Fabrication of Flexible Liquid Crystal Display with LC Alignment and Tight Bonding by Surface Grooves

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ABSTRACT

We propose a fabrication method for the flexible liquid crystal display (LCD) using micro-sized surface grooves formed on the UV curable polymer layer. The LC molecules are aligned uniformly with surface grooves and the top and bottom substrates are tightly bonded due to UV curable polymer layer and rigid spacers.

1. INTRODUCTION

Flexible displays have been attractive for the future displays due to their special characteristics such as light weight, good portability and possibility of continuous manufacturing process, so called roll-to-roll process. In addition, they have a possibility of wide application market for example smart cards, bendable electric devices and flexible papers in ubiquitos environment. Recently, many types of flexible displays compete for the future display. Among them, the technique of flexible display using liquid crystal (LC) is well established in comparison with other type of displays because flexible LCD can use the conventional LCD manufacturing process based on glass substrate. However, there are two critical issues to overcome and achieve these applications for flexible substrate-based LCDs. The one is the maintenance of uniform cell gap and the other is solving the problem of bonding between substrates. These problems may cause the demerits of flexible LCD such as defects in the pixel due to the bonding materials or weakness for the external mechanical forces. Many kinds of researchers have been reported for tight adhesion and good alignment of the LC molecules such as adopting thermosetting resin [1], polymer wall and/or network structure using anisotropic phase separation [2], pixel-isolated LC mode [3], structure using poly (dimethylsiloxane) (PDMS) [4], etc. However, the conventional adhesion methods have baking process in vacuum or low efficiency in a way of processing time. In addition, they have difficulty bonding substrates tightly.

In this paper, we propose a fabrication method for flexible LCD of which the UV curable polymer layer on the top substrate with patterned grooves have uniform LC alignment and tight bonding characteristics between flexible substrates. The micro-sized grooves carries out aligning the LC molecules uniformly and making tight bonding of plastic substrates with rigid spacers to maintain cell gap through polymer structure on the bottom substrtates, simultaneously.

2. EXPERIMENTAL

Figure 1 shows the fabrication process of our proposed cell. The pattern was transferred on the poly (dimethylsiloxane) (PDMS) layer by means of soft mold. That is widely used because of its good reproducibility due to hydrophobic surface characteristics. The patterns on the soft mold have 4 μm pitch and 1 μm depth. The used flexible substrates were polycarbonate (PC) of which transmittance is more than 90% through the visible light wavelength range [5]. The top substrate was coated with NOA63 (Norland Optics Ltd.) by using spin coating method[6], and then the PDMS mold was contacted on the NOA63 layer for transferring the groove pattern under UV irradiation with the intensity of 60 mW/cm^2 for 2 minutes. In this irradiation condition the surface patterns are well established on the UV curable polymer layer at top substrate. But this doesn't fully cured yet. On the bottom substrate, we formed the rigid spacers between pixels by using the negative photo-resist, SU-2005 (Micro Chem.). These are maintaining the cell gap and preventing the distortion from the external force such as pressing and bending. The height of the rigid spacer was about 5 μm ~ 6 μm. After that, the alignment layer coated over the rigid spacers and rubbed. The top and bottom substrates assembled with the 2nd UV irradiation for 30 min.

The intensity of the UV light is as the same as the 1st

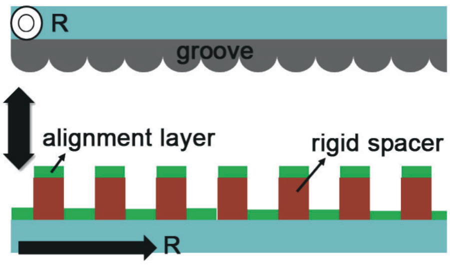


Fig. 1 The schematic diagram of flexible LCD cell

UV irradiation. The used LC was general twisted nematic LC from Merck. We made flexible LC cell of normally white twisted nematic (TN) mode based on the process of Fig. 1.

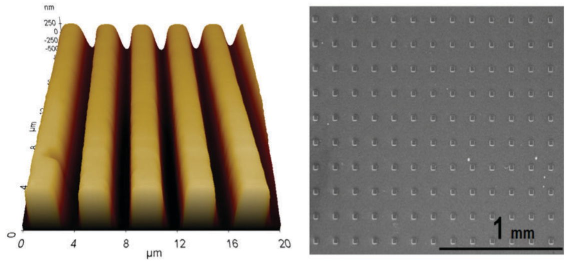
3. RESULTS AND DISCUSSION

Fig. 2 (a) shows the groove pattern formed onto the NOA63 polymer layer on the top substrate. We confirmed that the patternd groove was fully transferred without any distortion. The rigid spacers were formed properly on the bottom substrate (Fig. 2 (b)). The size of square rigid spacer on the bottom substrate is 30 *μm* x 30 *μm* with 130 *μm* spacing.

