Electro-optic Stability in a Flexible Liquid Crystal Display with Adhesive Spacers under Bending Deformation

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ABSTRACT

We propose a simple structure of flexible liquid crystal displays with patterned spacers out of negative photoresistor SU-8 acting as spacer and glue. This proposed structure has good electro-optic properties under flat and bending conditions. Also, this fabricating method is similar to the traditional manufacturing process of liquid crystal displays.

1. INTRODUCTION

The flexible displays have been expected to have versatile applications such as smart cards, mobile phones, and writing tablets because of their thin, lightweight and roll-able properties [1-3]. The varieties of the display modes have been suggested for realizing flexible applications such as the organic light emitting diodes (OLEDs) [4], the electrophoretic displays [5], and the liquid crystal displays (LCDs) with plastic substrates [6-9]. Especially, the plastic based LCDs among these display modes have been expected to have the high possibility of commercialization due to intensive researches and developments of the LCDs with glass substrates.

However, the flexible LCDs have an essential problem of non-uniform cell gaps under bending deformations because the radius of curvature of top substrate is different from that of bottom one. This problem also leads to another problem of the stability of electro-optic (EO) characteristics of display devices. Hence, maintaining the uniform cell gap is a key issue of getting high-quality flexible LCDs under various external conditions. The several techniques for uniform cell gaps were demonstrated such as pixel isolated liquid crystal (PILC) [6-8] and micro-contact printing (μCP) with additional adhesive materials [9].

In this paper, we propose a simple structure of flexible LCD with spacers not only as rigid spacers to maintain the cell thickness but also as glues to assemble between top and bottom substrates. And the fabrication procedures of our suggested structure are analogous to the traditional manufacturing processes of LCDs. Compared with traditional LCDs of twisted nematic (TN) mode. We also confirmed that this suggested structure has similar EO properties under flat condition and better EO properties under bending conditions.

2. EXPERIMENTAL

The fabricating procedures of our suggested structure are as follows:

At first, a pair of transparent substrates deposited with indium-tin-oxide (ITO) was coated with polyimide (PI) of the AL22620 (Japan Synthetic Rubber Co.). Consequently, the array of square-shaped spacers with a side of 35 μm and a height of 5.5 μm was formed on the bottom substrate through UV photolithography. And the patterned SU-8 spacers were just prebaked at 100°C for 5 minutes. The substrates with spacers on the PI layer and the others with the only PI layer were rubbed in the definite directions for TN LCDs using the rubbing machine. The substrates without spacers were placed PI-face to PI-face on the substrates with spacers orthogonally and assembled at 180°C for 90 minutes under high pressure. Finally, the TN liquid crystal (LC) of MAT-03-151 (Merck Co.) was injected into the assembled cell by capillary action above the clearing temperature Tni of 79.4 °C, which birefringence and the dielectric anisotropy are 0.104 and 5.5, respectively. The LC filled with this test cell was transited from isotropic phase to nematic phase when the temperature was cooling down and TN LC cell was completed in the result.

3. RESULTS AND DISCUSSION

The graph of figure 1 is the voltage – transmittance curve of TN LC cell by this suggested technique and the insert pictures are the microscopic textures of the cell at 0V, 2V and 4V. As shown in these images and graph, the transmittance of the cell had maximum value at no applied voltage and decreased rapidly when applied voltage increased from 1V to 4V. Also, the threshold voltage was 1.7V and the contrast ratio was 256:1. These phenomena are equal to the typical display performance of the TN cell of normally white mode in the report of Y.-J. Lee et. al [8]. Figure 2 shows the images of SU-8 spacers by scanning electron microscopy (SEM). As shown in these figures, the square-type micro-patterned spacers could be formed successfully and repeatedly on the substrate. The measured side length of the spacer was equal to the target of 35 μm. But the measured height was 5.05 μm which is smaller than the aim of production. This origin of this reduction was expected to press down under high pressure for assembling the substrates. Figure 3 is the contour graph of the measured cell gaps of the suggested TN cell which size is 5 cm by 6 cm. The minimum value was 4.89 μm at the darkest gray area and the maximum value was 5.10 μm at the brightest gray area. Also the average and standard deviation were 5.01 μm and 0.0625 μm.

