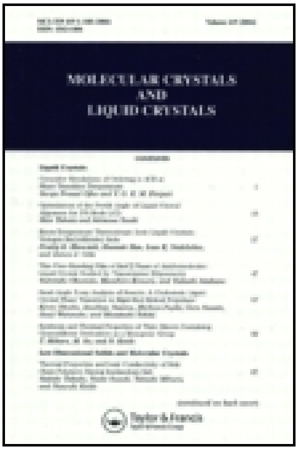

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Uniformity OF Characteristics for PTFE Aligned Rapid Prototype LCDs

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UNIFORMITY OF CHARACTERISTICS FOR PTFE ALIGNED RAPID PROTOTYPE LCDs

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Films of Poly-Tetra-Fluoro-Ethylene (PTFE) have been shown to be very effective alignment agents for liquid crystal materials. Such films may be deposited in a one step process offering advantages in time and simplicity, which is particularly appropriate for rapid prototyping for ergonomic and similar testing. Suitable deposition parameters for production of PTFE films have been identified previously but with single films there is still typically some variation of alignment due to the surface of the PTFE bar itself. Multiple films have been investigated as a means of achieving improved alignment uniformity and has been found effective in test devices of several cm^2. Electro-Optic measurements on multiple pixel test devices with a variety of liquid crystal materials show little variation across the device making matrix addressing possible. In conclusion PTFE films offer a very rapid method of producing alignment layers for devices having reproducible and uniform electro-optic characteristics.

Keywords: liquid crystal alignment; liquid crystal device; PTFE films; rapid prototyping

INTRODUCTION

There is currently considerable interest and commercial value placed on rapid prototyping and other techniques for reduction of the time to market [1,2], especially in the case of electronic consumer products such as mobile phones. The stylistic and ergonomic aspects of a design are best explored with a rapid prototyped physical object. With current computer aided design (CAD) and computer aided manufacture (CAM) techniques and equipment it is possible to download a drawing to a rapid prototyping facility and

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in a matter of hours have a physical realisation of the object. This rapid prototype allows styling and ergonomics of a design to be investigated without incurring the full tooling costs of a pre-production run.

Many of the consumer electronic products for which rapid prototyping is most applicable; e.g. mobile phones, portable information systems, global positioning systems etc. include a requirement for displayed information that impinges on the operation of the device and therefore on the display layout. In many cases the display will be specific to the application and the ability to test the suitability of the features before production of a large number of devices has similar advantages to the mechanical rapid prototyping. One approach is to programme a standard matrix addressed pixellated device to give approximations to the required images, however quality is inherently limited by the pixel size. Where application specific features are required to be displayed with good resolution a custom display may be required and rapid prototyping will be most relevant. Reduction of the time and complexity of processing involved in making a prototype display device will enhance the effectiveness of this approach and liquid crystal devices are well suited to this.

Typically the main processing steps required to produce a liquid crystal device are; preparation of glass substrates with the required transparent electrode patterns, application of an aligning layer to these substrates, filling with the liquid crystal material and attachment of polarisers. Using direct write lithography electrode patterns may be produced relatively quickly. Aligning layers in common use are polymers such as Polyimides and Nylon but application of these to the substrates require wet processing and usually significant periods of oven drying and/or baking. The alignment layer step represents a significant part of the fabrication of a prototype device especially in the very low volumes of rapid prototyping. PTFE drawn films are easily and quickly applied to ITO glass substrates and have been shown to be effective aligning agents for a wide range of liquid crystals [3,4,5,6,7]; this technique offers a significant reduction in the investment in time and materials required for low volume LCD prototyping.

Though the same level of functionality is not necessarily required of a rapid prototype as for the final production device good uniformity of threshold voltage and contrast are important to allow the display to be multiplexed. The variation in multiplexing characteristics for different liquid crystal materials in PTFE aligned devices have been investigated with multi-electrode test devices of 30 mm × 30 mm. Previous investigations of PTFE drawn film alignment layers have shown that single applications are prone to low surface pretilt and non-uniformity of application [7,8], and therefore poor device performance over large areas. Also, even minor machining marks in the PTFE bar leave artefacts in the applied PTFE film that are visible as variations in the finished device. These problems have been largely overcome by repeated PTFE applications incorporating a lateral displacement of the bar on each subsequent application.

