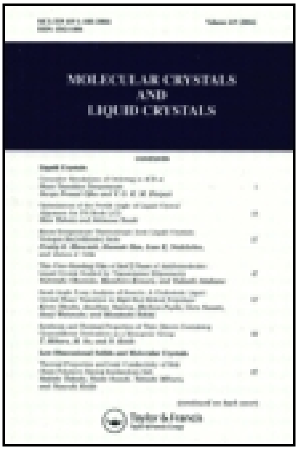

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Effects of Pulsed Electric Fields on a Nematic Device with a Ferroelectric Ceramic Substrate

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We report details of the interaction between a thin film of ferroelectric ceramic (lead zirconate-lead titanate) and an overlying layer of nematic liquid crystal. Pulsed electric fields of 1ms duration and of varying amplitudes and polarity have been used to achieve different degrees of poling within devices in which one substrate includes the ferroelectric ceramic layer. The degree of orientation of the nematic liquid crystal is found to depend on both the amplitude and polarity of the poling voltage employed. The magnitude of the poling voltage necessary to induce reorientation in the liquid crystal compares reasonably with the calculated value. The reorientation of the nematic liquid crystal due to the interaction with poled grains of PZT is stable for at least several months.

Keywords: local Freederickz transition; surface interactions; nematic

INTRODUCTION

The visualisation of domains in ferroelectric (FE) crystals through decoration of the surface with nematic liquid crystals (LC) is widely used in the study of solid-state FE substrates [1,2,3,4]. The technique utilises the fact that in a poled FE crystal the polarisation will couple with the nematic liquid crystal, inducing a reorientation which in turn produces an image of the parallel and antiparallel domain structure that occurs in the crystal. The reorientation of the nematic liquid crystal is readily visible in polarised light. Despite the common use of visualisation techniques, the interaction between the FE substrate and the overlying nematic LC which causes the reorientation is poorly understood.

As well as improving the understanding of the interaction between solid FEs and nematic LCs, there is a further interest in FE substrates since they have potentially interesting properties in devices. Blinov *et al* [5] showed that a ferroelectric polymer layer could be used as a substrate in a nematic liquid crystal device. We recently reported details of the interaction between the remnant polarisation of a thin, transparent film of a ferroelectric ceramic material, lead zirconate-lead titanate (PZT), with a nematic LC [6,7]. Understanding the interaction between the ferroelectric ceramic and the liquid crystal was hindered by the grain structure in the ceramic thin film in which the size scale is of the order of 10μm. Nonetheless, a well-defined local Freederiksz transition occurred above the poled grains and it was possible to obtain a measure of the reorientation by careful observation of the birefringence colour above the grain [8]. This paper presents a study of the different degrees of reorientation of a nematic liquid crystal that occur in a device with one substrate formed from a thin film of PZT, subjected to a poling field of varying amplitude. Voltage pulses 1ms wide and of different amplitudes and polarity are applied to the device. The poling voltage required to induce a reorientation in the overlying nematic liquid crystal layer is compared to the calculated value. The data is discussed with reference to the electrical hysteresis loop measured for the PZT thin film.

EXPERIMENTAL

The observations were carried out on a nematic LC device constructed with one plain glass substrate and one substrate that incorporates the thin film FE layer, as shown in figure 1. The transparent PZT 30/70 ($Pb(Zr_{0.30}Ti_{0.70})O_3$) layers were deposited by sol-gel/spin-coating onto indium-tin-oxide (ITO) coated glass [6] to a thickness of approximately 0.24μm. The hysteresis curve measured for the FE thin film is shown in figure 2. In constructing the device, a rubbed polyvinyl alcohol layer was coated onto the plain ITO/glass substrate to induce planar alignment of the LC at that surface. No alignment layer was employed on the FE substrate, allowing the direct interaction between the PZT and the LC to be observed. The device contained a 4.10μm thick layer of the nematic LC 5CB[9].

