SC4.S4.2 (Invited)
11:00 – 11:30

Fabrications of Mechanically Stable Plastic Liquid Crystal Displays

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Abstract *We present fabrications of mechanically stable plastic liquid crystal displays. The micro-structures support the stable molecular alignment of liquid crystals. Various tight bonding techniques are applied for enhancing the durability of the device.*

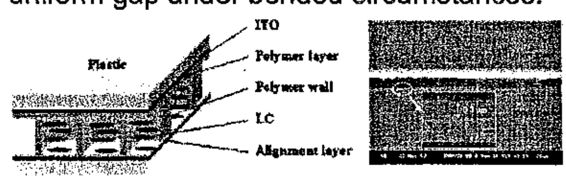
Introduction

In recent years, liquid crystal (LC) devices using plastic substrates have drawn much attention for their versatile applications such as smart cards, PDA, and head mount displays because of their flexibility, lighter weight, thinner packaging, and lower manufacturing cost through continuous roll-to-roll processing[1]. Different LC modes have been proposed in plastic substrates including twisted nematic (TN), cholesteric, PDLC, and bistable FLC modes. But, the mechanical stability of these devices were not satisfactory except for PDLC, since a solid mechanical support for preserving the molecular alignment of LCs is insufficient due to the lack of sustaining structure. Also, the device using PDLC has the limited applications since it only can use the scattering effect of the light. Therefore, the key technology to realize a practical device for flexible applications is to keep the uniform gap between flexible substrates against external deformations.

In this presentation, we proposed various fabrications to produce plastic liquid crystal display (LCDs) with enhanced mechanical stability by using the polymer micro-structures and new bonding techniques. The electro-optic (EO) characteristics of the samples by these methods are comparable to that of conventional LCDs and are not varied significantly when we applied high external deformations.

Pixel-Isolated Liquid Crystal Structure for Plastic LCD

The polymer walls and/or networks as supporting structures have been proposed and successfully demonstrated[2]. But, these methods have the weaknesses such as requiring high electric field to initiate the anisotropic phase separation or reduced optical properties and increased operating voltage due to the remaining residual polymers. We proposed the stability enhanced LC mode using anisotropic phase separation[3-6]. In these modes, LC molecules are isolated in pixels surrounded by interpixel vertical walls and horizontal polymer layers on the upper substrate, namely, the pixel-isolated LC (PILC) mode. The mechanical support provided by the rigidity of surrounding structures and the adhesive property of polymer maintain the uniform gap under bended circumstances.



(a) (b)

Fig. 1. (a)Schematic diagram of PILC structure. (b)Cross-sectional images of PILC sample by SEM.

Device configuration of PILC structure is shown in Fig. 1(a). The polymer walls can be made by various methods such as 3-D phase separation[3,4], photolithography using photoresist[5], or stamping technique[6]. The 3-D anisotropic phase separation supports the ease of fabrication, while the other methods can create more fine structures. After fabricating walls on the bottom substrate, we dropped LC/polymer mixture and induced the phase separation by UV irradiation. The thin polymer layer formed on the upper substrate support the tight binding of two substrates. The cross-sectional images are shown in Fig. 1(b).

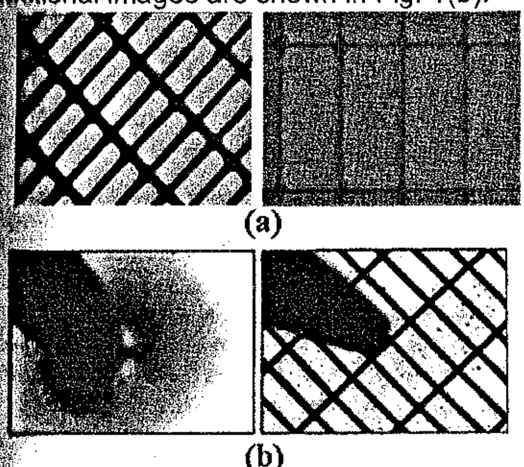


Fig. 2. Alignment textures (a)of 3-D phase separation method with nematic (left) and ferroelectric (right) LCs, (b)of a normal (left) and PILC sample using photoresist wall (right) in the presence of external point pressure with a sharp tip.

