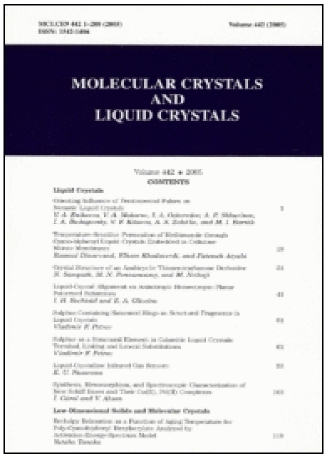

Molecular Crystals and Liquid Crystals
Publication details, including instructions for authors and subscription information:
http://www.informaworld.com/smpp/title~content=t713644168

Stability Enhanced Flexible Liquid Crystal Display Based on a Micro-Structure

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Online Publication Date: 01 January 2007
To cite this Article: Jang, Se-Jin, Kim, Jun-Hyung, Bae, Ji-Hong, Choi, Yoonseuk, Kim, Hak-Rin, Kim, Sang Il, Souk, JunHyung and Kim, Jae-Hoon (2007) 'Stability Enhanced Flexible Liquid Crystal Display Based on a Micro-Structure', Molecular Crystals and Liquid Crystals, 470:1, 191 - 197
To link to this article: DOI: 10.1080/15421400701495542
URL: http://dx.doi.org/10.1080/15421400701495542

Mol. Cryst. Liq. Cryst., Vol. 470, pp. 191–197, 2007

ISSN: 1542-1406 print/1563-5287 online
DOI: 10.1080/15421400701495542

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We demonstrate the stability-enhanced novel flexible liquid crystal display (LCD) mode by using the micro-structure of rigid columnar spacer array and a micro-contact printing (μCP) assembling method. Specially designed multi-column structure induces self-collected structure of adhesion material which resulted in the good adhesion properties of device to an external deformation as well as enhanced mechanical stability of electro-optic characteristics for flexible display application. Moreover, suggested method can easily inherit most advantages of conventional LCD technology such as low driving scheme, established process and LC mode selection freedom within a simple fabrication procedure. This novel technique can be highly applicable for realizing practical flexible display with enhanced mechanical stability and high performance.

This work was supported by Samsung Electronics Co., Ltd. and Korea Research Foundation Grant funded by the Korean Government (KRF-2005-005-D00165).

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Keywords: flexible liquid crystal display; mechanical stability; micro-contact printing; micro-structure

INTRODUCTION

For last few decades, the manufacturing of flat panel display (FPD) is most growing and evolving industry. From intensive researches of display technology, now various FPD technologies are successfully utilized like organic light emitting diodes (OLED), plasma display panel, and most popular liquid crystal displays (LCDs). Especially, the flexible display technologies are extensively demonstrated in recent years since it offers many advantages and potentials, such as very thin structure, ultra light weight, robust display system, the ability to flex and fold, high-throughput manufacturing and various portable and wearable applications [1]. For the realization of flexible display, diverse approaches are developed so far by using electrophoresis, OLED and LCD with plastic substrate [2–6].

In flexible displays, the maintenance of constant gap between two flexible substrates under various external conditions is a key issue to provide stable and uniform operation of the system. Especially, this is highly essential to the LC-based flexible display which is most dominant and advanced technique in the area. Nevertheless, although recent effortful developments like pixel isolated liquid crystal (PILC) structure [5,6] have shown the enhanced mechanical stabilities to an external forces, it has remains to be solved the limits such as complex fabrication, induced defects from polymer wall or residual polymer and especially narrow display application range.

In this letter, we demonstrate the novel technology for obtaining the stable structure of flexible LCD by using the micro-structure of columnar rigid spacer and the micro-contact printing (μCP) [7] assembling technique. The designed columnar spacer array combined with μCP bonding technique provides stable and uniform cell gap of the device as well as good adhesion properties and high mechanical reliability. Moreover, the capillary filling effect of designed multi-column spacer configuration generates a self-isolated structure of adhesive material which resulted in good electro-optic characteristics of device.