PROTOTYPE DEVICE FABRICATION

Device and Electrode Design

To investigate the uniformity of device characteristics an electrode design was used that allows separate regions of the device to be independently addressed and characterised. The active area of the test device was 30 mm × 30 mm and was divided up into 25 pixels, each 5 mm square, the size of this device is comparable to those found in many portable consumer products. This device area is sufficient to show up any tendency for the device to be non-uniform while allowing relatively straightforward techniques to be used for spacing of the glass substrates. The outline of the test device is shown in Figure 1. The glass substrates carry ITO transparent electrodes with a resistivity of 100Ω/□ which were patterned by photolithography and acid etching.

PTFE Film Deposition

The PTFE films were deposited by heating the glass substrates on a hot plate and drawing a bar of machined PTFE slowly across the surface.

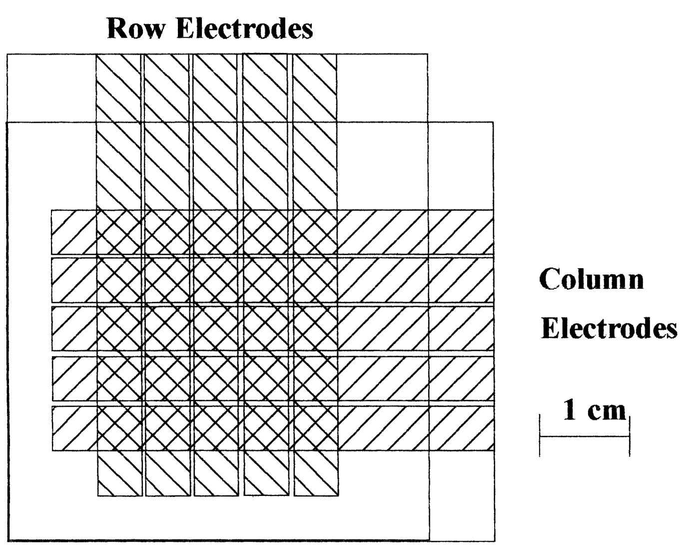

FIGURE 1 Design of the test device showing layout of the test pixel electrodes.

Effective conditions for deposition of PTFE films have been determined previously [3,4], for this work a hotplate temperature of 200°C and deposition velocity of 0.25 mm/s were used. The PTFE bar was machined to have a triangular cross section with the apex then machined flat giving a contact area wider than the test device and 3 mm in the direction of rubbing. In order to avoid gaps in the PTFE films and to reduce the effect of alignment artefacts from the machining of the PTFE bar five deposition strokes were used, for each one the substrate was moved 5 mm perpendicular to the rubbing direction. While taking a little longer than a single deposition stroke this technique still avoids the need for wet processing, spin coating, baking and then rubbing of for example polyimide alignment layers. Adhesion promoters were not used as the need to put such coatings down would detract from the simplicity of the method. Similarly barrier layers were not included, though normal in production devices, as longevity of the device was not considered of major importance in a prototype device. Following application of the PTFE layers the device was assembled with no further surface treatment.

Device Assembly and Filling

The glass substrates were assembled using appropriate silica bead spacers and the space filled with liquid crystal material, once complete the device was sealed using UV curing Norland Optical Adhesive. The cell thickness was verified by measurement of the pixel capacitance. One of several different liquid crystal materials were used to fill the device.

The TN devices were assembled using spacers giving a cell gap of close to 6 μm and were filled with the commercial liquid crystal MLC-6200–100, this material is not doped with an anti-reverse twist agent, to induce the necessary twist the substrates were assembled with the rubbing directions at 90° oriented to give a left handed helix to the molecular alignment. The induced surface pretilt on PTFE layers has been shown to be low [7,8], of the order of 0.1–0.3°, provided this pretilt is uniform across the device it will give a good quality device without significant areas of reverse twist and with consistent threshold voltage.

The FLC and AFLC devices were assembled with anti-parallel PTFE deposition directions using spacers giving a cell gap close to 3 μm. The devices were filled along the rubbing direction. The device using the commercial material FELIX 015–100 was easily aligned by slow cooling following filling down to the room temperature S_C^* phase. The other device was filled with MHPOBC [9] a research material exhibiting ferroelectric, ferrielectric and antiferroelectric phases and this aligned reasonably well with slow cooling.

