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MULTIDOMAIN STRUCTURES FOR IMPROVED VIEWING ANGLE TWISTED NEMATIC LIQUID CRYSTAL DISPLAYS

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Abstract The orientation of liquid crystals on spherulitic polymeric alignment layers can give both a radial and a concentric director pattern. These types of orientation lead to LCDs having a wide and symmetric viewing angle. Moreover, greyscale inversion is not observed within 60° polar angles.

INTRODUCTION

Most active matrix liquid crystal displays produced nowadays use the twisted nematic (TN) effect. A drawback of the TN effect is the deterioration of the picture quality when the display is viewed from an oblique direction, due to the asymmetric viewing angle characteristics and the occurrence of greyscale inversion. Improvement of the viewing angle properties of TN LCDs can be achieved either by applying compensator foils to the conventional TN effect[1,2], or by generating multidomain TN structures.[3-7]

Simulations of multidomain structures have shown that optimum viewing angle performance is obtained when at least four complementary domains within each pixel are present.[8] Controlled formation of these domains is rather elaborate, although photoalignment techniques show promising results.[6,7] Amorphous TN (aTN) has a much simpler processing, but the random formation of multidomains and the concomitant abrupt changes in the director pattern between two domains, leads to the formation of scattering disclination lines. These deteriorate the contrast and lead to hysteresis in the transmission voltage (T-V) curve. Therefore, structures having a more gradually changing director pattern are interesting, as these are expected to show less disclination lines upon addressing.

In this paper the formation of radial and concentric director patterns on polymer spherulites will be described. Other methods to obtain radially or concentrically oriented liquid crystals, such as flow-alignment[9] or photoalignment by illumination through a slit[10], have recently been described, but electro-optical data of devices using these alignment techniques have not been reported.

EXPERIMENTAL

Indium tin oxide (ITO) coated glass substrates were covered with a polymer layer by spincoating from a solution: nylon 6.6 from formic acid (0.5 - 2 wt %) and poly(3-hydroxybutyrate) (PHB) from chloroform (0.5 - 1 %; w/v). After drying at 100 °C, the polymer was melted during 5 minutes at 280 °C (nylon), or 220 °C (PHB). Crystallization at 20 °C yielded the spherulitic alignment layers. Polyimide layers were spincoated, cured (and rubbed) in a standard fashion.

Cells were assembled using spherical spacers to give a cell gap of approximately 4.5 μm, unless indicated otherwise. Cells were filled at 20 °C in vacuo with liquid crystal material (ZLI 4792 from E. Merck, Darmstadt) to which 0 - 1 % of the chiral agent S811 was added. Cells were characterized by electro-optical measurements at various polar and azimuthal angles.

RESULTS AND DISCUSSION

Spherulite formation and liquid crystal orientation

Nylon 6.6 and poly(3-hydroxybutyrate) (PHB) are known to crystallize readily into spherulites after melting.[11,12] In the 50-200 nm thick spincoated films used in this study, the size of the spherulites is generally in the range 50-500 μm. Short melting times must be used, as heating the polymer films above their melting points for prelonged times leads to considerable decomposition.

Polymer spherulites can be regarded as lamellar fibrils extending from a central point.[13] Orientation of liquid crystalline material parallel or perpendicular to these fibrils gives a radial or a concentric director pattern. The orienting abilities of spherulites were investigated for cells having a spherulitic alignment layer on one substrate and a nonrubbed alignment layer on the other substrate. These cells show a Maltese cross pattern between crossed polars for both nylon and PHB, characteristic of a radial or concentric orientation of the liquid crystal (figure 1).