DEVICE CONFIGURATION

Schematic diagram of suggested structure is shown in Figure 1 (a). Two flexible substrates are tightly assembled each other by adhesion material placed on the top of micro-column structure. The pillar array

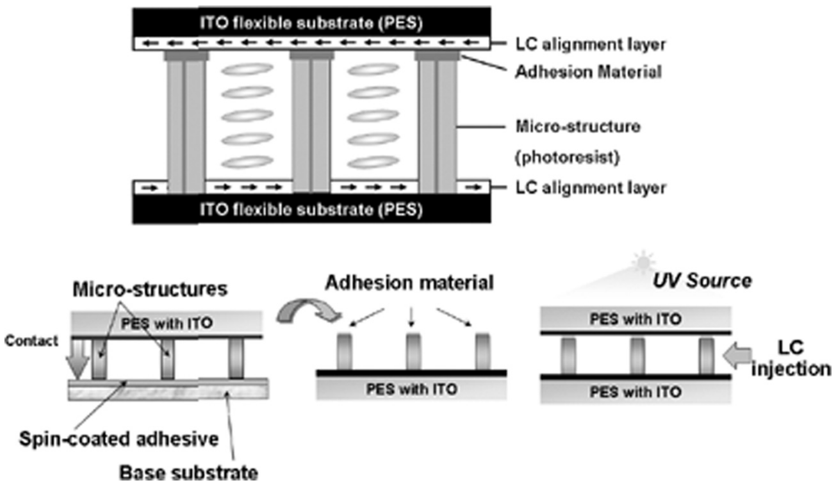


FIGURE 1 (a) Device configuration of flexible LCD mode based on a micro-structure; (b) Fabrication procedure of the device using μCP method.

maintains stable and uniform gap of device through whole area which is similar to the micro-wall structure in previous PILC configuration [5,6]. However in our configuration, unlikely to the PILC case, isolated adhesion concept of assembling technique provides LC alignment on the top substrate can be controllable. This assures that we can obtain the freedom for designing LC mode and easily adopt this method for diverse flexible display applications.

To assemble two substrates, μCP method is employed as illustrated in Figure 1 (b). The UV curable optical adhesive polymer SK-9 (Optical Bond) was placed on the top of micro-columnar structure by contacting and pressing as shown in the figure. Then the two substrates are assembled by a simple UV irradiation. Note that multiple adhesion points of rigid spacer array guarantee the mechanical stability of device at the edge of each pixel. A commercial photoresist material SU-8 (Microchem) was used as the columnar spacer.

RIGID COLUMNAR SPACER DESIGN

Figure 2 illustrates the configuration of designed rigid columnar spacer. We divide the conventional single pillar structure into the fraction to prevent overflow of adhesion materials and confine excessive agent in spacer area. Two types of design were demonstrated to check the mechanical stability and overflow effect variation. Type A rigid spacer have two pillar structures of $15\,\mu m \times 40\,\mu m$ with $100\,\mu m$,

