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Fast Ferroelectric Liquid Crystal Modes for Field –Sequential- Color and 3D Displays

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Abstract

The development of novel photoaligned fast ferroelectric LCD based on Deformed Helix Ferroelectric (DHF) and Electrically Suppressed Helix (ESH) mode is discussed. A high quality dark state of DHF FLCD has been obtained as well as V-shape switching with a high frequency. A fast response time and a high contrast ratio in ESH mode was observed. The applications in Field Sequential Color (FSC) and 3D LCD are envisaged.

1. Introduction

The response time of liquid crystal displays is still inferior to the existent competing technologies, such as plasma display panels (PDP) or organic light emitted diodes (OLED). The target LC cell response time for a field sequential color (FSC) and 3D displays should be less than 1 ms (240 Hz frame frequency) 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 field sequential color (FSC) and 3D LCD, which proved to be better in response time, especially deformed helix ferroelectric (DHF) mode and its modifications, which provide a high contrast, and extremely fast switching time for a very low applied voltage.

An extensive work studying optical and electrooptical response of ferroelectric liquid crystal (FLC), as well as developing new FLC materials with advanced surface alignment was made [1]. The new photoalignment materials potentially capable of being used in photo-aligning technology for LCDs were developed [2].

A fast switching FLC with V-shape switching, i.e. a number of gray scales can be used for field sequential colors (FSC) FLC LCD. In this case, we need FLC with a sufficiently low spontaneous polarization and fast switching. Ideally, we need FLC with a spontaneous polarization $P_s < 10 \text{ nC/cm}^2$ and response time of $100\mu\text{s}$ for the applied electric field $E < 2\text{V}/\mu\text{m}$. At the same time, FLC should be mechanically stable (shock free) and without any hysteresis in the electrooptical response. One of the possibilities is a polymer stabilized FLC to enable monostable V-shape switching (PSV- FLCD) [3]. However, further investigations are necessary to understand the PSV-FLCD advantages more in detail as the hysteresis almost inevitable in FLC electrooptical switching in this case.

Another opportunity is the application of the deformed helix ferroelectric (DHF) effect [4] and electrically suppressed helix (ESH) mode [5]. We are going to describe the new DHF and ESH FLC developments in this paper for Field Sequential Color (FSC) and 3D LCD applications.

2. Results

2.1. DHF mode

We have obtained some good results in studying deformed helix ferroelectric (DHF) effect. In particular, a high quality dark state of DHF FLCD has been obtained as well as V-shape switching with a high frequency (Fig.1). Two inherent properties of DHF-FLC have been observed (Fig. 1b): (i) similar to NLC cells, the electro-optical response is insensitive to the driving voltage polarity, but the response time is two orders faster as compared with NLC, i.e. $\tau_{0.1-0.9}^{on} \cong 80\mu\text{s}$,

$\tau_{0.1-0.9}^{off} \cong 60\mu\text{s}$; (ii) the response exhibits perfect V-shaped mode obtained for the case of rectangular alternating applied voltage pulses shown in Fig. 1a. As is illustrated in Fig. 1b, the electro-optical response frequency is twice higher than the driving voltage frequency.

A DHF-FLC FSC display cell with red, green and blue light emitting diodes (LED's) forming sequential fields of backlight around $100\mu\text{s}$ duration of each color has been elaborated. The cell was controlled by the voltage waveform appropriate for FSC displays (Fig.1b)).

LED's were placed in the position labeled in Fig.1a as "light beam $D > p_0$ " and synchronized to the driving voltage pulses with the specially designed software. Figure 1c shows that the cell light transmission is continuously tunable for each color field independently at both voltage polarities.

Thus V-shaped electro-optical response is shown to be an inherent property of a deformed helix ferroelectric liquid crystal cell (DHFLC) under a special choice of the applied rectangular alternating electric field waveform, frequency, and the cell geometry. In contrast to other known V-shaped ferroelectric liquid crystal (FLC) modes, the discovered V-shaped switching is observed in a broadband frequency range including one kilohertz, and not at a certain characteristic frequency. Frequency independent V-shaped DHFLC switching allows increasing drastically (up to 1 kHz) the operating frequency of field sequential color (FSC) liquid crystal display cells.

We have developed a special software for an advanced design of new FLCD prototypes [6,7]. Certain new FLCD prototypes can be optimized using our software, including the optimization of FLC configuration as well as the optical scheme. We have found, that the switching time of DHF FLC decreases with frequency of the applied voltage, which is in a good agreement with our experimental results [8].

