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Anisotropic hydroxypropylcellulose films as alignment layers of a bistable ferroelectric device

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Hydroxypropylcellulose films are used as the alignment substrate in a liquid crystal bistable electro-optical device. These alignment films were characterized by atomic force microscopy. The electro-optical behaviour of this device, which operates in the Clark–Lagerwall mode, is identical to that observed for typical SSFLC cells. In particular the bistability of the cell was clearly observed, the threshold voltage was measured and an estimation of the anchoring energy of the LC mixture used, in this type of system, was made.

1. Introduction

The surface alignment of Liquid Crystal (LC) molecules is of crucial importance to the function of LC electro-optical devices and, in particular, surface stabilized ferroelectric liquid crystal (SSFLC) cells [1]. The surface treatment that leads to the molecular alignment in this type of cell is typically obtained by rubbing a polymer coating, previously applied on a conducting glass substrate. Alternatively, as will be shown here using anisotropic hydroxypropylcellulose (HPC) films, the alignment properties can also be achieved by using a suitable pre-prepared polymer coating without any additional processing after applying to the glass substrate. It has been shown that this kind of film presents a morphologically tunable surface depending on the preparation conditions [2]. This fact opens new perspectives for preparing alignment layers for which the topography can be adjusted in order to optimize the electro-optical properties of the devices in which they are applied.

The use of anisotropic HPC films for alignment of nematic LCs was recently proposed [3] and the corresponding alignment mechanism was described [4]. HPC is a water-soluble polymer that is readily available at low cost. Lyotropic and thermotropic liquid crystalline behaviour can be obtained when HPC is dissolved in aqueous and organic solvents [5]. The polymer concentration necessary to form an ordered phase in water was found to be around 40 wt % at room temperature [6]. HPC is used in commercial applications such as rheology modification, encapsulation and chemical delivery. More recently, thin films (40–60 μm) of HPC, obtained from isotropic solutions, have been used to prepare electro-optical PDLC type cells [4, 7].

In this paper we present, for the first time, the realization of an SSFLC type cell using an HPC polymer coating as the alignment layer. The HPC films were previously characterized by atomic force microscopy (AFM). The prototype cells were studied by polarizing optical microscopy (POM), under the influence of an appropriate alternating electric field, with simultaneous monitoring of the polarization current. As will be described, a study of the electro-optical properties of the cells confirms their operation in the Clark–Lagerwall mode.

Very interesting properties are potentially attainable by developing this alignment method in ferroelectric LC devices. The tunable topography characteristics of the film, the low cost of the polymer and the fact that no additional surface treatment, like rubbing, is needed for molecular alignment in this type of cell, will probably mean that we can expect its production process to be simpler and eventually of lower cost than that used for conventional SSFLC devices.

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2. Experimental results and discussion

The prototype cells were constructed from two ITO-coated glass plates covered with the anisotropic, transparent HPC film described below. These plates were assembled face to face, with the HPC coating directions parallel to each other and separated by 10 μm spacers, as shown in figure 1. The devices were filled with the FLC mixture FELIX 017-100 [8]. This FLC mixture has the following phase sequence: (Cr–28°C–SmC*–73°C–SmA–77°C–N–84–87°C–I).

The solid films were prepared from a liquid crystalline solution (60 wt %) of hydroxypropylcellulose (Aldrich Chemical Co., nominal molecular mass 100 000 g mol^{-1}) in distilled water at room temperature. The films (~110–140 μm) were obtained by spreading the anisotropic iridescent solution on the conducting surface of the flat glass substrate using a calibrated ruler (250 μm), moving at a constant speed of 3 mm s^{-1}. The solvent was allowed to evaporate for at least 4 days at room temperature in a laboratory atmosphere.

A D3100 instrument with a Nanoscope IIIa controller from Digital Instruments (DI) was used for the characterization of the films by AFM. The measurements were performed in the *tapping mode*™ under ambient conditions. A commercial tapping mode etched silicon probe from DI and a 90 × 90 μm^2 scanner were used. Images consisted of raster-scanned, electronic renderings of sample surfaces.