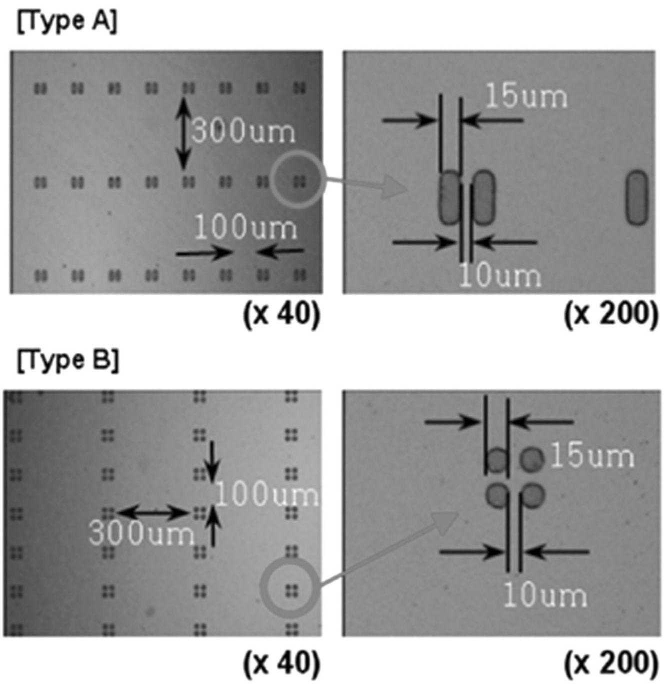


FIGURE 2 The photographs of designed micro-structure of columnar spacer array. Circled insets in left figures are magnified at the right by 5 times (×40 to ×200).

300 μm of lateral spacing, while type B have four columnar structures of 15 μm diameter with the same spacing as shown in the figure.

RESULTS AND DISCUSSION

To examine the mechanical stability and the cell gap reliability of suggested configuration, we demonstrated the basic ECB (electrically controlled birefringence) LC sample by using conventional plastic substrate of PES (polyethersulphone). As described earlier, one of the main advantages of our technique is to be suitable for diver LC mode which is essential to establish high quality display while the other LC based flexible techniques have restricted LC mode suitability. In our demonstration, homogeneous LC aligning agent Nylon 6 was used and rubbed in an anti-parallel direction to obtain planar LC alignment sample. Nevertheless, as depending on the LC aligning agent and rubbing direction, we can easily realize different LC mode for this system. A commercial nematic LC (ZKC-5085XX from Chisso) was utilized in this letter

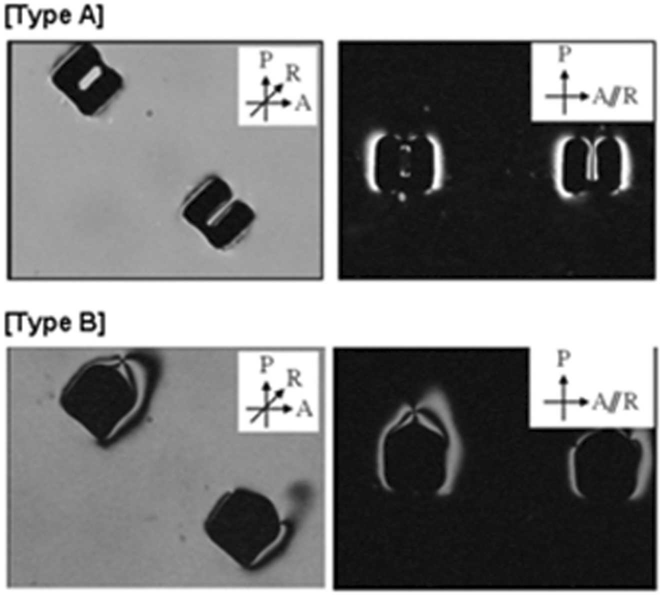
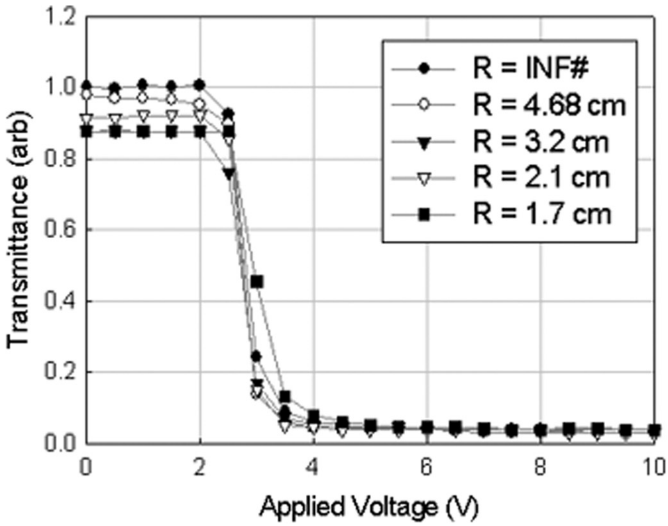


FIGURE 3 The photographs of LC textures under crossed polarizers around the rigid pillar spacer. Rubbing direction is parallel to the analyzer at the right dark images while that is 45 degree twisted to the analyzer at the left.

