode is frequency dependence of the electrooptical response time when FLC is driven by square wave[9], which is really exists in our case, shown in Figure 2. It is indicated that the response time of FLC595 in DHF mode tends to decrease with driving frequency increasing. Fast switching with less than 1ms response time is obtained with low voltage.

Figure 2 Response time vs. Frequency on fixed voltage

However, no frequency-dependent solution is applicable to this model [10]. In this case, Fourier series are used to describe square driving signal. When an electric field is applied, the FLC director rotates around the z-axis with a cone angle of $2\theta_0$. When the rotation angle $\varphi(z,t)$ is known, the light transmission level, I , can be derived accordingly [10]. The frequency dependence of the electrooptical response time can be calculated. Figure3 shows that the experimental results are in accordance with our theoretical

model. In order to obtain a good alignment quality with high contrast ratio in DHF mode, optimal anchoring energy of the orientation layer for FLC must be obtained. The parameters used in calculation are the parameters of FLC-587 at $T=23^\circ\text{C}$: $n_\perp=1.5$, $n_\parallel=1.72$, $\theta=34.5^\circ$, $K=10^{-11}$ N, $P_s=1.6\cdot 10^{-3}$ C/m², $\gamma_\phi=0.2$ Pa·s, $p_0=150$ nm.

Figure 3 Experimental and simulation results on frequency dependence of the electrooptical response time in DHF mode

The anchoring energy of alignment layer for FLC affects both optical quality of FLC sample and its capability to operate in electro-optical driving [11]. The method to measure anchoring energy by evaluation of relaxation time is proposed, which is valid for both helical and helix-free structure. To analyze the relaxation process of the cell an arbitrary waveform having regular interval between plus and minus pulses has been applied to drive the cell. Figure 4 shows the waveform applied and the electro-optical response of the cell. The switching ON and OFF time has also been defined in the Figure 4.

Figure 4. Top is the applied voltage to the cell and bottom is the electro-optical response of the cell.

Figure 5. Textures of FLC595 with 1.5μm thickness and alignment layers SD-1 with exposure time (a)30s; (b)10min; (c) 1hr

The electro-optical response exhibits relaxation time which corresponds to two independent processes i.e. the anchoring energy of aligning layer (τ_A) and the chiral twisting of the

helix (τ_E). After evaluating these two relaxation times, τ_A and liquid crystal layer thickness (d_{AFLC}) have been used to

evaluate the anchoring energy coefficient (W_0) by mean of Equation (3):

$$W_0 = \frac{\gamma_\phi d}{4\tau_A} \quad (3)$$

The texture of 1.5μm thick cell has been provided in Figure 5. In accordance with textures of short helix pitch material, the contrast ratio also exhibits dependence on anchoring strength. At room temperature, a contrast of 1300:1 is obtained with photosensitive layer SD-1 exposed under polarized UV light for 30 second. While the contrast ratio drops when anchoring strength exceed the optimal value.

4. Conclusion

In summary, the switching time and contrast ratio of FLC cells are investigated with the frequency range from 50Hz to 3000Hz. Switching time of 113μs is obtained with FLC595 in DHF mode and 70 μs in SSFLC mode at room temperature. Proposed ferroelectric liquid crystals show excellent properties which is high promising for future applications. Fast FLC switching enables high-quality color-sequential images without color filters, at the same time realizes low-power consumption.

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