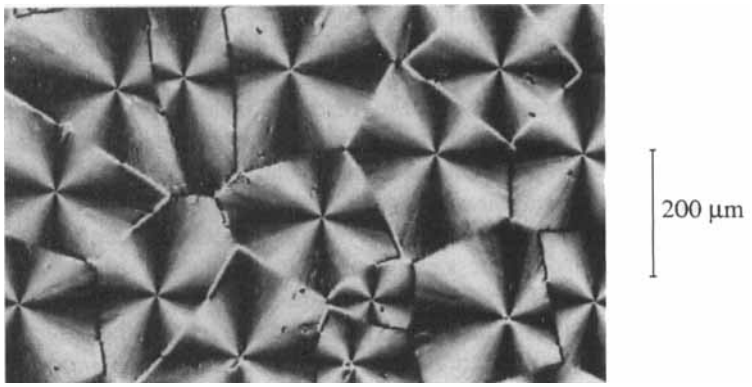

FIGURE 1 Texture of a cell having one PHB and one nonrubbed alignment layer

Which of these two orientations occurs, can be derived from liquid crystal cells having one spherulitic and one rubbed alignment layer. Between crossed polarizers these cells show a dark segment, corresponding to nontwisted areas, in a bright background. For PHB cells the dark segment is parallel to the rubbing direction, whereas it is perpendicular to the rubbing direction for the nylon cells (figure 2). In both cases the position of the dark segment is independent of the position with respect to the mutually crossed polarizers. Between parallel polarizers the position of the dark segments indicate 90° twist areas, which are perpendicular for PHB and parallel for nylon, relative to the rubbing direction. These results show that liquid crystals orient radially on PHB, but concentrically on nylon spherulites (figure 2).

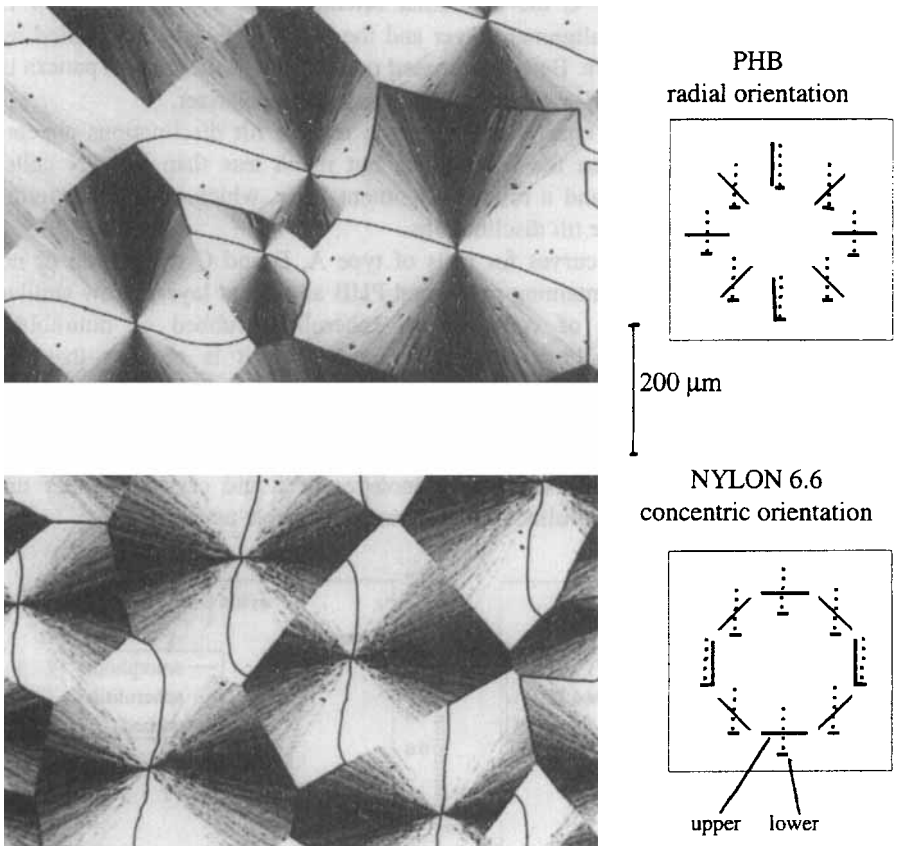

FIGURE 2 Textures of cells having a spherulitic layer on the upper substrate and a rubbed polyimide on the lower substrate (rubbed in vertical direction)

