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We have fabricated the Pixel-Isolated Liquid Crystal (PILC) mode using micro-supporting structures and anisotropic phase separation method. Since the cell gap is sustained by polymer walls and the phase separated polymer layer, this novel structure shows good electro-optic properties having stability against external mechanical distortion. The mechanical stability of this configuration against external forces like pressure and bending is confirmed to be useful for diverse flexible display applications.

Keywords: flexible LCD; mechanical stability; pixel-isolated liquid crystal

INTRODUCTION

Recently, liquid crystal (LC) devices with plastic substrates substituting have attracted much attention for the versatile applications such as mobile phone, PDA, smart card and head-mount displays because of their light-weight, thin packaging and flexibility [1–3]. However, it has been pointed out that the mechanical stability problem of

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plastic-based LC display (LCD) must be solved for a commercialization. Between the plastic substrates, a LC alignment cannot be supported stably and the cell gap is varied by engaging external mechanical distortion, which results in severe degradation of electro-optic (EO) property of the device. Another critical problem is that two plastic substrates are easily detached by bending distortion with increasing the size of displays.

To overcome these problems, the number of structures supported by polymer walls and/or networks have been proposed and demonstrated so far [4–6]. These structures were fabricated using anisotropic phase separations of LC/polymer mixture by applying patterned electric filed or UV light. However, these methods require high electric field to initiate the anisotropic phase separation and remain residual polymers in an unexposed region that reduce EO properties and increase the operating voltages of the devices.

In the previous work, we have demonstrated that the mechanical stability could be effectively enhanced by adopting Pixel-Isolated Liquid crystal (PILC) mode [7]. However, the fabrication method used in previous work required a rather complex three-dimensional anisotropic phase separation of LC/polymer mixture. To isolate the LCs within polymer walls, we exposed UV light in twice with and without photomask for anisotropic phase separation in lateral and vertical direction, respectively. However, perfectly uniform structures through lateral phase separation can not be obtained easily.

In this paper, we proposed a novel fabrication method for PILC mode where the polymer walls were made by photo-lithography or stamping method. The attachment between polymer walls and substrate was achieved by one-dimensional anisotropic phase separation. Since the cell gap and the LC alignment were supported by the polymer walls and the phase-separated polymer layer in our structure, the EO properties of device were stable to external mechanical deformations.

EXPERIMENTAL

Figure 1(a) is a schematic diagram of the proposed PILC device. As plastic substrates, ITO-coated polyethersulphone (PES) plastic films were used. The micro-supporting structures were fabricated on one plastic film by using conventional photo-lithographic method with negative photo-resist SU-8 (Micro-Chem). Figure 1(b) is a scanning electron microscopy (SEM) image of the micro-supporting structures. The pixel is enclosed by this micro-supporting polymer walls of $100\,\mu m \times 300\,\mu m$ and the distance between pixels is $30\,\mu m$. For the

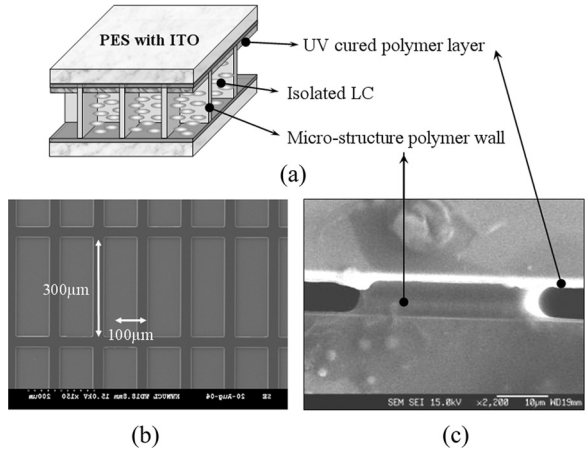

FIGURE 1 (a) Schematic diagram of the PILC structure. (b) and (c) are SEM images of the patterned micro-structure and cross section of the sample after UV exposure, respectively.

