41.3: Flow of Ionic Impurities in a Ferroelectric Liquid Crystal Device

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It is important to understand and to study ionic properties in liquid crystal devices, since the omnipresent ions can severely interfere with the device performance. Ionic properties, both static and dynamic, also present rich physical phenomena that are of great interest from a purely scientific perspective as well.

In all ionic phenomena observed and reported in the literature known to the authors, ions migrate along electric field lines, and accumulate around electrodes under the influence of DC or unbalanced Coulomb forces[1]. In this work, we report a newly discovered phenomenon of ionic behavior in a ferroelectric liquid crystal (FLC) device. We find that, if a pure AC voltage is applied to a FLC device having a very high concentration of ions, the ionic impurities can be found to move laterally along the smectic layers. Further, if the voltages on two adjacent regions are out of phase, i.e. the fields in the adjacent regions have opposite directions, then ions can accumulate asymmetrically to one side of the boundary between the regions.

Our experiments are performed using a thin, reflective, surface stabilized FLC spatial light modulator having 1280 columns and 768 rows of pixels. The smectic FLC exists as a single domain of C2 chevron structure. We drive the pixel array with a 60 Hz AC square wave signal having a 2.5 V amplitude which is applied between the pixels and the transparent, conducting ITO electrode on the opposing glass window. Our electronic driver writes pixel data to the array a row-at-a-time, and it requires about 600 s to re-write the entire array.

In a typical experiment, the direction of the FLC smectic layers is parallel to the pixel rows. The columns are then separated into 10 wide vertical stripes of 128 columns each, and the driver applies the 60 Hz signal to the panel, so that adjacent wide stripes are 180 degrees out of phase. After a period of time, the drive signal is removed and an analysis is made of the ion distribution.

The ion distribution analysis involves making spatially resolved measurements of the ion concentration[2]. In these measurements, the array is divided into 40 thin stripes of 32 columns each, and the ion concentration is measured separately for each thin stripe by time-integrating the current which occurs when the device is switched at 5Hz. The integration time is chosen to exclude the current contributions of the device capacitance and of the polarization switching of the FLC. This produces four ion measurements for each of the 10 wide stripes.

Figure 1 is a plot of the measured ion concentration as a function of the thin stripe position across a FLC panel before and after 2 hours of driving. It clearly shows that the ion concentration is periodic with the same period as the wide stripes and is greatest to the right side of each boundary between wide stripes. (The line connecting the data points is simply a visual aid.)

This periodic ion concentration does not develop at all if the wide stripes are parallel to the smectic layers. We established this fact by changing the driver so that it produces a set of six horizontal wide stripes and drives adjacent ones out of phase. Figure 2 shows the spatially resolved ion concentration before and after 2 hours of driving. The driving is seen to have produced little change in the distribution of ions.

The conclusion from these two experiments is that the ions accumulate at the boundaries when the smectic layers are perpendicular to the boundaries, but no ions accumulate when the smectic layers are parallel to the boundaries. This migration and accumulation of ionic impurities at the boundaries between oppositely phased stripes occurs in spite of the fact that the time-averaged electric field applied to the ions is exactly zero. Thus it is a completely new phenomenon.

The fact that we observe migration and accumulation of ions when the boundaries are perpendicular to the smectic layers but not when they are parallel suggests that this phenomenon might be related to FLC director motion during electro-optical switching. In the following, we propose a simple conceptual model of the dominant mechanism which is involved in this phenomenon.

It is well known that the smectic layers in a conventional FLC device like ours, adopt a local chevron structure. Zou, et al.[3] have shown that asymmetries associated with the electro-optical switching of such a chevron structure can cause an overall macroscopic flow of liquid crystal material which is parallel to the smectic layers. They named this behavior liquid crystal pumping. We argue that this pumping effect, together with the electric field between two oppositely switching regions, results in the observed asymmetric migration and accumulation of ions, as is illustrated qualitatively in Figure 3.