Figure 2 shows the 3D topography image (20 × 20 μm^2 scan) of the free surface of a sheared HPC film prepared as described above. The image shows two different periodicities: a primary set of 'large' bands, perpendicular to the shear direction, lying under a smoother texture characterized by a secondary periodic structure consisting of 'small' bands. The angle between the two sets of bands is about 18°. The height profile analyses were performed for two cross-sections: (i) from the cross-section taken along the shear direction, a periodicity of

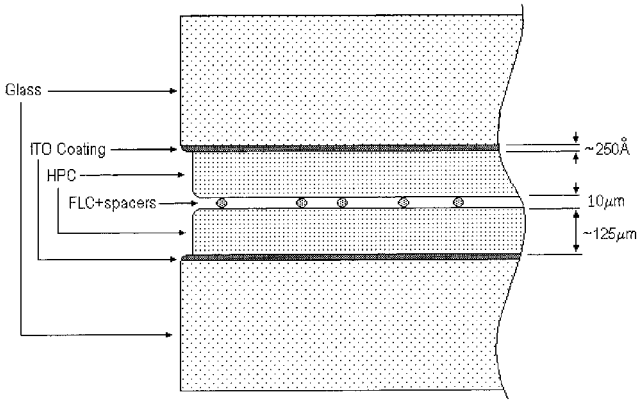


Figure 1. Schematic representation of the HPC + FLC cell.

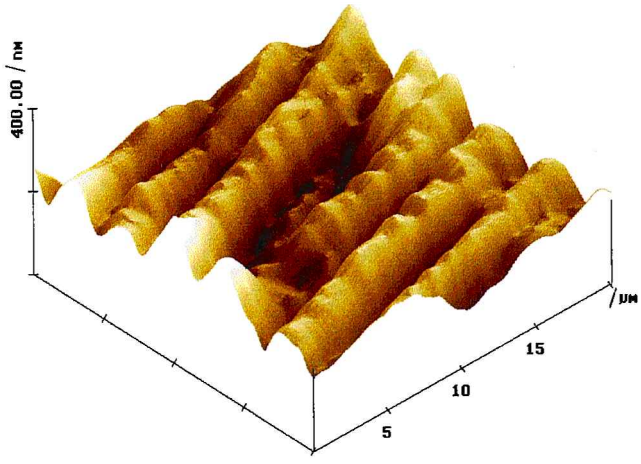


Figure 2. AFM image of the HPC polymer film surface.

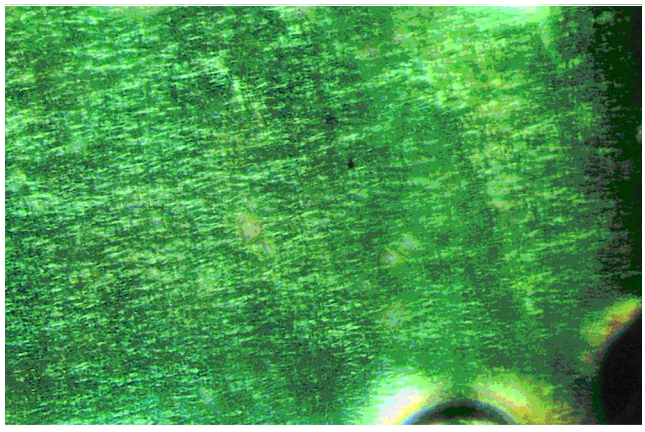
the 'large' bands, $\Delta l \sim 3.5$–4.0 μm, and an average peak-to-valley height for these bands, $h_1 \sim 90$–100 nm, were determined; (ii) from the cross-section taken along the direction of the secondary periodic 'small' bands, a periodicity, $\Delta l_2 \sim 1.4$–1.8 μm, and a peak-to-valley height, $h_2 \sim 7$–14 nm, were determined.

The two substrates with the HPC films were assembled together with an EPOXY resin and separated by 10 μm spacers. The cells thus obtained were filled by capillarity with the FLC mixture in the isotropic phase. The average cell thickness (HPC films plus ferroelectric layer) was ≅280 μm. The average ferroelectric layer thickness was determined by the spacers.