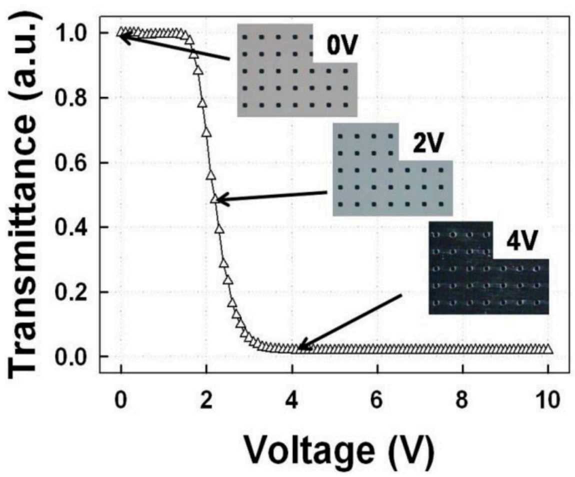

Figure 1. The voltage - transmittance curve of TN LC cell with the SU-8 patterned spacers. The insert pictures are the microscopic textures of this cell at 0V, 2V and 4V.

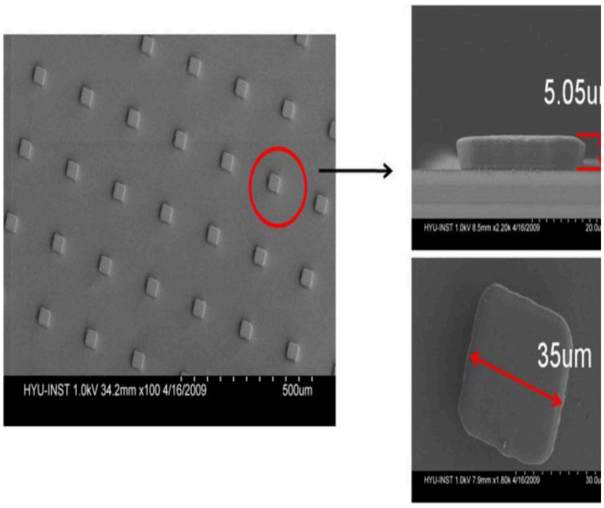

Figure 2. The SEM images of micro-patterned spacers. The height is 5.05μm and the patterned size is 35 μm.

Therefore the uniformity of cell gaps was 1.25% on the whole cell, which was calculated by following formula:

$$Uniformity\ (\%) = \frac{Standard\ Deviation}{Average}$$

The size of test cell is 5 cm by 6 cm. The value of R is the radius of curvature of the test cell and represents the degree of bending. For examining the EO stability, the test TN cell was made with plastic substrates by this suggested method. Figure 4 illustrates the schematic diagram of measuring system for EO characteristics under bending deformation.