The observed disclination lines are caused by the abrupt change of the director pattern between different domains. Addition of a chiral dopant to the liquid crystal does not affect the position of the dark segment, but the disclination line within one

spherulite rotates with respect to the rubbing direction. The angle between the rubbing direction and the disclination line can be used to estimate the pitch of the liquid crystal/dopant mixture in the cell.[9]

Optical and electro-optical characterization

Three types of cells were investigated: (A) on both substrates a spherulitic alignment layer; (B) one spherulitic and one rubbed alignment layer; (C) one spherulitic and one nonrubbed alignment layer

The twist angle for cells of type A and B is not constant throughout the cell, but depends on the overlap of the orientation directions on the top and bottom substrate. When viewed under a polarization microscope, cells of type A ($d\Delta n = 0.43\ \mu m$) show an irregular texture of orange areas with a black Maltese cross, in a white/light blue background. For cells of type C the azimuthal orientation of the liquid crystal is determined by the spherulitic alignment layer and the twist angle ϕ is determined by the liquid crystal/dopant mixture. Between crossed polarizers a Maltese cross pattern is observed, which is rotated by an angle $\phi/2$ with respect to the polarizer.

Upon addressing cells of type A and C, some reverse tilt disclinations appear, mainly on the borders between the spherulites, but much less than in aTN cells. Combination of a spherulitic and a rubbed alignment layer, which induces a pretilt, decreases the number of reverse tilt disclinations.

The transmission voltage curves for cells of type A, B and C show little or no hysteresis (figure 3a). Cells containing nylon and PHB alignment layers show similar behaviour. From comparison of cells having spherulitic, rubbed or nonrubbed (amorphous) nylon layers on both substrates (figure 3b), it is obvious that the hysteresis increases in the order 90° (rubbed) TN ≤ spherulitic << aTN and the contrast ratio decreases in the order order 90° TN > aTN > spherulitic. The low contrast ratios obtained by using spherulitic alignment layers can be ascribed to the retardation of the spherulites (in combination with the first monolayer of liquid crystal). Under the polarization microscope the spherulitic structure remains visible up to 15 V.

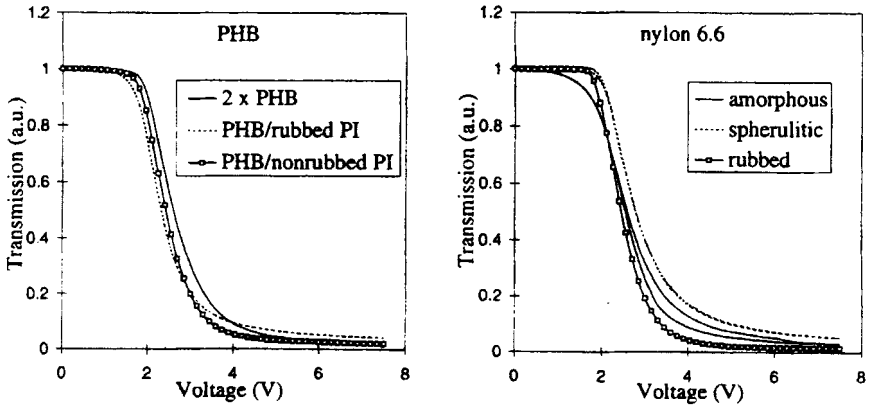

FIGURE 3 T-V curves for cells having spherulitic alignment layers (ZLI 4792 + 0.45% S811)

Viewing angle characteristics and greyscale inversion

Cells of type A and C show symmetric isocontrast curves, characteristic of a multidomain structure (figure 4; φ = azimuthal and θ = polar angle). This agrees well with previous theoretical and experimental results on multidomain structures.[4-8]

