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In-Plane Switching Deformed Helix Ferroelectric Liquid Crystal Display Cells

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Abstract: In-plane electro-optical switching (IPS) is a natural feature of a conventional planar aligned display cell based on deformed helix ferroelectric liquid crystal effect (DHFLC-effect) with sub-wavelength helix pitch if the tilt angle close to 40 degrees.

Keywords: deformed helix ferroelectric liquid crystal effect; in-plane switching

1. Introduction

As it is well known the principal advantage of in-plane switching (IPS) nematic liquid crystal (NLC) display cells [1 - 3] is the color accuracy due to the small gamma and color shifts, and since the principal axes of the NLC layer always remains in the substrates plane in the process of switching, the viewing angle is large and symmetric [4]. Together with this, the production of IPS-displays based on nematic liquid crystals is associated with the solution of rather complex technological problems caused by the need to form a grid of interdigitated electrodes (Figure 1).

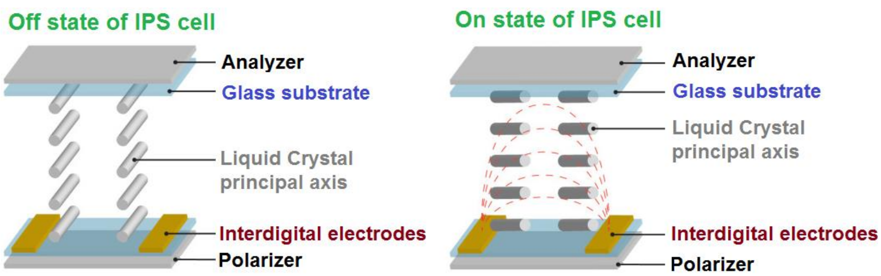

Figure 1. Off and on states of an IPS NLC cell. Red dashes show the lines of force of the electric field ***E***.

We show further that the in-plane switching effect is observed not only with NLC cells, but also in planar aligned deformed helix ferroelectric liquid crystal (DHFLC) cells [5]. The simple manufacturing techniques of planar aligned DHFLCs, where continuous but not interdigitated electrodes are in use (Figure 2), are well mastered, and the electro-optical modulation in these structures has been studied in detail both experimentally and theoretically [6 – 9].

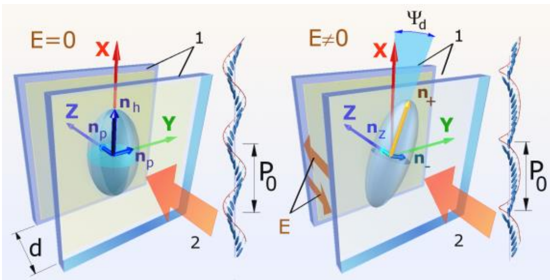

Figure 2. Geometry of a planar oriented DHFLC cell with a uniform lying helix: number 1 designates glass plates coated with a continuous indium tin oxide (ITO) layers, over which the aligning layers are deposited, arrow 2 shows the direction of propagation of linearly polarized incident light, *d* is the DHFLC layer thickness, p_0 is the helix pitch, n_p and n_h are refractive indices of the DHFLC helical structure at $E = 0$ [10], $\Psi_d(E) \sim E$ is deflection of the main optical axis in electric field.

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Replacing the periodical helical nanostructure of DHFLC cells with macroscopic ellipsoids of effective refractive indices (Figure 2) when analyzing light propagation through the structure will be quite correct at a certain wavelength λ, despite some difficulties related to effects of optical rotation and Bragg reflection, if [11]

