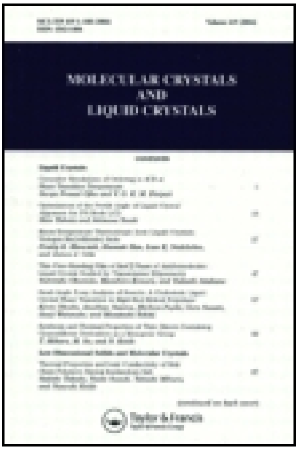

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A New Multi Layer Wide Angle Electro-Optic Shutter

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A New Multi Layer Wide Angle Electro-Optic Shutter

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A multi-layered device has been produced with a similar operating mode to a polymer dispersed liquid crystal (PDLC), but with a low molar mass (LMM) nematic mixture sandwiched between two homeotropically aligned polymer liquid crystal substrates. The refractive index matching between the LMM nematic and the polymer liquid crystal (PLC) in the 'on state' gives rise to a wide viewing angle of ±60°. In this paper we describe the preparation technique, the optical properties and the electro-optic behaviour. This geometry also negates the problems inherent in producing dispersions of polymer liquid crystal based PDLCs.

Keywords: polymer; multi layer; wide angle; PDLC

INTRODUCTION

The merits of polymer dispersed liquid crystal (PDLC) systems and their derivatives are well documented[1]. Primarily these devices rely on some form of phase separation[2] between an optically isotropic polymer binder and a low molar mass (LMM) material to create micro-domains of the LMM mesogen. From domain to domain the orientation of the director is random in the field

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off state and thus a scattering texture is achieved. Upon application of an aligning field the cell becomes transparent due to index matching between the extraordinary index of the nematic material ($\Delta\varepsilon > 0$) and the isotropic polymer. Their operation is thus polariserless. With these devices off angle haze is commonly identified as a key drawback for certain transmissive applications. This haze is due to the refractive index mismatch between the isotropic polymer binder and the anisotropic nematic component for non normally incident light. It was first shown by Doane *et al*,[3] that the use of a side chain polymer liquid crystal (SCPLC) as the supporting matrix could provide closer matching of the refractive indices, for all angles of incident light, and thus a reduction in off angle haze. Unfortunately this solution, in turn, has its own complications. The possible phase separation techniques employed for isotropic polymer based devices are not easily applied to SCPLC based systems, due in part to the increased compatibility between the two components. This compatibility can also lead to a reduction in the stability of the SCPLC component as it becomes plasticised by the LMM material and thus the overall durability of any cell fabricated is reduced.

We present herein a new approach to this problem, namely the use of the SCPLC as a substrate based alignment layer rather than as a matrix throughout the cell thus creating a multi-layer (ML) device. Although this is quite clearly not a dispersion system in the true sense of the word the end effect is the same and thus our device will be compared to the more usual PDLC.

MATERIALS & SAMPLE PREPARATION

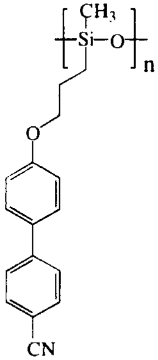

FIGURE 1 : Structure of SCPLC, where n≅57.

The SCPLC used in this work was a polysiloxane based homopolymer with cyanobiphenyl pendant side groups (Figure 1). The degree of polymerisation was approximately 57 and the polymer had the following phase sequence, $\mathbf{T_g}$ 37 $\mathbf{S_A}$ 148 **I** (°C). The low molar mass component was a fluorinated nematic mixture E209 (Merck, Poole, UK.). These two materials were chosen for their broad phase ranges (Table 1), almost eqivalent refractive index ellipsoid and contact preparation studies showed them to possess a highly defined miscibility limit.

In order to obtain the layered geometry the SCPLC was applied to both ITO coated substrates. This was achieved by first dissolving the polymer in acetone and laying down a 4μm wet film using a K-Bar coater. The substrates were allowed to dry over a period of a few hours. We estimate, based on weighing the substrates before and after coating and assuming a polymer density of 1g/cm^3, that the final film thickness achieved was approximately 0.5μm. The nematic material, incorporating 20 μm spacer beads (Dynospheres, Agar Scientific, UK.), was then pipetted onto one of the coated substrates and the second substrate applied. The device was then sealed using a UV curable adhesive.

The next step is to homeotropically align the SCPLC component. To this end the cell was heated into the isotropic region of both materials and an aligning field of 5V/μm applied. The sample was then cooled to room temperature with the field applied so as to store the alignment in the glassy phase of the polymer. Figure 2 shows the scattering texture achieved in the multi-layer (ML) sample (a) prior to alignment of the SCPLC and (b) after the aligning treatment. From the birefringence colours when viewed through crossed polarisers it can be seen that the surface of the polymer is sufficiently irregular to cause the required micro-domain randomisation of the nematic director. The SCPLC is, to some extent, plasticised by the LMM component and this will now be discussed in tandem with the differential scanning calorimetry (DSC) results.