DEVICE EVALUATION

Electro-Optic Characterisation

The electro-optic characteristics of each pixel of the test device were measured independently using the arrangement shown in Figure 2. A polarised He-Ne laser ($\lambda = 632.8\,\text{nm}$) was used as a light source and a BPW21 photodiode with an active area of $7.5\,\text{mm}^2$ operating in the photoconductive mode was used as a detector. Orthogonal polarisers were included in the optical path both before and after the test device, for the TN device these were oriented with the polarisation directions aligned perpendicular to the PTFE rubbing direction of the corresponding face of the device and for the FLC materials they were oriented for the maximum amplitude in the measured optical transmission. These polarisers were HN-22 sheet polarisers typical of those used on display devices. The device was mounted on an x-y mechanical translator and moved with respect to the laser beam to bring the laser to the centre of each of the 25 pixels of the test device in turn. For each pixel the characteristics were evaluated using the appropriate driving waveform applied to ITO electrodes of the device.

For the TN device the optical transmission was measured as a function of the amplitude of a 1 kHz square wave driving signal applied to the electrodes. For the FELIX 015–100 device a driving waveform consisting of a fixed duration bipolar reset pulse followed by a variable duration write pulse was used. The reset pulse puts the material into a known state prior to application of the test pulse [10]. In order to be consistent with the measurement technique used by the manufacturer a delay of 20 ms was left between the reset and write pulses as shown in Figure 3. Due to limitations in the available pulse generator the waveform amplitude was fixed at ± 10V, the duration of each half of the reset pulse was 500 μms to ensure a fully switched state. The duration of the write pulse was increased until the measured transmission following switching was half of the fully switched value in during the reset pulse. Since the cell gap was too large for the devices to show good long term bistability the memorisation and critical

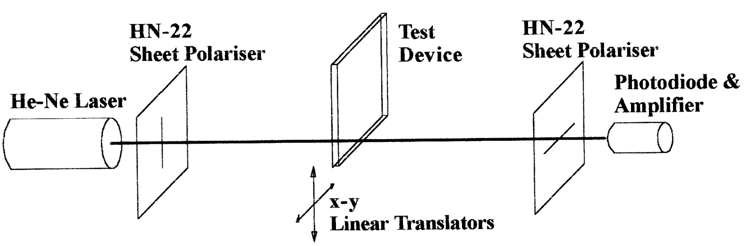

FIGURE 2 Device characterisation experimental arrangement.

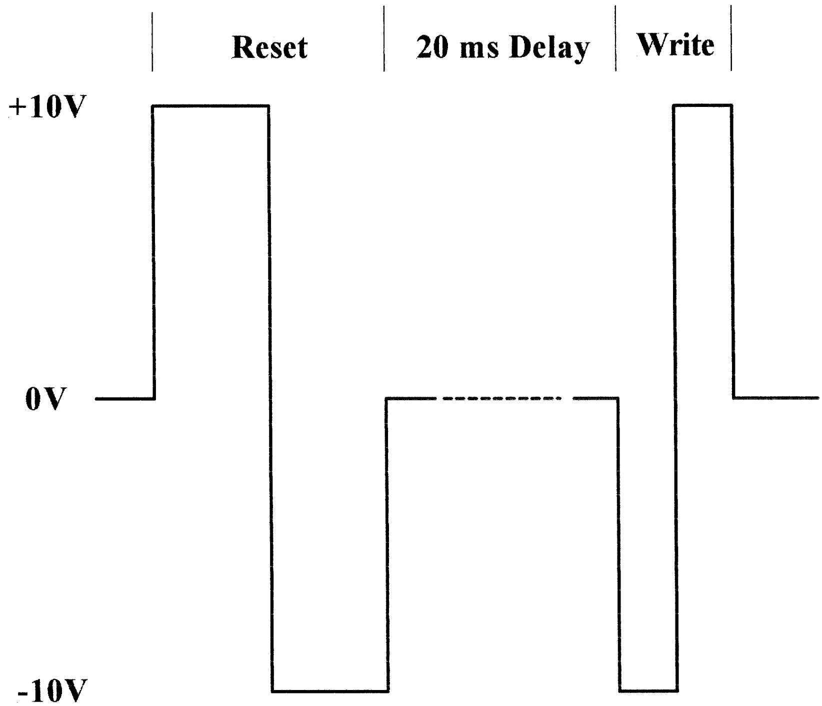

FIGURE 3 Bipolar test waveform used for FLC Critical Pulse Width measurement.