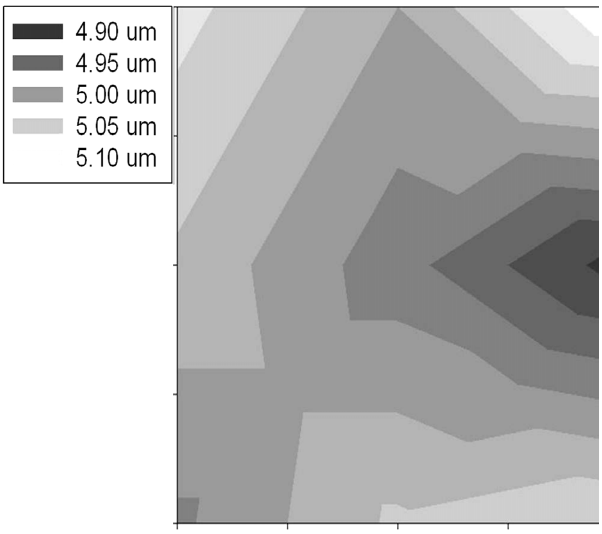

Figure 3. The uniformity of cell gaps of the suggested TN cell

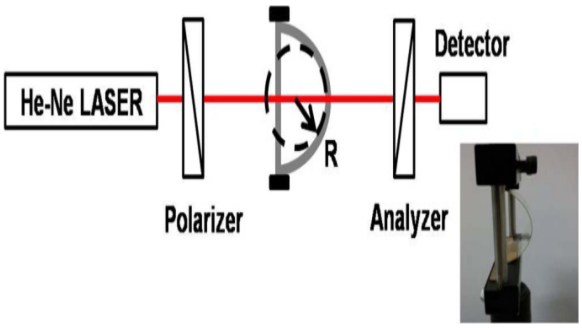

Figure 4. The schematic diagram of measuring system for EO characteristics with respect to the radius of curvature.

The source of light is He-Ne laser made by Melles Groit Co., which wavelength is 633nm. Amplified Si photo-detector PDA55 (Thorlab Co.) and digital multimeter 2000 (Keithey Co.) were connected each other and measured the change of intensity under various external conditions. And the bending of the test cell was controlled by changing the distance between linear translation stages, where the value of R is represented by the radius of curvature of the cell as shown in figure 4 and is decreasing when the amount of bending increases. When R is 30mm, drop of transimittance is about 92%.

Figure 5 shows the change of transmittances of the plastic based LCDs dependant on applied voltages under flat and bending conditions. This figure shows the decrease of transmittance with respect to the decrease of the radius of curvature. When the value of R was 30mm, the transmittance was about 92% in comparison with flat condition. This phenomenon means that the cell gap of the TN sample with plastic substrate was varied depending on the bending force because the curvatures of top

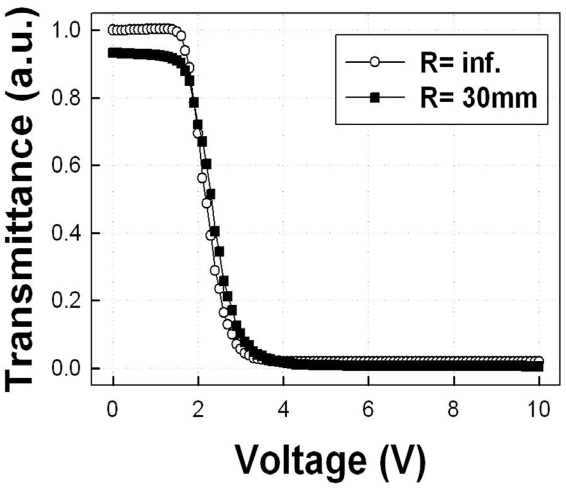

Figure 5. The EO properties of a suggested plastic sample depending on degree of bending.

and bottom substrate are different each other.However, when the value of R was 30mm in case of conventional TN cell, the transmittance was approximately 60% in comparison with flat condition in the report of Y.-J. Lee et. al [8]. This means that the cell gap of the test cell with SU-8 adhesive spacers was supported well against external bending pressures compared with convention TN cell.

4. Summary

In this work, we proposed a simple assembling technique using patterned spacers made out of negative photoresistor SU-8, which play double roles of the rigid spacer to maintain the cell gaps between top and bottom substrates as well as of the pastes to assemble these substrates stickly. Therefore, the cell gaps of this structure are quit uniform. And the EO stability of this suggested TN structure was enhanced in comparison with that of conventional TN cell with plastic substrates under bending distortions. Hence this assembling technique could be suitable to solve the serious problem such as low performance of plastic LCD under external deformations. Also, we respect that our suggested technique is expected to be highly useful for manufacturing flexible display with versatile usages.

ACKOWLEDGEMENT

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5. REFERENCES

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