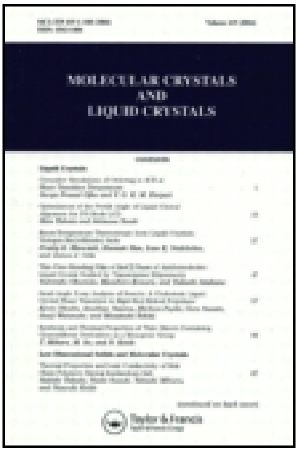

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A Switchable Liquid Crystal Impregnated Porous Polymer Device

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A SWITCHABLE LIQUID CRYSTAL IMPREGNATED POROUS POLYMER DEVICE

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Abstract This paper describes the fabrication and performance of a novel device based on liquid crystals dispersed in a polymer matrix. A low molecular weight liquid crystal material is introduced into a pre-formed, thin, porous, low density polymer film. Application of an electric field across the thin film produces a change in the transmission of the film just as in conventional Polymer Dispersed Liquid Crystals (PDLC) due to the reorientation of the liquid crystal director. Thus the device acts as a shutter. One significant advantage of this type of device over conventional PDLC is that there is no intermixing of the liquid crystal and monomeric material. Also compressible porous polymer matrices can be formed[1] giving the potential for controllably distorting the pores in a given direction. The formation and switching characteristics of a device using a porous polymer based on styrene and divinylbenzene is described.

INTRODUCTION

There has been much interest recently in the use of nematic liquid crystals encapsulated within polymeric networks as novel types of liquid crystal devices usually for shutter applications[2]. There are many terms used within the literature for such materials. The liquid crystal can be in the form of droplets, each of which is entirely separated from its neighbour by the encapsulating medium and this is called Polymer Dispersed Liquid Crystals (PDLC) or the network can be such that the droplets are interconnected and this is often called Polymer Networked Liquid Crystals (PNLC) or gel networks[3].

These materials offer many advantages over normal types of liquid crystals for device construction. The high polymer content materials form pseudo-solid state films which are comparatively easy to work with. There are however many problems with these materials due to the intermixing which occurs between the liquid crystal and the material which will form the encapsulating polymer. It has been found that full phase separation does not occur. This is especially true when the PDLC has been formed using the Polymerisation Induced Phase Separation (PIPS) technique. Indeed work has been done to characterise how much intermixing remains after the film has been formed[4]. This intermixing leads to a degradation in expected film performance. This led the authors to consider the possibility of forming the encapsulating polymer network separately from the liquid crystal which can be done using a polymerised High Internal Phase Emulsion (HIPE) as the network.

METHOD

Making the HIPE

HIPEs may be formed from a wide variety of monomers used both singly or in mixtures. The HIPE is formed by the controlled mixing of aqueous and oleaginous (oily) phases. To prepare the styrene HIPE used in this work the two phases had the following ingredients.

The aqueous phase

De-ionised water
Calcium Chloride
Potassium Persulphate

The oleaginous phase

Styrene
Divinylbenzene (DVB)
Sorbitan Monooleate (Span 80)

The surfactant used to stabilise the emulsion was Span 80. Potassium persulphate was the polymerisation initiator and the concentration of calcium chloride was varied to control the pore size. By controlling the ratio of aqueous phase volume to final total volume the pore dimensions in the polymer can be established. Typically between 85% to 97% aqueous phase[6] would be used. Below 85% there was too little pore interconnection for the material to be of use. The DVB was used as the cross-linking agent. 10g/l of calcium chloride and 2g/l of potassium persulphate were used in this work.