The plane of Figure 3 is parallel to a smectic layer, and each of the ten sub-figures shows three wide stripes and the boundaries between them. The individual pixels within each wide stripe are too small to be shown at the scale of the figure. The sub-figures depict important instants of time spanning one cycle of AC driving. The arrows indicate the direction of the electric field (except in 3b and 3g), and the small dots represent positively charged ions. We have determined by our current vs. time measurements that the ion mobility is so high that all of the ions will transit the FLC layer in about 10 ms. For low AC frequencies, then, the ions will have collected near one electrode just prior to switching the field directions, as shown in 3a and 3f. The inter-stripe gaps will have been swept free of ions, too, since the gaps are about equal in size to the FLC thickness. The wide stripes are shown switching electrically in 3b and 3g. Following Zou, we take the convention that the down-to-up transition of the electric field will be accompanied by a flow which is stronger and in the opposite direction from the flow accompanying the up-to-down transition, and these two flows

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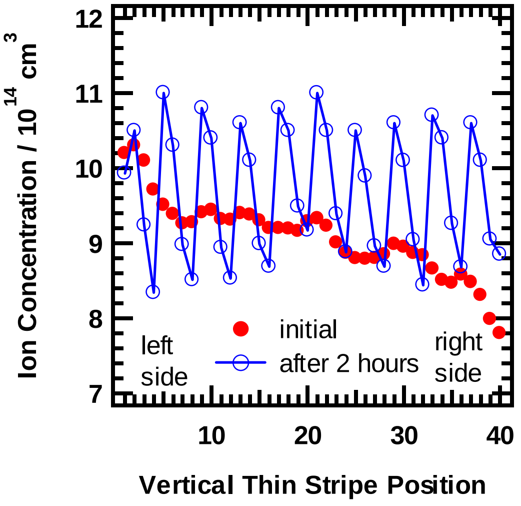

Figure 1. Spatially resolved ion concentration measured within a FLC SLM before (dots) and after (open circles) 2 hours of driving with a stripe pattern. The wide stripes are perpendicular to the smectic layers.

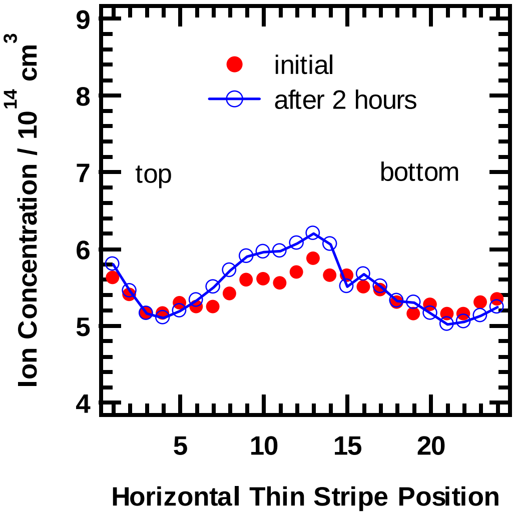

Figure 2. Spatially resolved ion concentration measured within a second FLC SLM before (dots) and after (open circles) 2 hours of driving with a stripe pattern. The wide stripes are parallel to the smectic layers.

are represented by the directions and sizes of the horizontal arrows in 3b and 3g. The FLC switches in about 150 s, and, as it does, ions near the down-stream edge of each stripe will be kicked out into the inter-stripe gap. The flows die out quickly, and the fields indicated in 3c and 3h cause the ions to move. Ions which are at the top of a gap next to the window electrode will be driven back within the field of the nearest stripe. However, ions in the gap at the bottom next to the pixel electrodes are transported across the gap by the inter-stripe field. These actions are shown in 3d,e and 3i,j. The end result is that positive ions are transported from the left side to the right side of each boundary during the course of each