$$p_0 \leq \lambda / 5. \tag{1}$$

Figure 2 illustrates the specific biaxial transformation of the ellipsoid of effective refractive indices $n_+ \sim E^2$, $n_- \sim E^2$ and $n_z \sim E^2$ in electric field E in combination with the main optical axis deflection on the angle $\Psi_d \sim E$ [6 – 10], which occurs perpendicular to the electric field direction [10], that is, in the plane of the substrates (indicated by the number 1 in Figure 2). Thus, there is some analogy between switching the main optical axis in IPS NLC (Figure 1) and planar aligned DHFLC (Figure 2) cells. Consequently, the IPS effect in DHFLC cells is possible if the mentioned above biaxial transformation of effective refractive indices does not significantly affect the propagation of light in the DHFLC layer. This paper is devoted to experimental proof of the existence of such a possibility. Our approach is based on the fact that when condition (1) is fulfilled, the light transmission T of a planar aligned DHFLC layer located between crossed polarizers is described by the relation proved both theoretically and experimentally [7]:

$$T(E) = \sin^2 4\Psi_d(E) \cdot \sin^2 \frac{\pi \Delta n_{eff}(E) d}{\lambda}, \tag{2}$$

where $\Delta n_{eff}(E) = n_+(E) - n_-(E)$ is the effective birefringence of the DHFLC layer in electric field.

2. Experimental results and discussion

Two multicomponent ferroelectric liquid crystal (FLC) mixtures with sub-wavelength helix pitch (p_0 < 100 nm) were elaborated by the authors for investigations of IPS switching in DHFLC electrooptical cells. These are FLC-587-F7 possessing the tilt angle $\theta = 31.6°$ at 22°C and FLC-650 ($\theta = 38.4°$ at 22°C, as shown in Figure 3). Both nano-scale helix pitch FLC mixtures are composed of biphenylpyrimidines as an achiral smectic C matrix and trifluoromethylalkyl diesters of p-terphenyldicarboxylic acid as chiral dopants possessing very high helical twisting power, as it has been described in detail [12]. These mixtures, which are special cases of the general material science approach described in [12], were taken into consideration, since they are characterized by rather different dependencies $\Delta n_{eff}(E)$ and $\Psi_d(E)$, see Figure 3.

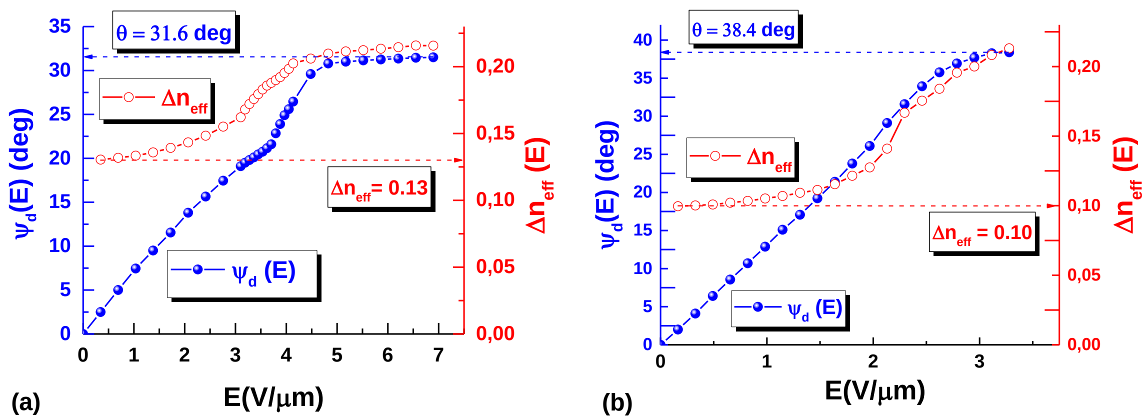

Figure 3. Dependencies of $\Delta n_{eff}(E)$ (red circles) and $\Psi_d(E)$ (blue balls) that on the left relates to the FLC-587-F7, and on the right to the FLC-650. Measurements were carried out at 22°C, at wavelength λ = 632.8 nm.