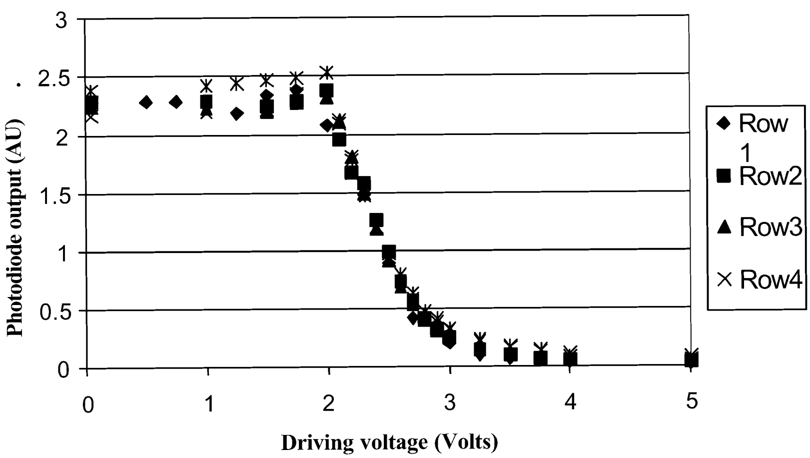

FIGURE 4 Electro-Optic transmission curves taken across a row of pixels.

pulse widths were measured by sampling the optical transmission 20ms after the end of the write pulse as this would still show any variation in switching characteristics across the device. Both the FELIX 015–100 and MHPOBC devices were evaluated using a ±10V triangular wave at 100 Hz to show up any tendency for asymmetry in the optical hysteresis.

TN Threshold Characteristics

Figures 4 and 5 show examples of the electro-optic curves obtained for the 25 pixels of the TN device. Figure 4 shows the measured response of the first row of pixels and Figure 5 shows the corresponding characteristics for the first column of pixels. Though there is some variation in the maximum transmission, probably due to thickness variation across the test device, it is clear that the characteristics of all of the pixels are very similar and that the threshold voltage and slope are both very uniform. In order to compare the results of the pixels over the area of the device the variation in electro-optic parameters have been calculated.

Measured Contrast Ratios

The contrast ratio obtained is strongly dependant on the quality of alignment of the device as any non-uniformity in the alignment will increase the dark state transmission and therefore degrade the contrast. The 'maximum' contrast of the TN device was measured as the ratio of the transmission at 0 V to the transmission at 5 V, this is the contrast that would

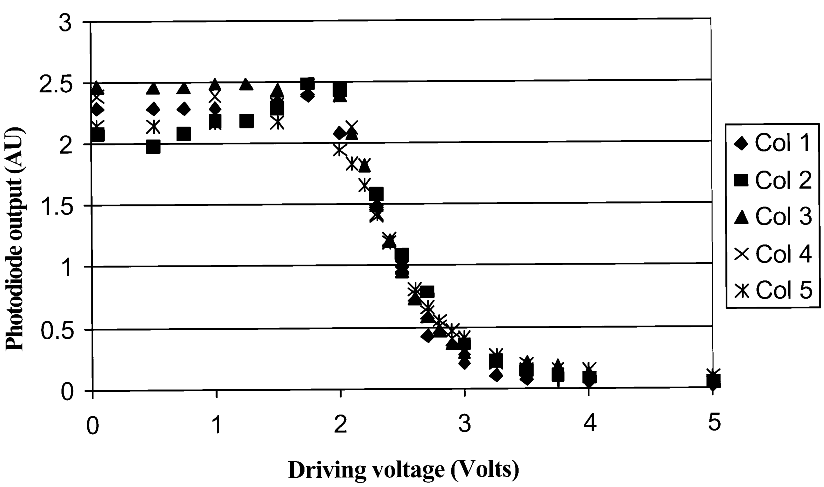

FIGURE 5 Electro-Optic transmission curves taken along a column of pixels.

be obtained in the case of direct drive of the device though with multiplexing the available contrast would be reduced from these values. The average contrast ratio over all of the pixels was 63:1 and most of the pixels had a contrast ratio in excess of 40:1, these values are entirely adequate for a test device. The polariser set up was not appropriate for a direct measurement of the contrast for the FLC device though similar alignment quality was achieved.