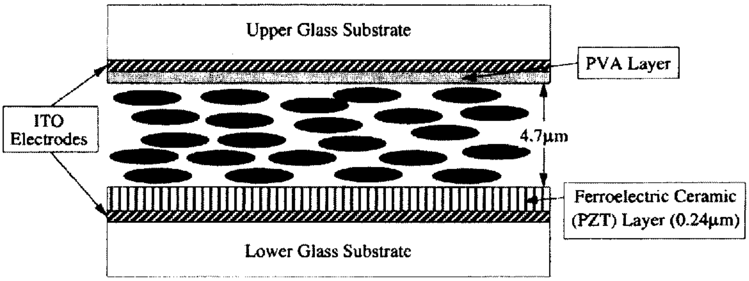

FIGURE 1. A schematic of the LC device. Note that the FE substrate has no alignment layer.

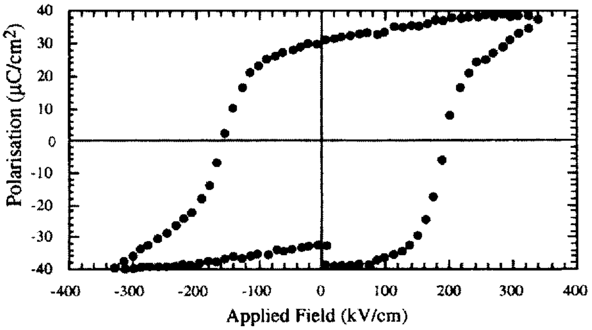

FIGURE 2. The hysteresis curve produced for the PZT thin film used in constructing the device.

The calculation of the voltage, V_0, that must be applied across a device configured as shown in figure 1 in order to pole the FE has been presented elsewhere [7], and is given approximately by the expression in equation 1:

$$V_0 = V_{FE}\left(1 + \frac{\varepsilon_{FE} d_{LC}}{\varepsilon_{LC} d_{FE}}\right) \tag{1}$$

The subscripts *FE* and *LC* refer to the different layers, ε is the dielectric permittivity of the layer and *d* is the layer thickness. In order for the PZT to be poled, V_0 must be sufficient to produce a field order of the coercive field across the 0.24μm thick PZT layer. It can be seen that the required poling voltage depends on the dielectric permittivity and layer thickness of the both PZT and NLC. In this experiment, carried out on devices comprising 4.10μm thick layer of 5CB and a 0.24μm thick layer of PZT, the calculated value of V_0 is approximately $150V_{rms}$.

Voltage pulse trains comprising of 1ms wide pulses at a frequency of 500 Hz were applied to the device for approximately 5 seconds. In order to observe the influence of positive voltages of increasing amplitude, followed by negative pulses of increasing amplitude, the amplitude of the pulses was changed according to a strict sequence. The influence of the changes induced in the PZT layer by the applied voltage on the overlying nematic LC were observed using polarising microscopy with the device alignment direction at 45° to the crossed polarizers. The devices were photographed approximately 5 seconds after the applied voltage had been removed, allowing sufficient time for the LC, which is oriented by the poling field, to relax to an approximately planar orientation. This waiting time also eliminated the possibility of observing effects due to ionic conduction or defect motion in the device.

RESULTS

Photomicrographs of the device with a magnification of approximately 100× are shown in figures 3(a) to (e). The electrode edge is indicated by the line, with the electrode area on the right of the image. The photographs are labelled in the same time sequence as the experiment was performed and the voltage pulses applied to each photograph are as follows: (a) 0V (before poling), (b) +60V, (c) –20V, (d) –30V, (e) –40V. The original green colour of the device is as would be expected for a birefringent material of 4.10μm thickness with Δn = 0.21.