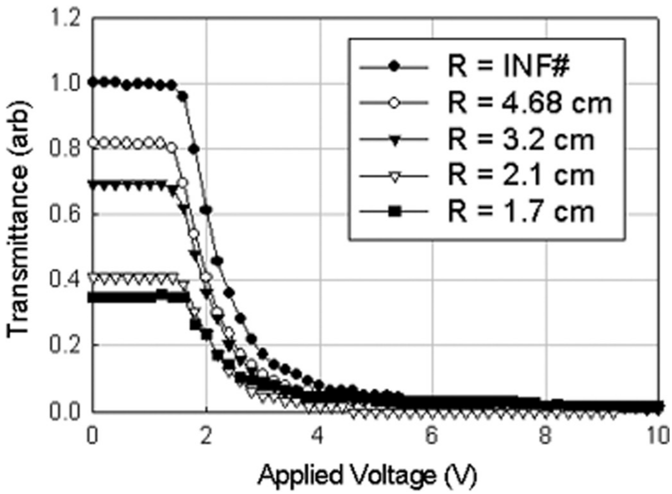
and its birefringence (Δn) and $\Delta\varepsilon$ is 0.1515 and 9.57, respectively. The cell gap was maintained as 3 μm by rigid photoresist micro-structure.

The clear isolated rectangular shaped structure of adhesive polymer was observed in the texture of LC sample as shown in Figure 3. From the capillary effect, more self-aggregated polymer structure was obtained in the type B, which we can expect that this type can be more suitable and effective to show better adhesion properties and maintain stable cell gap against the external distortion. In our first mechanical stability test, the sample is fixed in the air with increasing the additional loads to check the adhesion reliability. The measured maximum capable loads without breaking sample were about as 2.54 and 4.56 N/cm^2, for type A and B, respectively. This result can be easily understood by matching the LC texture observations and our general expectation from the pillar design. Note that the small boundary effect disturbs LC alignment around the columnar spacer in the figure.

In final, we check out the cell gap reliability to an external bending by measuring electro-optic characteristics of the device. From the experiment, our μCP adhesion (in this case we examined the type B



(a)



(b)

FIGURE 4 Electro-optic characteristics of the sample under various external deformations. (a) Voltage-Transmittance curve of flexible display ECB mode sample with micro-structure and μCP assembling technique. (b) V-T curve of conventional ECB sample with plastic substrate and ball spacer only.

sample in ECB mode) can tolerate hard bending of $R = 1.0\,\text{cm}$ (R is the radius of bending curvature), while conventional bonding sample is broken after engaging bending action of $R = 1.5\,\text{cm}$. Note that smaller R represents the increased external bending forces. Moreover, as shown in Figure 4, the electro-optical (EO) characteristic of our structure is almost identical (15% drop at the maximum transmittance) as increasing external deformations (see Fig. 4 (a)), which proves that this technique supports stable cell gap of the device under high external bending forces. Otherwise the EO characteristics of conventional ball type spacer sample (ECB mode) is critically damaged (65% drop) to the engaging distortions as shown if Figure 4 (b). From these results, we can conclude that the suggested method can be useful to realize the flexible LCD with reliable device performance. Note that various device parameter should be optimized for reducing EO variation at rest.

CONCLUSION

We demonstrate the stability-enhanced novel flexible LCD by using the micro-column spacer array and the μCP assembling technique. Designed pillar spacer array creates the confined structure of adhesive by capillary effect and μCP bonding supports the good adhesion of two flexible substrates. From various experimental results, we confirmed that much stabilized flexible LCD can be obtained within a simple fabrication procedure. In addition, suggested configuration can easily adopt diverse LC mode because the control of LC alignment at top substrate is possible, diverse flexible LCD can be realized by using this technique. In conclusion, the micro-structure based flexible LC mode is expected to play a critical role in the practical application for manufacturing flexible display with versatile usage.

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