The above dependencies were obtained in the experimental setup based on the scheme of the Mach-Zehnder interferometer, which is described in detail [8]. Note that the quantitative value of the

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tilt angle θ of molecules in smectic layers in helicoidal structures of FLCs is determined by the level of saturation of the $\Psi_d(E)$ experimental curve, whose behavior in the electric field (as well as $\Delta n_{eff}(E)$) depends on the tilt angle magnitude, as can be seen in Figure 3.

Figure 4 shows measured *T(E)* dependencies of two planar aligned DHFLC cells (filled with the FLC-587-F7 on the left and with the FLC-650 on the right) and calculated values of the factors included in the relation (2). Measured dependencies of $\Psi_d(E)$ and $\Delta n_{eff}(E)$, which are presented in Figure 3, were taken for the calculations.

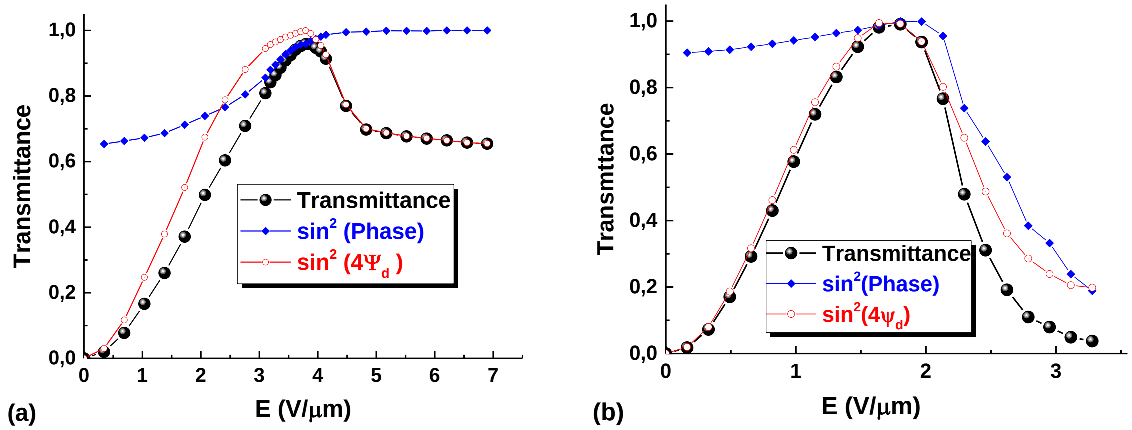

Figure 4. a) Measured total light transmittance *T(E)* (black balls) and calculated values of the factors included in the relation (2) for the DHFLC cell filled with the FLC-587-F7 at d = 1.45 μm and placed between crossed polarizers; b) the same data but for the FLC-650 at d = 3.05 μm. Calculated components of the transmittance are shown by red circles and blue diamonds. Measurements were carried out at 22°C, at wavelength λ = 632.8 nm.

Since the measured *T(E)* dependence in Figure 4b (blue diamonds) is practically coincides with the calculated dependence $sin^2(4\Psi_d)$, and the factor $\sin^2(\pi \Delta n_{eff} d/\lambda)$, which is denoted as $sin^2(Phase)$ in the Figure, does not practically change when $0 \le T(E) \le 1$, it can be argued that in this case the electrooptical modulation is very close to in-plane switching. However, the same factor in Figure 4a changes by 45 % when $0 \le T(E) \le 1$, which is not very consistent with the definition of the IPS-mode. Thus, the electro-optical modulation in the planar aligned DHFLC cells approaches the in-plane switching mode as the θ angle increases, which can be seen when comparing Figures 3 and 4.

3. Conclusions

It is experimentally shown that the in-plane switching electrooptical mode can be observed in DHFLC cells with sub-wavelength helix pitch. Planar aligned DHFLC IPS cells have a technological advantage compared with NLC IPS cells, since for manufacturing of DHFLC cells continuous and not interdigitated electrodes are in use. In addition, any DHFLC cells provide electro-optical modulation in the kilohertz range [6, 12], which is also their obvious advantage over IPS NLC.

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