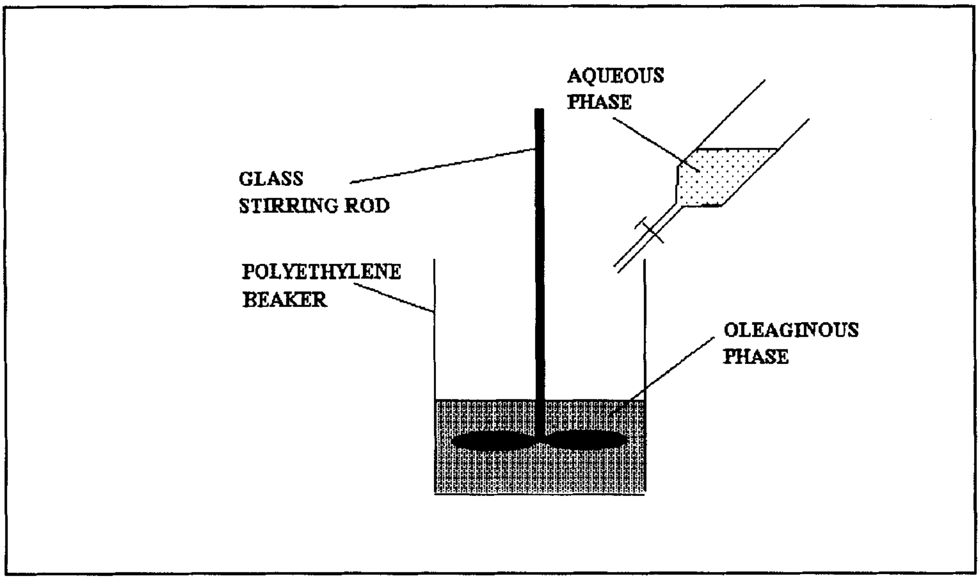

FIGURE 1 Apparatus for mixing the HIPE

The method used to form the HIPE is described below. The components of the oleaginous phase were mixed in a plastic beaker using a stirring rod. The aqueous phase components which had been prepared and mixed to give an approximately 90% pore volume were added dropwise whilst the stirrer was rotated at 200 rpm. It was found that the stirrer should roatate just below the liquid surface for best results. This process continued until all of the aqueous phase had been added to the beaker and a thick white foam was left. This was the HIPE.

Making a thin film of HIPE

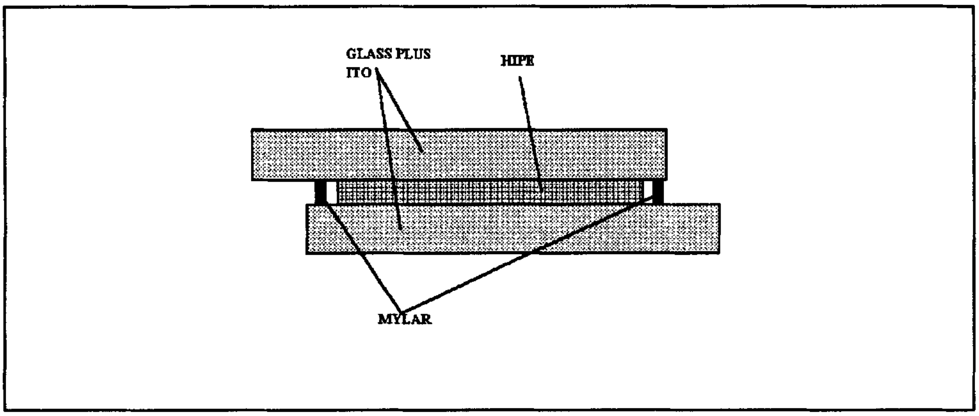

FIGURE 2 The squish filling method

Having made the HIPE a thin film cell was constructed. This was achieved by the 'squish filling' method. This technique is often used when PDLC is formed by the SIPS process, and is used in the present work because the HIPE is not suitable for flow filling into preconstructed cells. The method followed these steps. Two glass substrates with indium tin oxide (ITO) conducting layers on one side were cut to an appropriate size and were then cleaned. A small amount of HIPE was taken and placed on one of the substrates so as to be in contact with the conducting layer. In order to control the film thickness two strips of mylar of the required thickness were placed onto the substrate either side of the HIPE. The second glass/ITO substrate was placed onto it with the ITO directly on top of the HIPE and the sandwich was pressed down until the topmost glass substrate was held above the bottom one by only the thickness of the mylar.

The HIPE was then polymerised by a suitable technique, in the above example the styrene mix was polymerised by placing it in an oven at 65 degrees centigrade for 3 hours. The polymerised HIPE was still filled with water at this stage. It was found that by using a 'Soxhlet' apparatus we could remove the water content from our cells.