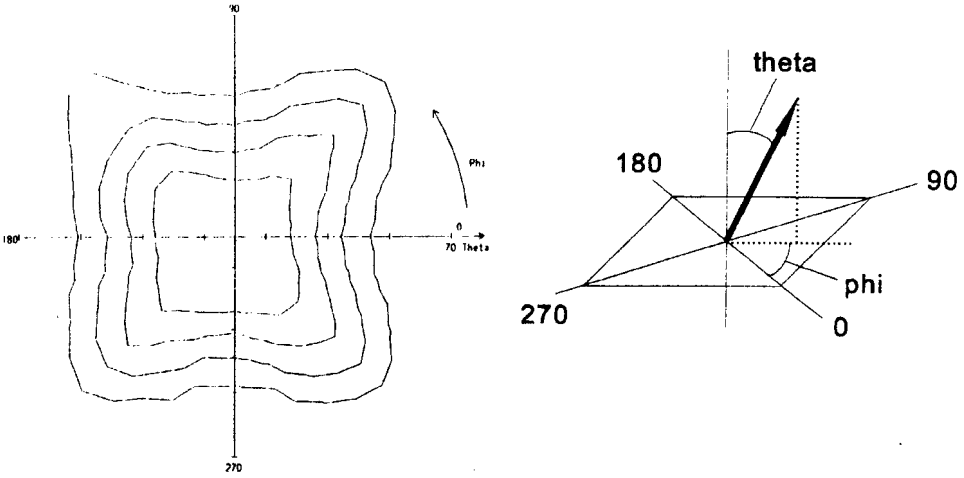

FIGURE 4 PHB/nonrubbed alignment layers; ZLI 4792 + 0.45%S811
Isocontrast plots with contrast ratios 5, 10, 20 and 40 (0/10 V)

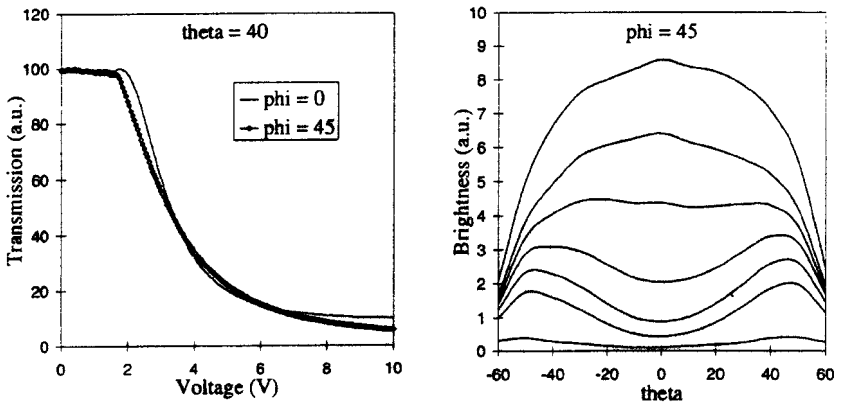

FIGURE 5 PHB/nonrubbed alignment layers; ZLI 4792 + 0.45% S811

The T-V curves at 40° polar angle decrease continuously (figure 5a) and no greyscale inversion is observed both along and between the polarizer axes (φ = 45° and 0°, respectively). From the brightness of several greylevels versus the polar angle, it appears that no crossing of the greyscales occurs up to 60° polar angles for the radially or concentrically aligned cells with $d\Delta n$ = 0.43 μm (figure 5b). The occurrence of

greyscale inversion is mainly due to the increased luminance of the dark states at high polar angles, and occurs more readily for thicker cells (at approximately $\theta = 50°$ for $\varphi = 0°$ and $d\Delta n = 0.56\ \mu m$).

Cells of type B show 2-fold symmetric isocontrast curves, since no averaging of all viewing directions occurs in this case. The exact form of the curve depends on the angle between the rubbing direction and the polarizers. As compared to conventional 90° TN, greyscale inversion is reduced and occurs at larger polar angles.

CONCLUSION

Radial and concentric liquid crystal orientations are readily obtained on spherulitic alignment layers, without the need of a rubbing treatment. However, the retardation of the spherulitic layer limits the attainable contrast ratios. The advantage of radial and concentric director patterns is a multidomain structure with a gradual change of the liquid crystal orientation. This leads to a small number of disclination lines when a voltage is applied. As a consequence (almost) no hysteresis in the transmission voltage curves is observed, as opposed to aTN LCDs. Furthermore, a wide and symmetric viewing angle is obtained and greyscale inversion is largely reduced: horizontal and vertical ranges without greyscale inversion over 120° were achieved.

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