Switching Process in a Surface-Stabilized Ferroelectric Liquid Crystal Film

Rıdvan KARAPINAR
*100.Yil University, Department of Physics,*
65080 Van-TURKEY

Abstract

In this paper we first discuss the operating principle of a ferroelectric liquid crystal film in the surface stabilized configuration, and then examine the switching characteristics using optical measurements performed with a polarizing microscope.

1. Introduction

The use of liquid crystal (LC) devices has been spreading profoundly throughout the world. The material used in these electro-optic devices is a nematic LC [1]. Nematic LCs have been widely used in watches, calculators and other displays because of their low cost and power. Nematic LCs have also been used in portable computer and television systems. However, since the response of a nematic LC to an applied electric field is slow, this is one of the drawbacks for its potential use. A great deal of interest has been shown recently in ferroelectric liquid crystals (FLCs), since these materials have shown considerable promise as fast electro-optic devices [2]. Indeed, the response time of a FLC is fast enough for flat-panel displays and also allows full color on each pixel which means higher quality on a display of a given size. This is because in the FLC devices the electric field couples directly to the spontaneous polarization, whereas in the nematic LC devices the field interacts with the dielectric anisotropy of the medium.

FLCs are characterized by orientational order and varying degrees of positional order of their molecules [3]. Molecules are arranged, on average, in equidistant planes what is known as a layered structure. The average direction of the molecular long axis, defined as the director $\mathbf{n}$ is tilted at an angle of θ with respect to the layer normal (Figure 1). Furthermore, the director orientation from layer to layer follows a helix. FLCs have permanent dipoles perpendicular to the long molecular axes, so these materials show a permanent or spontaneous polarization (P) when they are subjected to an electric field. This polarization allows reorientation of the molecule due to an inversion of the applied

field and leads to the possibility of switching in both directions.
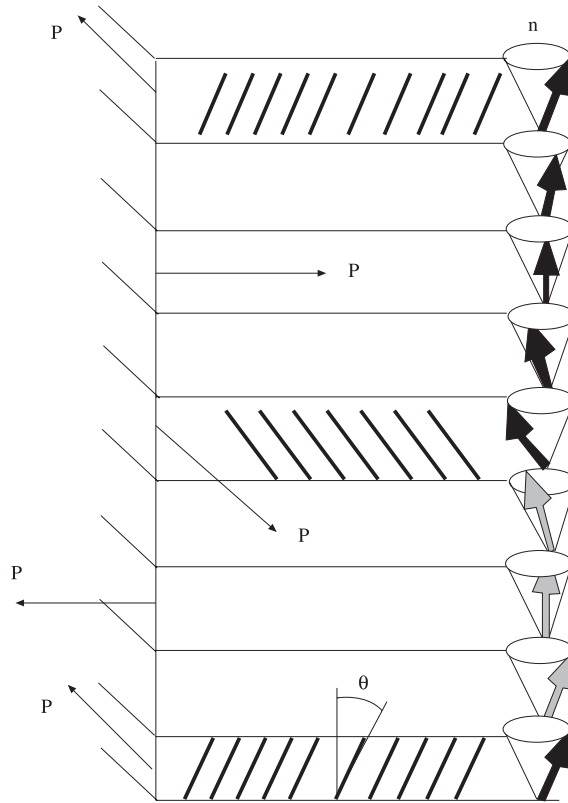

Figure 1. Director orientation and molecular arrangement in the FLC material.

The electro-optical properties of the FLCs dominate the performance of a display device. In this study, the operating principle of FLC cell is described, and switching behavior of the cell is analyzed. It is found that the experimental data agree well with the theoretical predictions.

2. Method and Experiment

The existence of spontaneous polarization is a microscopic property of a FLC thin layer. However, bulk FLC samples do not show spontaneous polarization because of the helicoidal structure of the FLC sample, which is shown in principle in Figure 2. It can be seen that the polarization vector (**P**) changes with helix, averaging to zero over the pitch length. The pitch of a FLC material is typically in order of 1-100 μm, whereas the thickness of one layer is of the order of 20-30 Å. In order to have bistable switching, the helicoidal structure has to be unwound. The most common way of doing this is to

sandwich the FLC sample between two glass plates in such a way that the layers are perpendicular to these structures. In this surface stabilized FLC cell [4], the helicoidal structure is suppressed by surface interactions. This type of layer arrangement is called "bookshelf geometry" [5]. Thus, the molecules in contact with the layers can not freely rotate around the cone, but are forced to lie in the plane.
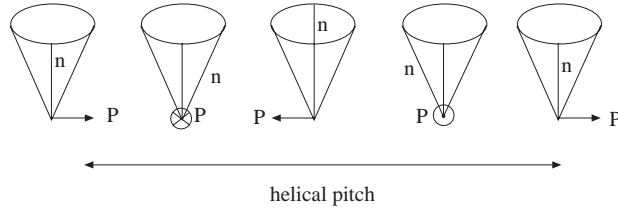
Figure 2. Heliocidal structure of the FLC material. The **P** is perpendicular to the **n**.

