Substrate-Assembling Technique using Adhesive Patterned Spacers for Flexible Liquid Crystal Displays

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Abstract

We proposed an enhanced substrate-assembling technique using adhesive patterned spacers for flexible liquid crystal displays (LCDs). The negative photoresister was used for the rigid columnar spacers and the strong substrate-bonding agent. The proposed technique is expected to be a good candidate for manufacturing method of flexible LCDs.

1. Introduction

The flexible display technologies have attracted great interest due to novel applications such as smart cards, head mount displays, and wearable displays [1]. For flexible display applications, the variety of the display modes such as the organic light emitting diodes, the electrophoretic displays, and the flexible liquid crystal displays (LCDs) [2-5]. Except for the LCDs, the manufacturing processes for these display techniques are not well established yet and the display performances are still insufficient. Even in the flexible LCDs, however, the mechanical stability and the uniform cell gap between two plastic substrates are critical factors of retaining the long-term LC alignment against external perturbations such as pressure, a bending distortion, and a mechanical shock. To improve the mechanical stability of the flexible displays, several techniques such as the pixel isolation with UV curable polymer [4,5] and the micro-contact printing with thermal curable polymer [6,7] have been reported. Although these techniques provided the good display performances, they still involved the complicated processes.

In this paper, we propose the enhanced assembling technique for the flexible LCDs with the adhesive patterned spacers. The patterned spacers for maintaining the cell thickness act as the adhesive agent for the strong assembly of the two substrates. Bonding two substrates, any additional adhesive materials were not introduced. Furthermore, the adhesive strength was improved comparing with the UV curable bonding agent between the rigid spacers and the substrates.

2. Experiment

Figure 1 shows the fabricating procedure of the flexible LCD with the adhesive patterned spacers. The negative photoresister of SU-8 (MichoChem Co.) was used for the adhesive patterned spacers. At first, the

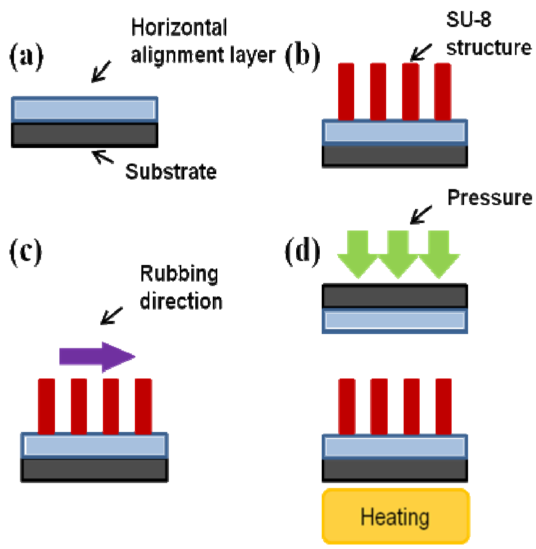

Figure 1. The fabrication process; (a) coating planar alignment layer on substrates, (b) forming the patterned spacers with SU-8, (c) rubbing the substrate, and (d) assembling two substrates under heating and pressing

polyimide (PI) of the AL22620 (Japan Synthetic Rubber Co.) was coated on an indium-tin-oxide (ITO) substrate (see Fig. 1(a)). Next, the array of square spacers with a side of 35 μm was formed on the bottom substrate through the photolithography of the SU-8 as shown in Fig. 1(b). Here, the patterned SU-8 spacers were just prebaked at 100 °C for 5 minute. The height of the spacers is measured to be 5.5 μm.

The twisted nematic (TN) LC mode was used for a demonstration of the flexible LCDs. The bottom substrate with the patterned spacers on the PI thin layer and the top substrate with the only PI layer were rubbed with the rubbing machine. Two rubbed substrates were assembled orthogonally and post-baked at 180 °C for 90 minutes under pressure as shown in Fig. 1(d). Finally, the namatic LC of MAT-03-151 (Merck Co.) was injected into the assembled cell by capillary action in the isotropic phase. The birefringence and the dielectric anisotropy are 0.104 and 5.5, respectively.

3. Results and discussion

In our fabricating procedure, the alignment layer on the bottom substrate was prepared before forming the spacers through the photolithography and the rubbing process was introduced after forming the spacers which were not post-baked. In such situation, the alignment layer would be affected by photoresister, developer, and solvents, which should have an effect on the alignment properties and the resultant EO characteristics.