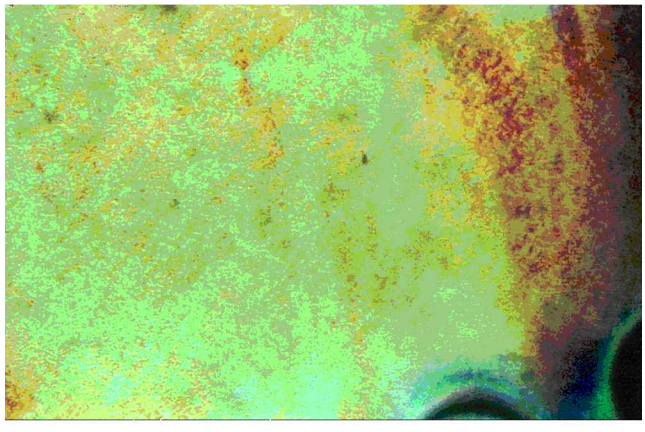
The electro-optical properties of the HPC + ferroelectric cells were studied by POM under the influence of an appropriate alternating electric field, with simultaneous monitoring of the polarization current.

In figures 3 (*a*) and 3 (*b*) we present the optical textures (magnification 175 ×) obtained in the isotropic phase of the FLC (83°C) as observed in a cell mounted between crossed polarizers. In figure 3 (*a*) the cell was oriented between the crossed polarizers in such a way that the darkest state was observed. In figure 3 (*b*) the crossed polarizers were rotated by 45°. The difference observed between the two photographs gives evidence of the optical anisotropy of the HPC film, as expected. The temperature of transition from the anisotropic to the isotropic phase for the polymer used is around 180°C. Some defects can be observed in the photographs due to the simple prototype cell assembly process and heterogeneities in the solid films.

In figures 4 (*a*) and 4 (*b*) we present the two stable optical states (ON/OFF) of the cell at 53°C obtained by applying a ± d.c. voltage (> 22 V_{PP}) to the cell. The two optical states are clearly seen. The OFF state is equivalent to the ON state if the polarizers are rotated

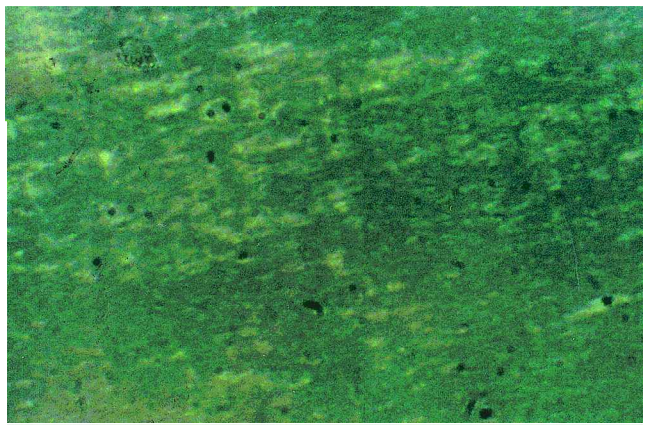


(*a*)

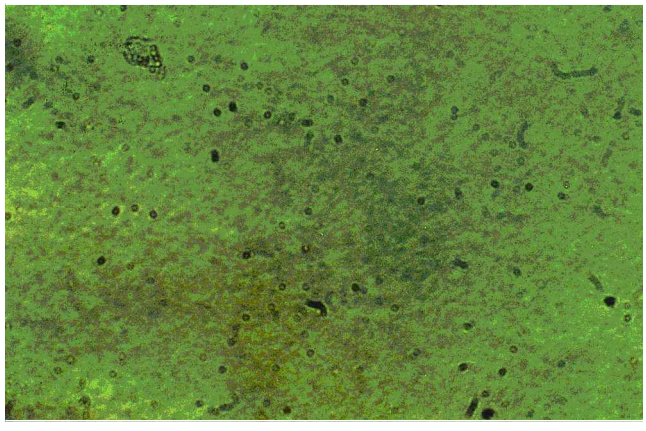


(*b*)

Figure 3. HPC + FLC cell with the LC in the isotropic phase (83°C) (*a*) between crossed polarizers (magnification 175 ×), (*b*) between crossed polarizers rotated by 45° with respect to the orientation used in (*a*) (magnification 175 ×).