Filling the film

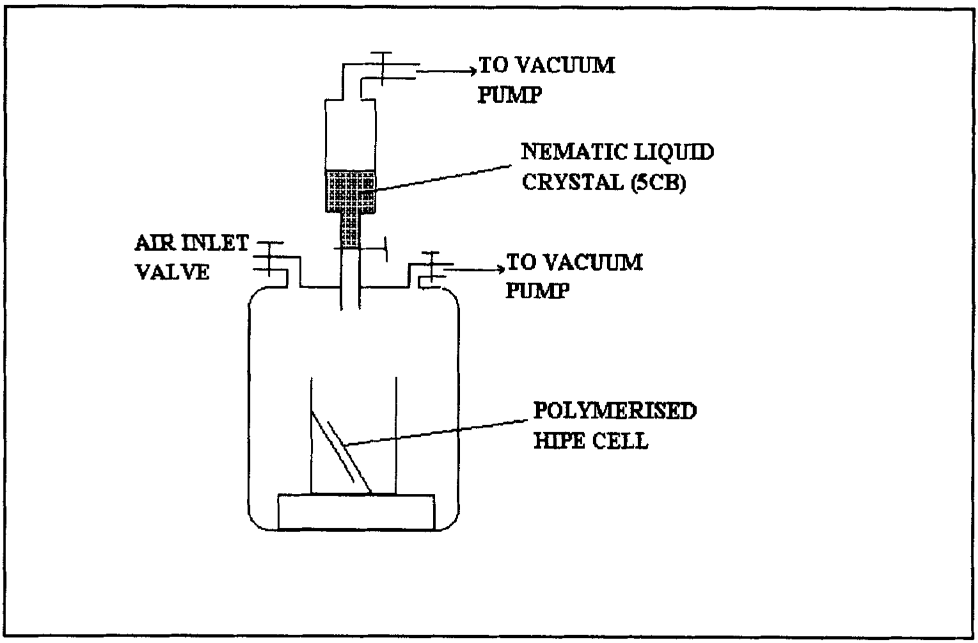

FIGURE 3 The vacuum filling apparatus

The thin film sandwich was then vacuum filled with a nematic liquid crystal material (figure 3). The polymerised HIPE cell was sealed on three sides with Norland Optical Adhesive 65 and placed in a small beaker with the open side downmost. The beaker was then placed within the vacuum vessel. The liquid crystal was held in a funnel above the beaker and the funnel valve was closed. The vessel was sealed and evacuated, as was the funnel containing the liquid crystal. The liquid crystal was observed to de-gas. Once the vacuum had been formed the liquid crystal was allowed to drop into the small beaker by opening the funnel valve. Sufficient liquid crystal was used to fully cover the opening in the cell. All valves leading to the vacuum pump were then closed and air bled slowly into the vessel. Thus the liquid crystal was forced into the cell.

EXPERIMENTAL TESTING OF THE CELLS

Two tests were performed on the HIPE cells filled with the nematic liquid crystal 5CB. These were to determine the 'static' and 'dynamic' response of the cells.

Static testing

A 1 kHz frequency sine wave a.c. voltage was applied across the cells. The voltage level was ramped up and down over a period of several minutes. A He-Ne laser was positioned so as to shine through the cell orthogonaly to the cell substrates. From the cell the beam was directed onto a detector which had a 1 mm aperture. The cell to detector distance was 20 cm. The cell optical throughput was monitored as the voltage was ramped up and down. Results are presented for a twelve micron thick cell with transmission plotted against applied voltage (peak - peak).

Dynamic testing

In these tests the cell was again set up as above. The applied voltage was switched between a defined test voltage (1kHz sine wave) and zero volts. The rise time was defined as the time taken for the cell to switch between the scattering state and the clear state upon application of the voltage. The measurement was taken between the 10% and 90% transmission points. The fall time is the measurement of the time between 90% and 10% transmission after the voltage is removed.

Results

The graph in figure 4 shows that the cell has a transmission-voltage characteristic in which the optical throughput of the cell increases with increasing voltage. In the general case for PDLC, at zero volts the liquid crystal director within the polymerised HIPE matrix is randomly orientated. Light entering the cell orthogonal to the glass substrates sees an effective liquid crystal refractive index which is some average of n_e and n_o. This is different from the refractive index of the polymer matrix and so scattering takes place. As the voltage across the cell is increased, the liquid crystal director aligns with the field (given a positive dielectric anisotropy) so light entering the cell orthogonal to the substrates sees a liquid crystal refractive index which is reducing