2.2 ESH mode

We have discovered a new electrooptic mode, which we called Electrically Suppressed Helix (ESH) mode [5]. The mode is characterized by a high contrast ratio and very fast electrooptic response and is highly suitable for FSC and 3D applications. DHF mode exists at $V \leq V_c = 0.4V$ and the helix is completely suppressed by electric field at $V \geq 1V$, see Fig. 2 right part and linear dependence of the inverse response time at $V > 1V$ in Fig. 3, where the response time has absolutely the same behavior as in surface stabilized FLC (SSFLC) mode. Despite of these similarities, it should be emphasized that at $V > V_c$, strictly speaking, there is no SSFLC mode but an electro-optical mode with completely electrically suppressed helix arises (ESH-mode). It would seem that between SSFLC and ESH modes there is only a formal difference in initial conditions (the helix is suppressed by surfaces in SSFLC, but this does not happen with ESH), as the dynamics of a completely identical. Actually, the presence of helix without applied voltage is the cause of the unique high alignment quality in ESH-mode (see top right insertions in Fig. 2).

The unique high alignment quality, however, is observed only if the helix elastic energy is comparable but obligatory not less than the anchoring energy normalized to d_{FLC} :

$$Kq_0^2 \geq \frac{2W_0^0}{d_{FLC}} \quad (1),$$

where W_0^0 is a coefficient the anchoring energy. We have measured $W_0^0 = 4 \cdot 10^{-4} \text{ J/m}^2$ just for the cell whose properties are illustrated in Figs. 2, 3, thus confirming the validity of inequality (1), when outstanding alignment quality (top right insertions in Fig. 2) is observed.

A very uniform FLC alignment exists just only in ESH-mode when $V > V_c$ (right top insertion in Fig. 2) while at $V < V_c$ it is worse because the FLC layer is divided into two-domain helical structures with the domains principal axes deployed at an angle around double FLC tilt angle 2θ . When observed with a polarizing microscope, these helical domains are perceived as homogeneous dark and light areas with their characteristic sizes around 10-50 μm , see left top insertion in Fig. 2. The domains are completely suppressed by a weak electric field $E_c < E < 1V/\mu\text{m}$ (right top insertion in Fig. 2) thus forming perfect chevron-free alignment in ESH-mode.

The contrast ratio in ESH mode is more than 12000:1 up to 1 kHz at $\pm 1.5V$ and up to 2 kHz at $\pm 3V$; the light transmission is about of maximum in this case, see insertion to Fig. 4. In addition to this the shock stability has also been found good

for the ESH mode. The contrast ratio was measured with time after removing the mechanical pressure. The contrast can be restored in very short time after removal of mechanical pressure. The electro-optical response manifests evident saturation at 500 Hz and $\pm 1.5V$ with the response time $\tau_{0.1-0.9} = 130 \mu\text{s}$ (Fig. 5).

3. Conclusion

Two electrooptic modes in FLC: Deformed Helix Ferroelectric (DHF) and Electrically Suppressed Helix (ESH) mode were investigated. The possible applications include FSC FLC with a high resolution, low power consumption and extended color gamut, which can be used in the screens of portable PCs, mobile phones, PDAs. FSC FLC microdisplays, which is now one of the most advanced technologies for pico-projectors can be also made.

4. Acknowledgements

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Figure 1. DHF FLC V-shape switching with a gray scale. From left to right: (a) DHF-FLC structure and applied voltage; (b) the electro-optical response of the cell, placed between crossed polarizers at $\beta = 0$, V-shaped DHF-FLC light transmission. (c) V-shape switching at three frequencies of operating voltage.

Figure 2 Dependence of switching on time of 1.5 μm cell filled with the FLC-595 [5].

Insertions: bottom right is the driving voltage waveform; top the FLC layer textures between crossed polarizers, horizontal scale of all images is 200 μm; top left - the voltage is not applied, top right - textures at +1V and -1V.

Figure 3 The frequency dependencies of the response time at different voltages under condition $V \leq 0.5V$; (•) - linear dependence of the inverse response time $\tau_{0.1-0.9}^{-1}(V)$ at $V > 1$ V [5].

Figure 4. Dependencies of the contrast ratio on driving voltage frequency at $V=1.5V$ and $V=3V$. The FLC-595 [5] layer thickness is $1.5\mu m$, no SiO_2 layers, measurements have been carried out at $T=22^\circ C$, wavelength $\lambda=0.63 \mu m$.

Insertion left: Dependencies on voltage: measured tilt angle and the cell light transmission in comparison with transmission of empty cell placed between crossed polarizers.

Insertion right: Contrast ratio dependence on time after the application of mechanical shock.

Figure 5. Top is the applied voltage, bottom – electro-optical response of $1.5\mu m$ FLC-595 based cell measured at $T=22^\circ C$, wavelength $\lambda=0.63 \mu m$.