(*a*)



(*b*)

Figure 4. HPC + FLC cell at 53°C (SmC*) as observed between crossed polarizers (magnification 700 ×) in (*a*) the OFF state, (*b*) the ON state.

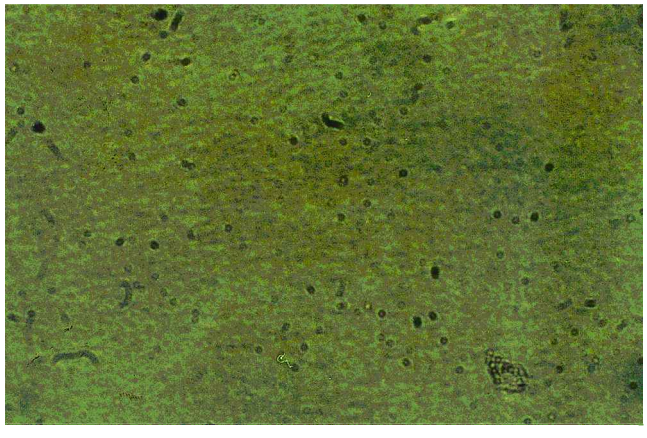


Figure 5. HPC + FLC cell at 53°C (SmC*) as observed beween crossed polarizers (magnification 700 ×) in the OFF state but with the polarizers rotated by 45°.

by 45° as observed in figure 5. This rotation angle is in agreement with the optical tilt angle provided by Clariant for the considered temperature.

The electric current circulating through the cell's circuit was also measured using a Hall probe, recorded on a digital oscilloscope and processed in a PC computer. In figure 6 we present the electric current flowing in the circuit when a triangular voltage $\sim 22\ V_{PP}$ was applied to the cell. This figure clearly shows the three characteristic components present in an SSFLC cell operating in the Clark–Lagerwall mode: the capacity current, the ionic current and the spontaneous polarization current peaks.

Additionally, the cell was optically characterized in order to obtain a contrast curve which allows determination of the threshold voltage. As usual in SSFLC devices, the cell was placed between cross polarizers, with the polarizer set parallel to the optical axis of the liquid crystal in order to maximize the contrast ratio. After applying a single rectangular pulse of 153 ms to the cell, one of the optical states was obtained. Inversion of the pulse allows the other optical state to be obtained.

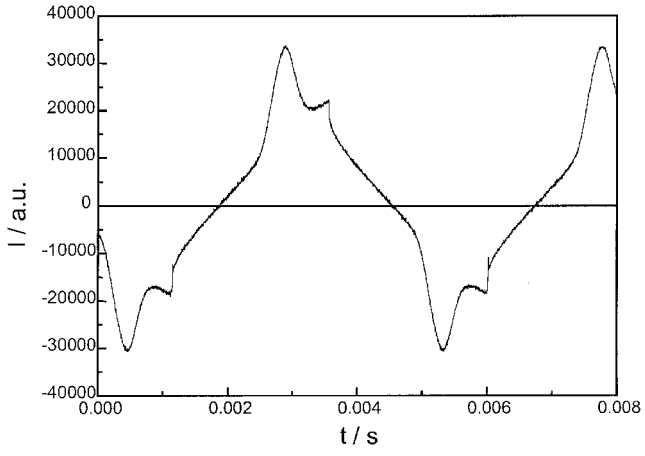


Figure 6. Electric current flowing in the circuit when a triangular voltage is applied to the cell.