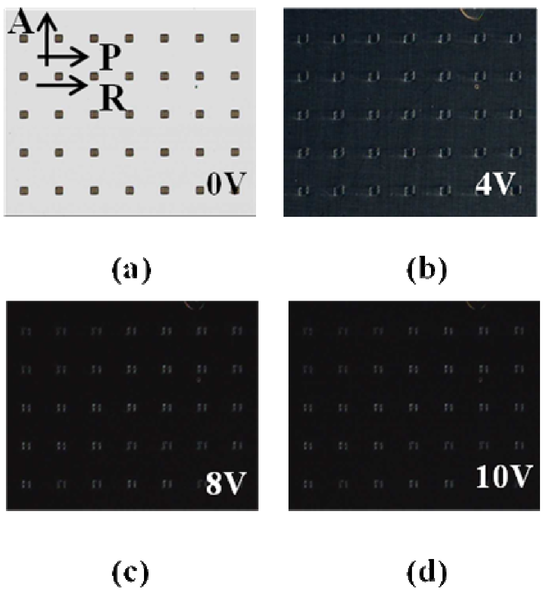

Figure 2. Microscopic photographs of the TN mode fabricated with the adhesive patterned spacers at (a) 0 V, (b) 4 V, (c) 8 V, and (d) 10 V. Here, *R*, *A*, and *P* are a rubbing direction of bottom substrate, a direction of the upper analyzer, and a direction of the lower polarizer, respectively.

Figure 2 shows the microscopic images of the TN cell fabricated with the adhesive patterned spacers under crossed polarizers. Here, *R*, *P*, and *A* depict the rubbing direction of the bottom substrate patterned SU-8 spacers, the polarizer direction faced to the bottom substrate, and the analyzer direction contacting with the top substrates. In the absence of an applied voltage, the bright state was obtained as shown in Fig. 2(a). Here, the dark squares represent the patterned spacers. When the applied voltage increases, the transmittance gradually decreases (see Figs. 2(b)-(d)). These textures show the typical EO characteristics in a normally white mode. Near the spacers, the light leakage was observed due to the distortion of the LC directors by the boundary effects of the rigid spacers.

The EO characteristics of a conventional TN cell fabricated with placing glass spacers on the rubbed PI layer and our TN cell fabricated with adhesive patterned spacers on the non-rubbed PI layer are shown in Fig. 3. Both voltage-transmittance curves showed the similar EO characteristics in a normally white mode. In our TN cell, however, the subtle

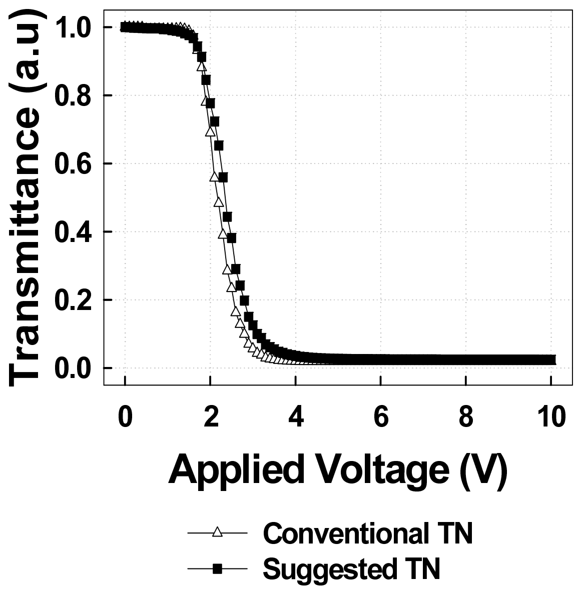

Figure 3. EO curves of the conventional TN LC cell and our TN LC cell fabricated with the adhesive patterned spacers.

changes in a threshold behavior and a saturation voltage were observed. These variations would be originated from the slight degradation of the surface anchoring energy. The more detail analysis remains for a future work.

The bonding strength of the adhesive patterned spacers was measured for the application to the flexible displays. For measure of the bonding strength, the bottom substrate was fixed with glue on the table and the top one was pulled with increasing tension until the cell has been broken. In our adhesive patterned spacers, the bonding strength was measured to be 75.0 ± 4.3 kg/cm^2 and improved in comparison with that in our previous technique [6].

4. Summary

We proposed the enhanced substrate-bonding technique using the adhesive patterned spacers for flexible LCDs. The adhesive patterned spacers were prepared with the negative photoresister through the conventional photolithography on the alignment layer. The prebaked spacers adhered two substrates through post-baking under pressure maintaining the cell gap without any additional glue. In addition, the adhesive strength was improved comparing with the UV curable bonding agent between the rigid spacers and the substrates. The stable EO properties were observed. The substrate-assembling technique proposed here is expected to be one of the excellent candidates for fabricating the flexible LCDs.

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