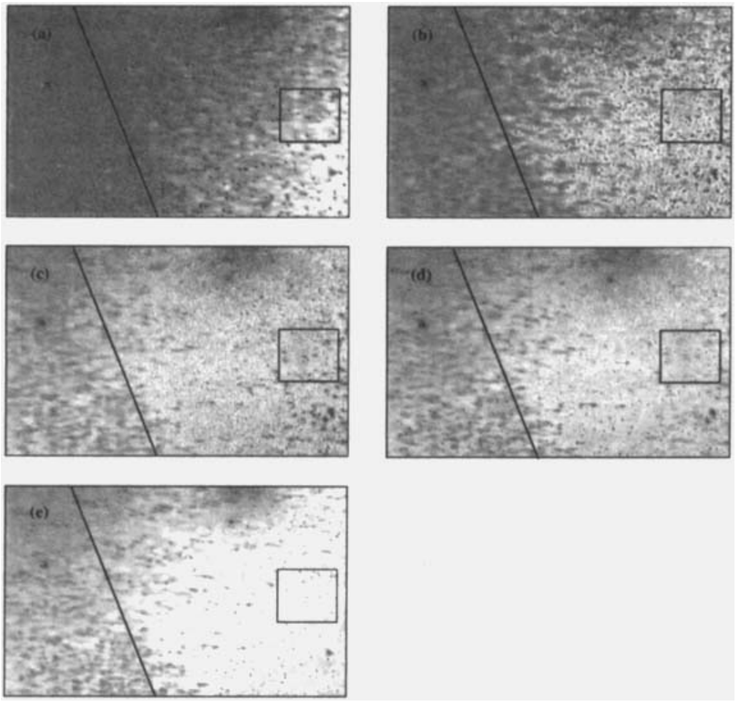

FIGURE 3. Photomicrographs of the device fabricated with a FE ceramic substrate. (a) before the application of a poling voltage to the device, (b) the appearance of the device after the application of +60V poling pulses, (c) to (e) the appearance of the device following the application of poling voltages in the sequence –20V, -30V, -40V respectively. See Color Plate I at the back of this issue.

DISCUSSION

Evidence for the interaction of the poled regions of the PZT film with an overlying layer of NLC are clear from figures 3(a) to 3(e), where the device has been subjected to a series of different poling voltages. The poled grains of the PZT are visualised as a change in the birefringence of the NLC (green to orange to yellow). The transparent PZT film does not contribute to the optical retardation of the device [6] as the birefringence and film thickness is much smaller than those of the LC. It is the local Freederickz transition that is responsible for the clearly observed change in birefringence colour of the nematic LC above the poled grains. The size of the PZT grains is approximately 5-10μm.

Birefringence before poling	Birefringence change after voltage pulse			
0.212 (0V)	0.11 (+60V)	0.10 (-20V)	0.08 (-30V)	0.07 (-40V)

TABLE 1. The effective birefringence of the poled areas designated by boxes in figure 3.

A qualitative description of the change of birefringence in selected areas (boxes in figure3) is shown in the table 1. The birefringence is calculated from observation of the birefringence colour and knowledge of the device thickness. Positive and negative pulses of different amplitudes give different degrees of orientation in LC. It is found that lower amplitude voltages are required to orient the nematic LC when negative pulses are applied to the sample. The fact that a higher degree of reorientation (lower effective birefringence value) occurs for negative pulses is consistent with the appearance of the hysteresis curve measured for the PZT film, figure 2. The hysteresis curve is asymmetric, with negative voltages poling the PZT to a greater extent than positive pulses.

It is worth noting that the calculated value of the poling voltage for the device was approximately 150V, though it is clear that the PZT experiences some degree of poling well below this threshold (several tens of Volts). However, it is extremely difficult to measure the electrical properties of the PZT film, so the approximate factor of four difference between the observed and calculated poling voltage is good agreement for this system.

CONCLUSION

This investigation confirms that the influence of pulsed electric fields on a FE ceramic substrate may be visualised by the normal 'nematic decoration' processes mentioned earlier. It has been demonstrated for the first time that changing the polarity and amplitude of the pulse produces different degrees of orientation in the nematic LC, and that the degree of orientation agrees qualitatively with the hysteresis curve measured for the FE substrate. The reorientation of the nematic LC due to the interaction with the poled PZT was found to be stable for several months. In the context of liquid crystal devices, such a result may have implications for the production of stable grey scale in nematic systems. The ferroelectric ceramic substrates reported here have a grain structure that results in a rather uneven optical effect. However, recent variations to the production process [10] have changed the way in which the ceramic structure grows from the substrate, producing much more uniform films which have greater potential for device fabrication.

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