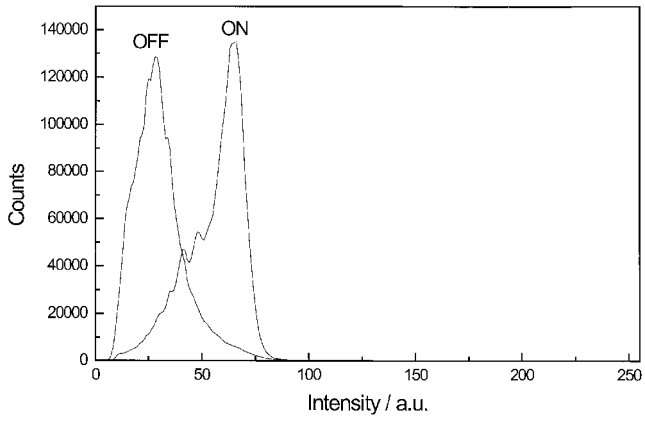


Figure 8. 8 bits grey-level histograms in the ON and OFF states.

The optical transmission was measured in both states using a CCD camera coupled to the polarizing optical microscope and connected to a computer. The process was repeated for increasing voltage. The resulting contrast curve is presented in figure 7. An 8-bit grey-level histogram of both states is presented in figure 8.

The anchoring energy W_d of the FLC mixture in this system may be estimated in a first approximation using the expression [9]:

$$E_{th} \cong \frac{4W_d}{\mathbf{P}_s d} \tag{1}$$

where E_{th} is the threshold field characteristic of the Clark–Lagerwall effect, d is the distance between the two conducting substrate walls, and $\mathbf{P}_s$ is the spontaneous polarization of the ferroelectric liquid crystal. It is clear that the distribution of the applied field between the HPC and the FLC layers should be considered in order to get an accurate measurement of the anchoring energy. In the case of our prototype cell, the separation surfaces are surely irregular and the effective thicknesses are not easy to determine. Therefore we consider as a first approximation, a constant field across the system. This very simple approach gives us only an order of magnitude of the anchoring energy, assuming similar orders of magnitude of the dielectric constants of both media [4, 8, 10]. In our case, $E_{th} \times d \cong 5$ V, and $\mathbf{P}_s = 470\,\mu C\,m^{-2}$ [8], which gives a value of $W_d \sim 588\,\mu J\,m^{-2}$. This value is not very different from others usually found in standard SSFLC cells [9].

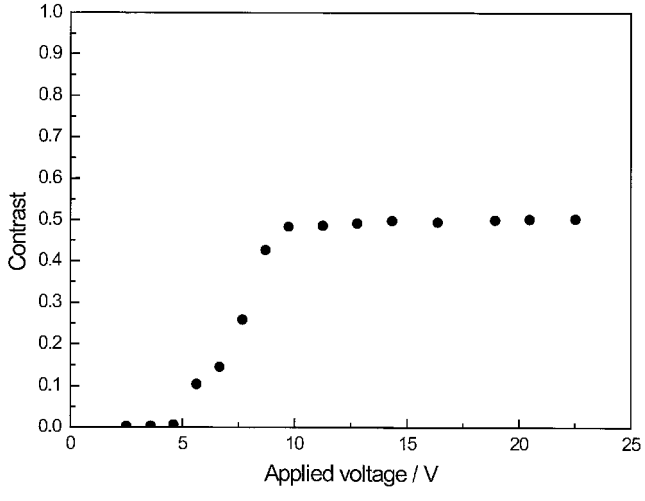


Figure 7. Contrast values, $(I_{ON} - I_{OFF})/I_{ON}$, as a function of applied pulse voltage, V.

The results presented here clearly show the bistability of the cell assembled with anisotropic HPC films as alignment layers. However, due to the HPC film thickness some defects could be observed over the active cell area. Work is being done in order to decrease the thickness of the HPC films and, consequently, the overall cell thickness. By doing so we expect to increase the performance of this type of cell. The bistability of this cell can be an advantage in terms of power consumption over PDLC-type devices which use nematic liquid crystals. The special tunable morphological characteristics of HPC alignment layers, for instance the amplitude and characteristic length of the two topographic periodicities and the angle between their directions, are very important aspects which should be explored in order to optimize important aspects of both cell construction and performance.

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