In planar oriented samples for which the cell gap is smaller than the pitch length, the helix is completely unwound. In this configuration, application of an applied electric field (E) causes switching of the director around the cone so that spontaneous polarization is aligned with the applied field. This means that when the electric field is applied to the film, one of two orientations (up and down) is energetically favorable (Figure 3). When FLC cell is placed between two crossed polarizers and is aligned such that the one tilt direction is parallel to the direction of one polarizer, the cell will switch from dark (up) to bright (down) states.
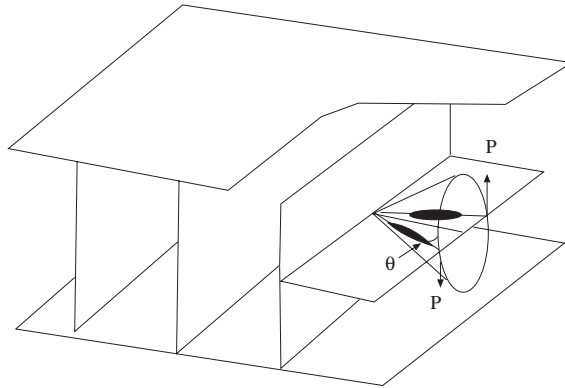
Figure 3. Schematic representation of the FLC cell in the surface stabilized state.

The director properties of a FLC sample determine its response to the applied electric field (E). Unlike nematic LCs where dielectric constants are responsible for the interaction, the spontaneous polarization is present in FLCs. Thus, the response of the FLC cell is characterized by a dielectric anisotropy ($\Delta\epsilon$) and P. The electrooptic effect in a FLC material is due to reorientation of the director in response to the electric field. When the

electric field is applied to the cell, the sample will respond in order to minimize the field terms of the free energy. Thus for the FLC sample electro-static energy is related to PE. Upon the application of the electric field to the FLC cell, an electric torque (Γ_e) arises:

$$\Gamma_e = |\mathbf{P} \times \mathbf{E}| = PE\sin\theta \cong PE\theta, \tag{1}$$

$\theta = 0$ and $\theta = \pi$ correspond to the two fully switched states. The electric torque tries to turn the director into a new position. However, the FLC material reacts with a viscous torque (Γ_v) directed so as to reduce the existing angular velocity of the director:

$$\Gamma_v = -\eta\frac{d\theta}{dt}, \tag{2}$$

where η is the rotational viscosity which is of practical importance for efficient design of the FLC devices, since it controls the response of displays to the electric field. So, the molecular motion can be described by the following equation taking into account the torque balance [6]:

$$\eta\frac{d\theta}{dt} + PE\theta = 0. \tag{3}$$

The switching time (τ) can be obtained from the solution of Equation (3):

$$\tau = \frac{\eta}{PE} \tag{4}$$

The switching time is inversely proportional to the applied electric field. This equation is valid in the high field strength and indicates that the higher P materials will switch more quickly.

In our experiments the switching properties of homogeneously aligned FLC cells were carried out using a polarizing microscope. The FLC material was introduced into a cell by means of capillary action at an elevated temperature. Film thickness of 3 μm was adjusted using spherical glass spacers. In the experiments the FLC material SCE13 was used. This chiral smectic C mixture has high isotropic phase transition point (100.8 °C). Moreover, the spontaneous polarization of SCE13 is higher than those of similar mixtures. So, this material is suitable for display applications.

The FLC sample under investigation was placed on a heating stage under the microscope. A schematic diagram of the experimental set-up used is shown in Figure 4. The optical response from a switching FLC cell was acquired by applying an electric field to the cell, and by monitoring changes in the light transmittance with a photodiode attached to the microscope. The output signal from the photodiode was displayed in a digitizing oscilloscope, where the waveform can be transferred to a computer. In order to switch the FLC cell, the applied voltages were obtained by a signal generator and amplified by a high voltage amplifier. A current-to-voltage amplifier was connected to the cell in order to analyze the spontaneous polarization when the electric field is applied to the cell. The temperature of the FLC cell was controlled by a programmable temperature control system.
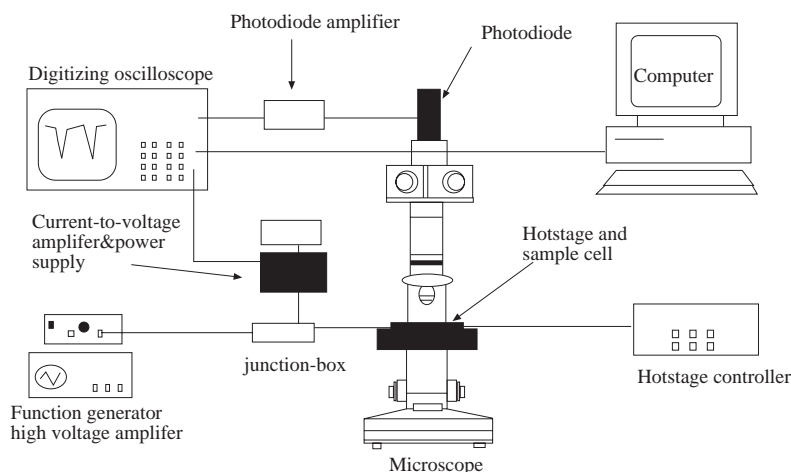
**Figure 4.** Schematic diagram of the experimental set-up.