TN Threshold Voltage

While contrast ratio is a good indication of the quality of alignment in a device in order to be able to multiplex a prototype device the threshold characteristics must be consistent across the device area, particularly with respect to threshold voltage. Figures 4 and 5 show clearly that the driving voltage for 50% of the maximum transmission is very similar for all of the pixels across the device, this consistency in the driving voltage to switch the device suggests that a multiplexed device is also feasible. For multiplexing to be possible the variation in threshold voltage across the device must be significantly less than the difference between the select and non-select voltages. From the measured data the threshold voltages differ by around 50 mV with a switching voltage of 2.4 V. This implies that selection ratios down to the order of 1.1 are possible, corresponding to 100 multiplexed lines [11]. The contrast and number of grey levels available will therefore be largely determined by the liquid crystal fluid and not the uniformity of the PTFE aligning layer.

Felix 015–100 Device Characteristics

The switching threshold fields for the FELIX 015–100 device were measured as being close to ± 900 mV, variation of this value across the device was within ± 75 mV with most pixels having a threshold very close to the nominal value. The critical pulse areas for this device were measured as nominally 1400 Vs/m, across the surface of the device almost all of the pixels were within ± 90 Vs/m of this value. The memorisation of the pixels measured 20 ms after the write pulse was around 60%.

MHPOBC Device Characteristics

The antiferroelectric switching of the MHPOBC device was observed at a temperature of 105°C, due to the limited field available it was not possible to fully unwind the helix though the switching was observed to be highly symmetrical. The switching threshold fields across the device in the ferroelectric phase were observed and found to be highly symmetrical with a value close to 950 mV, the variation in this value across the device was again found to be minimal for most pixels.

DISCUSSION

Use of PTFE drawn films as aligning agents in liquid crystal device prototyping avoids a significant part of the wet processing which both reduces the time involved and the complexity of making a device. PTFE friction deposited films induce only low values of surface pretilt, but by using multiple depositions it is possible to achieve good uniformity of the aligning layer and therefore good device performance. With uniform surface pretilt in the TN device there is some degree of control of the liquid crystal twist and though there is evidence of regions of reverse twist in the test devices the electro-optic characteristics are suitable for product demonstrator and rapid turnaround development applications. For the FLC and AFLC materials the threshold fields show excellent symmetry on PTFE alignment. The critical pulse width measurements for the FELIX 015–100 device show symmetrical switching with good image retention given the cell thickness. The measured critical pulse width is larger than that specified by the manufacturer by a factor of 2.5. This is probably due to the relatively low driving field used since the voltage time product does not hold accurately for low driving fields, especially with thicker cells. However the, what is important for this study is that there was no significant variation in the measured value over the surface of the device. The good alignment results obtained using multiple depositions with a lateral offset between strokes also mean that much larger substrates could be coated with many repeated depositions using a bar of PTFE narrower than the width of the device.

The electro-optic results indicate that a significant level of multiplexing of a PTFE aligned device is possible over a useful area, including grey levels if necessary. However, prototyping for such applications may be better served with one of the readily available dot matrix panels. The applications where this technique is envisaged to have most benefit is where it is necessary to prototype a product specific electrode pattern, perhaps with direct drive or a moderate degree of multiplexing of application specific symbols. Modern microcontrollers are available capable of generating multiplexed drive schemes directly from their input/output lines with the addressing scheme being programmed in software, such electronics complement a rapid prototyped LC device.

CONCLUSIONS

From the measured characteristics it is clear that multiple depositions of PTFE with a lateral offset give liquid crystal devices, which have uniform switching characteristics across their surface. The uniformity of measured device characteristics is sufficiently good to allow reasonable levels of multiplexing making this aligning technique potentially useful for device rapid prototyping applications.

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