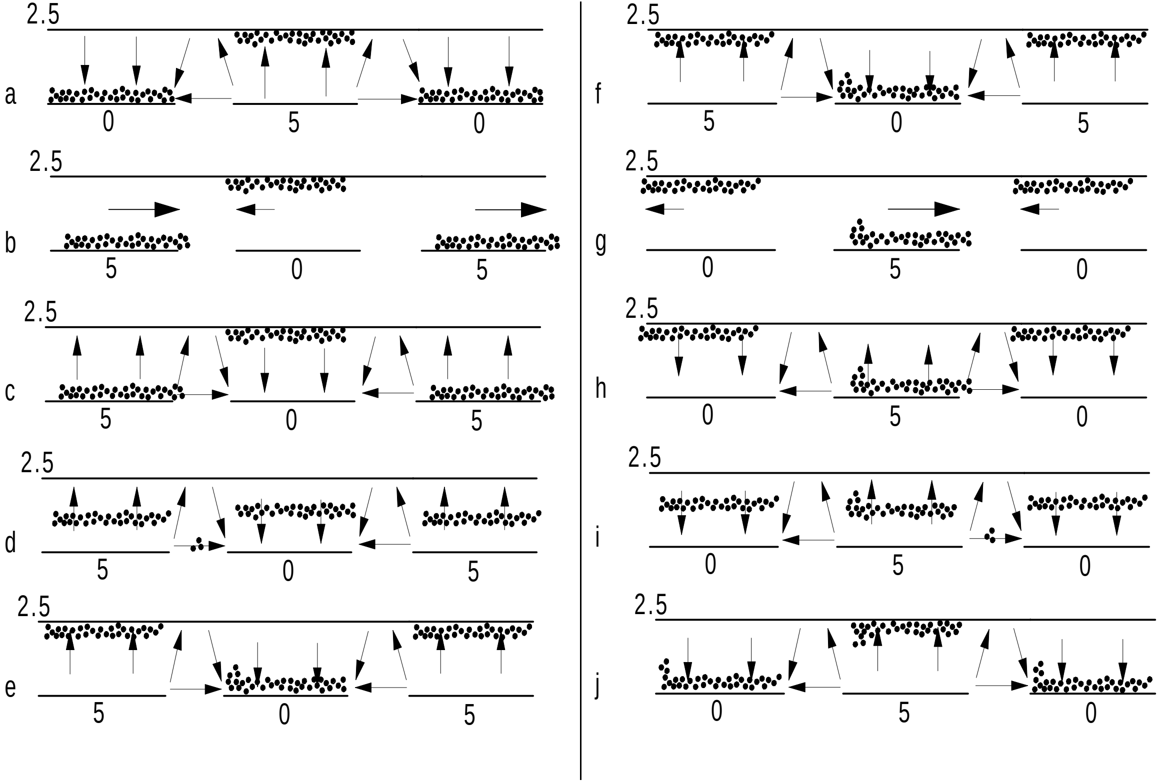

Figure 3. Schematic illustration of asymmetric ion migration across boundaries between oppositely-phased switching wide stripes.

complete AC cycle. The foregoing depiction implies that the FLC switching and the concomitant flow shown in sub-figures 3b and 3g occur during a special time interval when no electric fields are present. In fact, fields are always present, and the events of 3b and 3c proceed together, as do the events of 3g and 3h. The special sub-figures 3b and 3g have been included only as a means to focus attention on the central mechanism that is involved in our model.

We do not generally know that the stronger flow is associated with the down-to-up transition of the field. Nor do we know that the flow has the directions shown. The results, however, are independent of these conventions in the following sense. If we make the stronger flow correspond to the up-to-down transition, then this model implies that negative, rather than positive ions will accumulate at the boundaries. If we reverse the directions of both strong and weak flows, then this model implies that the ions will be transported instead from right to left and will accumulate on the left side, rather than the right side, of the boundaries. Finally, we can report that the same accumulation of ions occurs when the AC frequency is increased to a few hundred Hz, and all the ions do not have time to completely transit the FLC layer in one half-cycle. The essential asymmetry of the model remains true even in this circumstance, so the fundamental mechanism for the transport remains the same.

To conclude, we have discovered a new ion transport phenomenon which is unique to FLC devices, whereby the ions are transported by a net flow which accompanies the AC electro-optical switching of a FLC device. The direction of transport is predominately along the smectic layers, and the ions accumulate asymmetrically at the boundary between any two regions when the boundary is not parallel to the smectic layers and when the regions always have oppositely directed electric fields. We have also described a simple conceptual model of the dominant mechanism which produces this new ionic effect.

References.

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