It is notable that this PILC mode can be applicable to realize any LC modes using nematic and ferroelectric LCs as we demonstrated the resultant textures in Fig. 2(a). With the pressure test in Fig. 2(b), it is clear that the PILC structure can support the mechanical stability of the device.

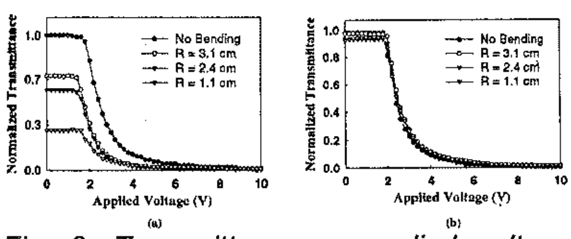


Fig. 3. Transmittance vs applied voltage (a)for normal and (b)for PILC cell at various bending states.

The EO characteristics of normal and PILC samples are shown in Fig. 3. Decreasing the curvature (R) means increasing the degree of bending. For the normal plastic sample, the transmittance and contrast ratio are reduced about 70% at the maximum degree of bending. However, the PILC cell shows almost the same behavior except for a minor decrease in the low voltage regime. It is clear that this mode shows not only good mechanical stability but also equivalent optical behavior with respect to the normal mode without a polymer.

Plastic LCD by Patterned Rigid Spacers and Micro-contact Bonding Technique

In the PILC structure, the applicable LC modes are limited due to the lack of alignment layer at upper substrate. To overcome this problem, we developed plastic LCDs supported by rigid spacers[7]. In this device, the UV curable adhesive are placed on top of the rigid spacers by the micro-contacting technique and irradiated to bind two plastic substrates tightly (Fig. 4(a)). Since the alignment layer can be used on the top substrate, the different LC modes such as TN mode can be applied in this plastic LCD (Fig. 4(b)).

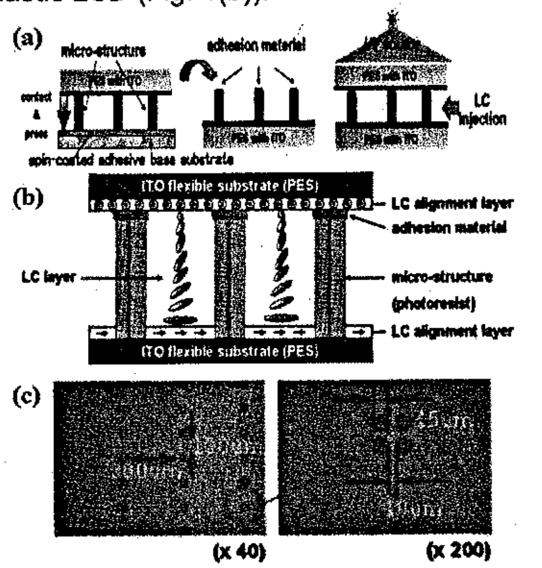


Fig. 4. (a)Fabrication process using micro-contact bonding technique. (b)Device configuration with TN mode. (c)Design of patterned rigid spacers.

To prevent the overflow of adhesive during the bonding process, we designed the rigid spacers as the assembly of four micro-pillars (Fig. 4(c)). The excessive adhesive is confined into the rigid spacers and results in the fine optical properties of the device. The measured EO characteristic of our plastic

TN sample was comparable to the conventional case (threshold voltage: 2V, driving voltage: 6V).

Table 1. Mechanical stability test by increasing weight of the loads before breaking the sample.

(Dimension: N/cm^2)

Test	1	2	3	4
Max Loads	4.35	5.00	5.00	3.01

In our mechanical stability test, the maximum capable loads without breaking sample were measured as $4.56N/cm^2$.