3. Results and Discussion

In the experiments, the switching times of the FLC cell was measured as a function of the applied voltages. To this aim, voltages of up to 30 V with a frequency of 1 kHz were applied to the sample using a signal generator. The form of the signal was varied for different measurements. The cell was positioned between two crossed polarizers under the microscope. A typical electro-optic response of the cell is presented in Figure 5. The optical response shows that the transmission relaxes after the switching pulse, thus the surface stabilized state somewhat differs from the fully switched state. The data of the switching time is shown in Figure 6 as function of the applied voltages. The switching time was measured by applying a square signal to the cell and monitoring the intensity of transmitted light by a photodetector. It can be seen from the figure that the data obtained experimentally agree well with the values calculated from Equation 4. The switching time is inversely proportional to the applied voltage. For FLCs it is interesting to apply high voltage to switch the cell. This is not the case in the nematic LC case which is governed by a relaxation time which depends on the physical parameters of the LC material and the film thickness. However, for the FLC sample Frank elastic constants do not play any role in switching if the field is high enough. Furthermore, application of the opposite signs of the electric field switches the FLC sample into opposite states and so the FLC cell switches at much higher speeds. The spontaneous polarization and the rotational viscosity are the two main parameters of the FLC material that must be taken into account. In this study we also analyzed the electric field dependence of the spontaneous polarization. A typical current signal by applying a field with a triangular form is shown in Figure 7. The current due to the polarization realignment starts to arise from the very beginning. This means that there is no threshold voltage for deforming

the helix. As the applied electric field is linearly reversed, a critical amplitude is reached. This process is accompanied by a rearrangement of layer polarization which induces a charge seen as the large peak on the current response curve. The magnitude of the P was measured as a function of the temperature by using a triangular wave method [7] , and it was found that P decreases when the temperature increases [8]. The FLC cell used in our experiment has a uniform director configuration in two switched states. Application of the electric field to the direction of the spontaneous polarization causes the optic axis to rotate twice the cone angle. It was observed that when a small electric field was applied to the cell the molecules were partially switched inside the cone. This means that the director wants to return to its original position, which is the surface stabilized state. However, on applying a higher field to the sample, the director takes the other surface stabilized state and thus the FLC cell becomes bistable [9].
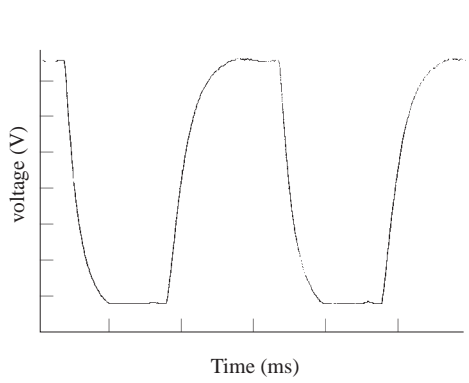
Figure 5. A typical electro-optic response of the FLC film.
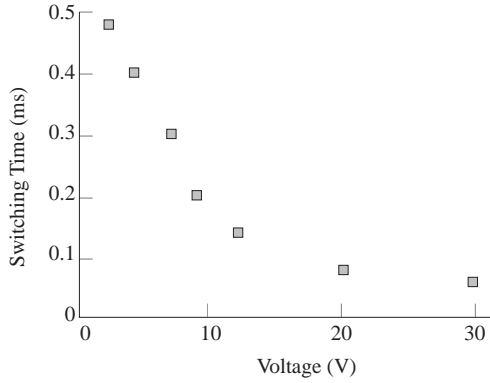
Figure 6. The switching time of the FLC sample as a function of the applied voltage.
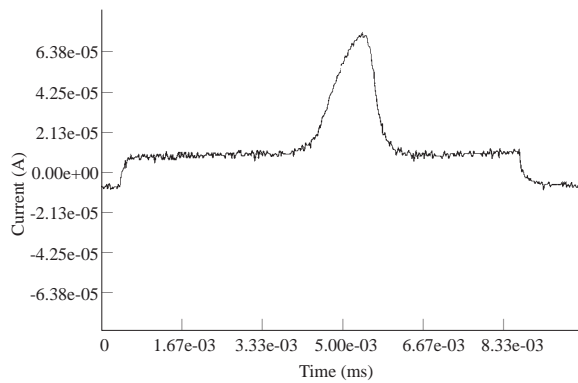
Figure 7. A typical current signal by applying a field with a triangular form.

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In conclusion, using an optical measurement technique we have analyzed the switching characteristics of the FLC cell with SCE13, and reported data for this compound. There is a linear coupling between the polarization and the applied electric field which makes the switching in both directions on the field reversal. The switching of the FLC cell is very fast compared to the twisted nematic devices.

Acknowledgment

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