alignment layers, we used 2 wt% Nylon 6 (Aldrich) solution. The alignment layers spin-coated on the polymer wall structured substrate followed by rubbing for achieve a homogeneous alignment of LCs. The materials used for LC and polymer were conventional nematic LC (NLC) E7 (Merck) and UV curable polymer NOA-65 (Norland), respectively. A mixture of LC and pre-polymer with weight ratio of 90:10 was dropped on the microstructure and a bare ITO-coated PES substrate is just placed on the top of micro-supporting structure. Then, we irradiated the UV through bare ITO-PES substrate to generate a complete and uniform one-dimensional anisotropic phase separation of pre-polymer/NLC mixture. In our experiment, polymerization was initiated by a UV light of $\lambda = 350$ nm at 200 W. Under this UV irradiation condition, a sufficient intensity gradient is produced in the vertical direction from the ITO-PES substrate since the UV light is predominantly absorbed by the LCs in the solution [8]. Consequently, NOA65 molecules first undergo polymerization near the upper substrate in Figure 1(a) and the LCs are expelled from the polymerized volume, forcing them to diffuse away from the upper substrate. The solidified polymer layer makes strong attachment between the micro-supporting structure and the opposite substrate and enhances the mechanical strength of the PILC cell. Figure 1(c) is a cross sectional SEM image after phase separation of our PILC cell. It shows the clear phase separation and tight bonding between two substrates.

To avoid degradation of EO properties, the polymer layer should be uniform and no residual polymer exists in the LC bulk. We successfully demonstrated such structure by optimizing the phase separation conditions such as relative surface wetting properties between pre-polymer and LCs, UV intensity gradient, and mixing ratio of composite, etc. [4–9]. In our structure, since the LC molecules are completely wet to the LC alignment layer of the bottom substrate whereas the pre-polymers are partially wettable [8], our choice of the LC and pre-polymer is very good combination to obtain the complete phase separation.

RESULTS AND DISCUSSION

Figure 2 shows polarizing microscopic textures of a normal plastic LC cell using glass spacers and a plastic PILC cell in the presence of an external point pressure with a sharp tip. Under the same amount of the point pressure, the alignment texture of the normal sample was severely distorted due to the cell gap variation and deformation of LC alignment in a relatively large region as shown in Figure 2(a). Otherwise, our proposed PILC cell shows no appreciable structural changes since the hydrodynamic property of LCs is spatially confined and the cell gap are sustained by the pixel-isolating polymer walls represented by dark lines in Figure 2(b).

Now, we examined the mechanical stability of our PILC structure quantitatively compared to the normal plastic sample. Figure 3 illustrates a schematic diagram of our measurement setup. We measured electro-optical properties of the samples with various degree

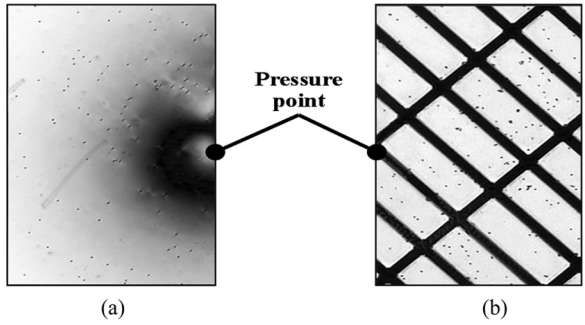

FIGURE 2 Alignment textures of (a) a normal sample and (b) a PILC sample fabricated with the plastic substrates. The polarizing microscopic textures are taken in the presence of an external point pressure with a sharp tip.