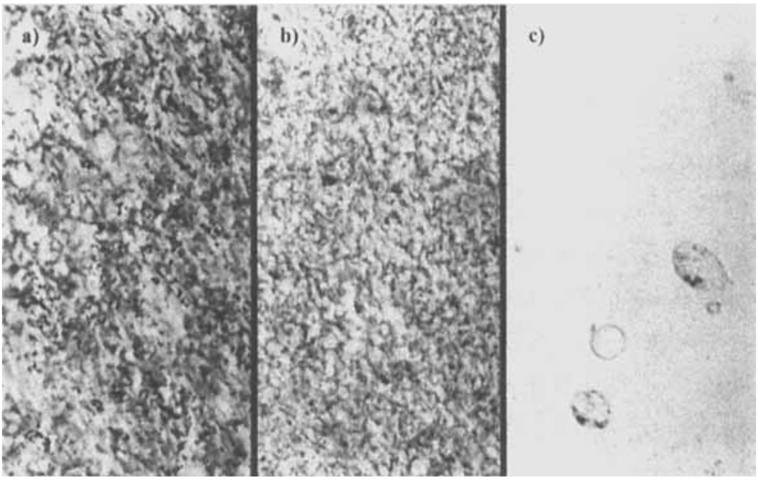

FIGURE 2 : Videographs of the scattering texture of the ML cell (a) prior to alignment of the SCPLC, (b) post alignment, no field, and (c) the transparent field on state (5 V/μm), all at room temperature. In (c) the 'yellow' sphere is the glass spacer bead, i.e. 20μm diameter.

(See Color Plate XVII at the back of this issue)

DSC RESULTS

Table 1 gives DSC (Differential Scanning Calorimetry) data for the individual materials and a 50% w/w mixture of the two components. From the E209 transition enthalpies of the pure sample and the mixture it is possible to estimate the amount of nematic which is not absorbed by the SCPLC. Here we make the reasonable assumption that the composition, and thus enthalpy, of the free nematic material is not unduly changed by the fully substituted polymer. The fraction of free material over that which is absorbed is given by (after Smith and Vaz[4]);

$$\alpha = \left(1 + \frac{m_p}{m_{lc}}\right)\frac{\Delta H_{obs}}{\Delta H_{lc}} \quad , \qquad (1)$$

where ΔH_{obs} is the observed transition enthalpy of the free nematic component of the mixture, ΔH_{lc} is the transition enthalpy of the pure nematic, and m_p and m_{lc} are the masses of the polymer and LMM components respectively. From equation 1, α is calculated to be 50%. This suggests the miscibility limit of the nematic in the polymer is approximately 25% w/w. This was confirmed by DSC measurements wherein only a single transition was visible for a 25% E209/SCPLC mixture.

Material	***Transition (°C.)***	***ΔH (J/g)***
E209	N 109.1 I	2.418
SCPLC	S_A 147.6 I	3.498
E209 *(*)*	N 115.2 I	0.602
SCPLC *(*)*	S_A 125.3 I	1.375

***Components of 50% w/w mixture**

TABLE 1 : DSC data for the individual components and mixture.

ELECTRO-OPTIC PERFORMANCE

As will be shown below the key advantage of this hybrid display is the increased viewing angle performance. In order to demonstrate this we[5] made a conventional E209 based PDLC display using an epoxy resin (Epicote 828) with a chemical curing agent (Capcure 3-800). This PDLC was also 20μm thick with droplets of ~1μm. The transmission angle data (Figure 3) for both the PDLC and ML devices was acquired using a light scattering set up (similar to that of Doane *et al*[3]) employing a HeNe laser source and photodiode detector (collection angle ~1°). The samples were immersed in index matching fluid (di-*n*-butylpthalate) and rotated using a PC controlled stepper motor. From figure 3 it can be seen that indeed the viewing angle performance is greatly increased from ±30° to ±60° and it may also be argued that the direct view performance is also improved. This is presumably due to the decrease in the number of refractive interfaces within the cell.

FIGURE 3 : Transmitted light intensity as a function of angle for (a) a standard PDLC and (b) the ML system.

The threshold voltage for the ML sample was about 0.4V/μm and 90% of maximum transmission was achieved with 1V/μm field (1kHz). Figure 2 (b) & (c) show the optical textures of the ML cell with and without an applied field. The measured response time (T_{10-90}) for a field of 1V/μm was 36ms and the relaxation time (T_{90-10}) after field removal was 50ms.

Finally, due to the obvious plastisisation of the SCPLC we ensured the durability of the homeotropic alignment. The sample was heated to elevated temperatures and left for a period of at least an hour. No loss in the quality of alignment was witnessed up to 105°C. Not surprisingly this alignment was completely removed above the isotropic point of the SCPLC (126°C).

CONCLUSION

We believe this is the first example of a SCPLC based scattering display having a multi layer geometry. This structure successfully addresses the haze effects inherent in PDLC systems whilst still providing highly stable optical characteristics that are maintained up to >100°C. The operating fields are low (~1V/μm). The threshold field is much lower than conventional PDLC devices and close to the value of neat E209. More work is needed on developing an understanding of the alignment effects in the micro-domains at the SCPLC/LMM boundary and the influence of the weak plasticisation. We are continuing research on the use of SCPLC materials as substrates and matrices for multi-layer and ferroelectric PDFLC devices[6,7] in order to achieve optimised electro-optic performance in flexible plastic substrates.

Acknowledgements
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