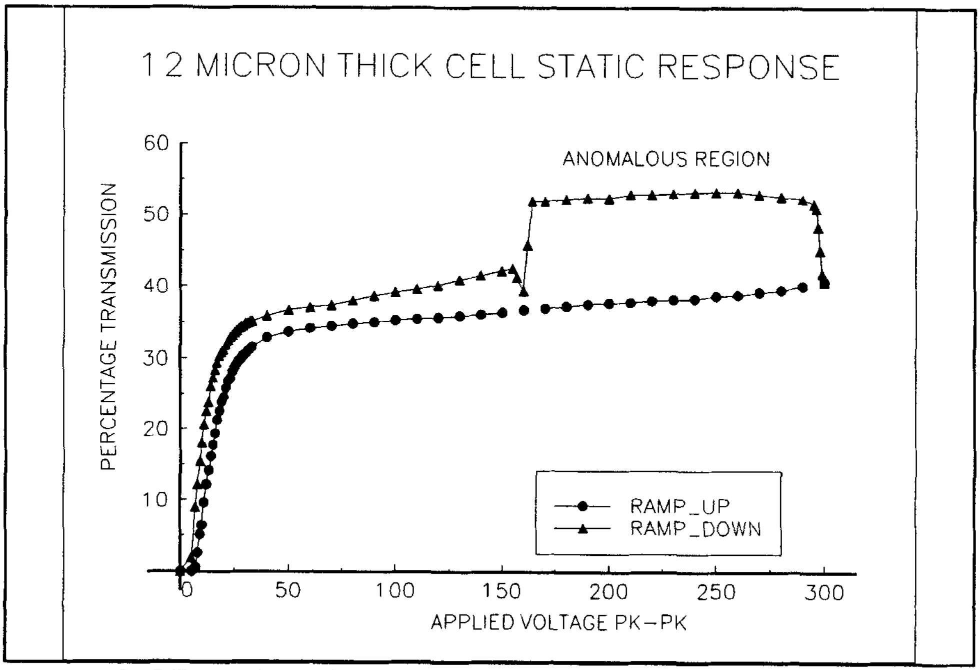

FIGURE 4 The static response curve

to n_o. If the materials are optimised such that n_o matches the matrix refractive index and no scattering would take place. The fact that the maximum optical throughput is approximately 40% on the ramp up curve is due to the fact that polystyrene (the polymerised HIPE) has a refractive index of 1.59 and the liquid crystal (5CB) has an ordinary refractive index n_o of 1.52.

There is a region in the graph where the voltage applied to the cell is reduced and the optical throughput rises. This is the anomalous region labelled on the graph. This is probably due to conduction through the cell causing heating to occur. The 5CB being warmed goes through its nematic to isotropic phase transition and this phase has a refractive index which more closely matches that of the matrix and scattering is reduced.

Figure 5 shows typical dynamic response results. As expected the cell rise times reduce with increasing drive voltage and the fall times remain approximately constant until higher voltages. The rise times are faster than would be seen in typical PDLC cells at these voltage levels. The relaxation times are slightly slower than would be seen in normal PDLC devices[7].

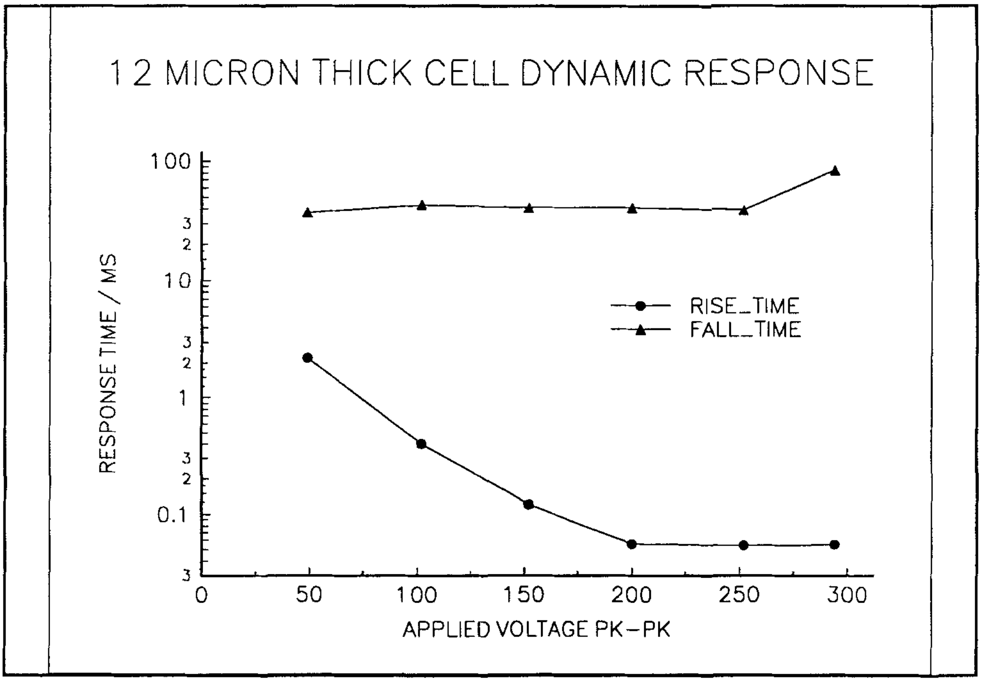

FIGURE 5 The cell dynamic response

CONCLUSION

Switchable polymer network / liquid crystal devices have been prepared and demonstrated using the techniques described in this paper. Response times are of the order required for shutter applications. There is considerable potential for improving the performance of this type of device by optimising the refractive index of the polymer HIPE for use with typical nematic liquid crystals.

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