The alignment of liquid crystal is induced by surface morphology (groove) or molecular chain ordering on the organic alignment layer. Among these theories, Berreman had established the model of surface grooves related with the groove pitch and depth [7,8]. This model describe the azimuthal anchoring energy, formulated by

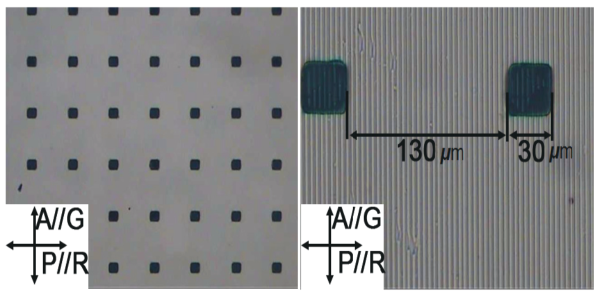
$$W_a = 2k\pi^3 \frac{A^2}{\lambda^3} \qquad \textbf{(1)}$$

where the *k* denotes the mean value of elastic constant of used LC material. *A* is the depth of the groove and λ is the pitch of the groove. From this equation, we can calculate the actual azimuthal anchoring energy of groove patterned cell. In our case, the mean elastic constant of LC is 12.85 pN and the pattern size was fully transferred from the PDMS mold. Using by the Berreman equation, we get 1.25 x 10^{-5} J/m^2 of the azimuthal anchoring energy. The order of 10^{-5} J/m^2 whose magnitude of the anchoring energy generated from the grooves is sufficiently enough to align the LC molecules on the groove surface uniformly [9].



(a) (b)

Fig. 2 (a) The AFM image of groove on the UV curable polymer, (b) the FE-SEM image of rigid spacers. (a) and (b) were formed on the top substrate and the bottom substrtate, respectively.



(a) (b)

Fig. 3 (a) and (b) shows the microscopic images: A and P denotes the direction of the analyzer and polarizer, respectively. R and G denotes the direction of the rubbing and groove.

Figure 3 shows microscopic images of our LCD cell under the crossed polarizers. The signs of P, A, R and G indicate the direction of the polarizer axis, the analyser axis, rubbing on the PI layer of the bottom substrate and the grooves of the top substrate, respectively. In Fig. 3(a), the initial texture without any voltages showed the bright state because the initial LC aligning was parallel of the respective transmission axes on the near surfaces. This means that the LC molecules are well aligned by the grooves on the top substrate. Fig. 3(b) is the image magnifying Fig. 3(a) and we can see the clear patterns of the groove. The threshold and saturation voltage of our cell was 5 V and 14 V, respectively. The voltages were relatively higher than the conventional TN cell. It is because the thickness of the UV polymer layer. The contrast ratio was about 105:1.

Now, we examined the mechanical stability of our proposed flexible display for external forces. We measured EO properties of the samples with the curvature of radius which were controlled by a pair of linear translation stages in the laboratory set up. The curvatures of radius are represented by the radius (R) of the cell such as rectangular solid shown in Fig. 4. The figure 4 shows the EO characteristics versus applied voltages under degree of bending. When the bending radius of R was 1.6 cm which represented severe bending condition, the transmittance and the contrast ratio were decreased the only 12 % in

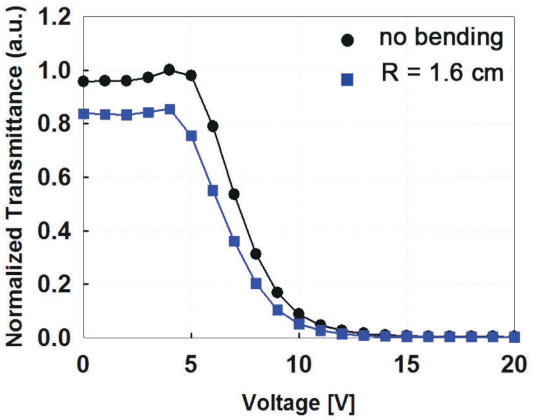


Fig. 4 The Electro-Optical characteristics of our flexible LCD depending on the curvature of radius.

comparison with those of the cell without bending (i.e. R = ∞). This means that the rigid spacers maintain the cell gap between the top and the bottom substrate well and the cell also has good stability from bending stress.

4. SUMMARY

We proposed a fabrication method for flexible lilquid crystal display (LCD) using micro-sized grooves formed on UV curable polymer layer. The LC molecules were well aligned due to grooves on the UV curable polymer and we could tightly bond the flexible top and bottom substrates with rigid spacers, simultaneously.

5. ACKOWLEDGEMENT

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