Single Substrate Plastic LCD by Laminating Technique

One of the advantages of plastic LCD is the use of cost-effective roll-to-roll process. The single substrate LCD is regarded to be very suitable one to apply this process. Recently, we developed the simple technique for fabricating mechanically stable plastic LCD with a single substrate[8].

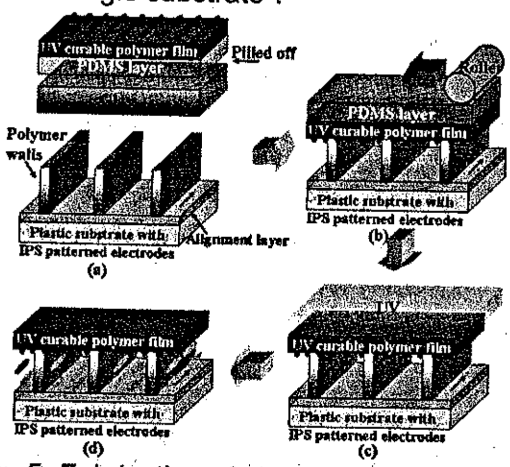


Fig. 5. Fabrication of single substrate plastic LCD (a)Preparation of cover film and bottom substrate with polymer walls. (b)Laminating process. (c)UV irradiation for solidification. (d)LC injection.

In our structure, a cover film of UV epoxy was tightly attached to the bottom wall structure of photoresist by laminating technique, and LCs were uniformly aligned by Berreman effect of micro-grooves formed on the cover film (see, Fig. 5).

Uniform LC alignment was verified by the microscopic textures. In the field-off state, the initial texture showed the dark state because LCs were aligned homogeneously along the rubbing directions. As increasing the applied voltages, the textures became brighter due to in-plane reorientation of LCs along the field direction. All textures under the applied voltages were also highly uniform.

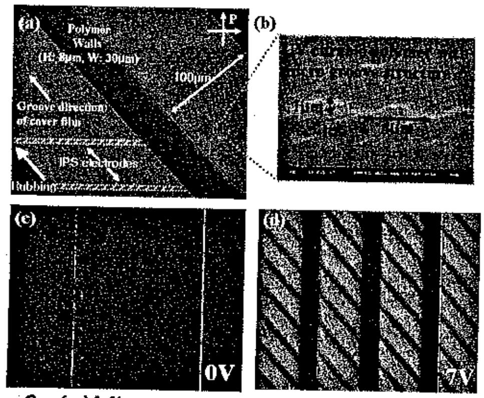


Fig. 6. (a)Microscopic textures of the single substrate LCD. (b)Cross-sectional SEM image of the micro-grooves. Polarizing microscopic images at applied voltages of (c)0V, and (d)7V.

Conclusions

We reported various fabrications of mechanically stable plastic LCDs. The proposed devices are expected to play a critical role in the next-generation flexible displays.

Acknowledgement

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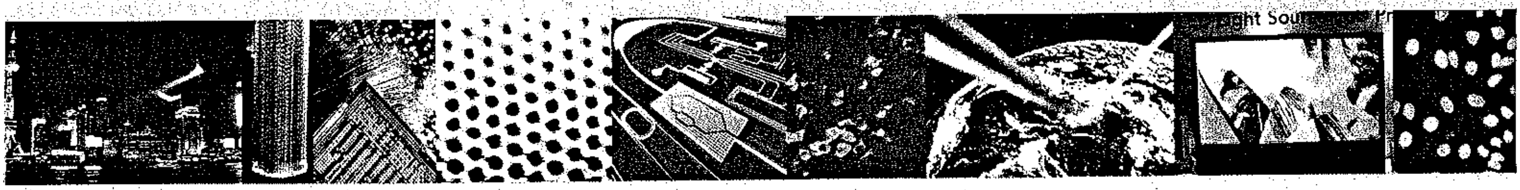

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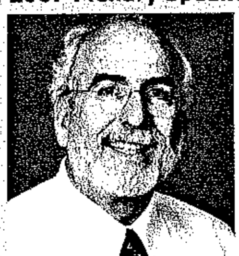

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