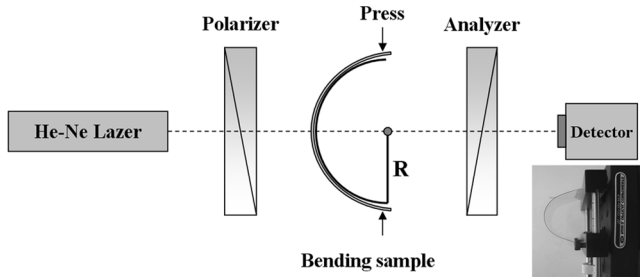

FIGURE 3 Schematic diagram of measurement setup for EO characteristics with respect to bending pressure. The inset is the real image of bending stage with sample.

of bending which was controlled by a pair of linear translation stages. The degree of bending is represented by the curvature of the cell (R) as shown in Figure 3. When decrease the value of R, the amount of bending is increasing. Figure 4 shows the transmittance characteristics versus applied voltages under various degree of bending. The cell gap of the normal plastic sample was varied depending on the bending force because the curvatures of top and bottom substrate are different. Such effects resulted in the decrease of the transmittance as increasing bending pressure as shown in Figure 4(a). When the value of R is 1.2 cm which represented by severe bending condition, the transmittance and the contrast ratio are decreased about 70% to those of the cell without bending in a normal sample. However, our PILC cell shows almost the same transmittance properties irrespective to the amount of bending pressure through whole operating voltage range as shown in Figure 4(b). This means that the LC alignment and the cell gap of our PILC cell are supported well against external bending pressures by the polymer structures.

CONCLUSIONS

We demonstrated the novel PILC structure for stability enhanced flexible LCDs. The stable LC alignment and uniform cell gap could be achieved by isolating LC molecules into the pixel surrounded by micro-patterned polymer wall structures. The adhesion of two substrates was achieved by the solidified polymer layer produced by anisotropic one-dimensional phase separation from polymer/LC composites. The mechanical stability tests for the proposed PILC structure

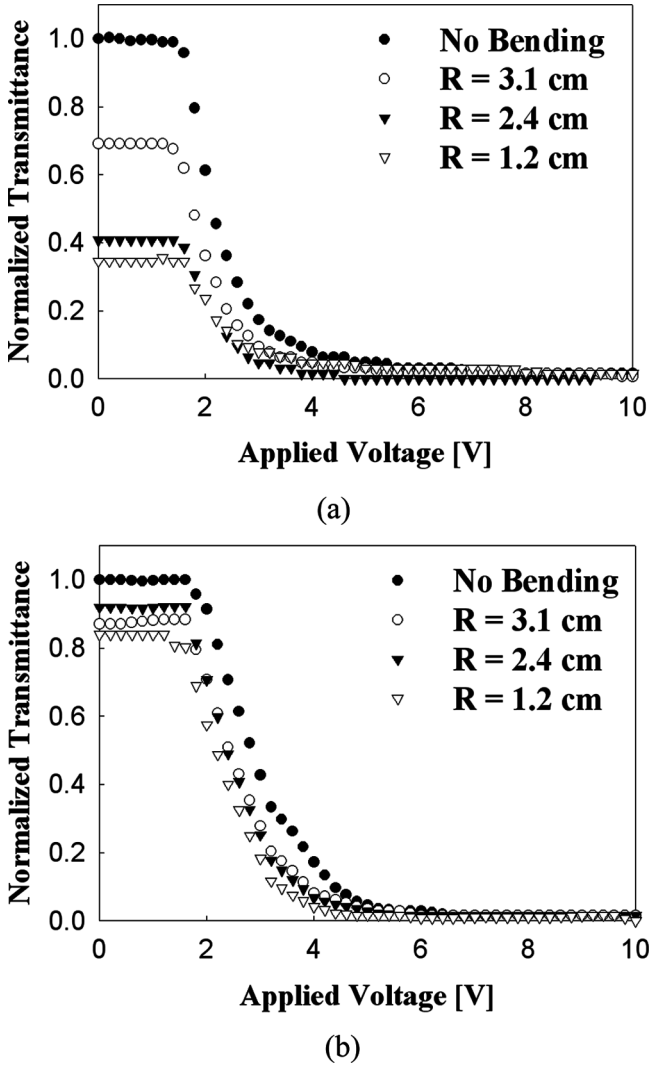

FIGURE 4 EO properties of (a) a normal sample and (b) a PILC sample depending on degree of bending.

show good EO properties irrespective to the point pressure and the bending distortion. We respect that this novel PILC structure could be highly suitable to solve current main problems in plastic LCD technology.

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