New Structure of Rigid Spacers for Tight Bonding of Two Plastic Substrates in Plastic LCD

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Abstract

We have developed tight bonding of plastic LCD with new rigid spacer. For tight bonding of two plastic substrates, we designed structures to collect UV or thermal epoxy placed on the top of rigid spacer spontaneously by capillary effect. We confirmed that tight bonded plastic LCD has a good adhesion without induced defects and a high mechanical stability against the various external deformations. This method can be applicable to the fabrication of large plastic LCDs using stamping process.

1. Introduction

In flexible display technologies, the researches based on a liquid crystal display (LCD) system are extensively studied because it exhibits flexibility, light weight, durability, high-throughput manufacturing and various portable and wearable applications [1]. One of main issues in these techniques is maintaining constant cell-gap between two plastic substrates to provide the stable and uniform operation of the system. Especially, this is highly essential to the LCD-based flexible display because of intrinsic properties of liquid crystal (LC). In our previous research, we had suggested the mechanically stabilized plastic LCD with pixel isolated liquid crystal (PILC) structure and anisotropic phase separation method. However, these modes should solve the limits of the device for the practical application such as the induced defects from residual polymer in the pixel and especially the restricted selectivity of LC mode [2-3]. In order to solve these problems, we have proposed new rigid spacer structure [4]. Designed rigid structure provides not only the precise and stable cell-gap through whole sample but also good adhesion properties without induced defects from the overflowed UV epoxy.

In this paper, we have proposed bonding technique of plastic LCD with new rigid spacer using stamping method. Also, we have studied mechanical stability of our sample. We confirmed that the self-aggregated polymer structure maintains the stable cell-gap against the external distortions.

2. Experimental

Schematic device diagram of our proposed structure is shown in Fig. 1. Two flexible substrates are tightly assembled each other by adhesion material which is placed on the top of rigid spacer. The rigid spacer array maintains stable and uniform cell-gap of device through whole area which is similar to the micro-wall structure in previous PILC configuration. However, in the case of PILC, it can't provide alignment layer on top substrate because of formed polymer layer by anisotropic phase separation. In our proposed structures, the isolated adhesion concept of assembling technique provides LC alignment on the top substrate can be controllable. It assures that we can obtain the freedom for designing LC mode and easily adopt this method for various flexible display applications.

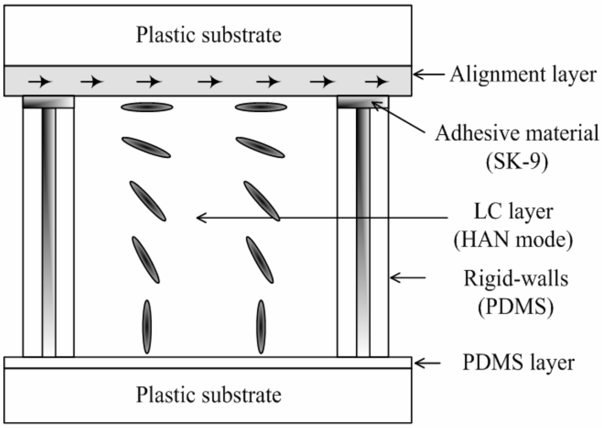


Fig. 1. Device configuration of tight bonding structure based on a micro-structure.

To examine the mechanical stability and the adhesive reliability of our proposed structure, we demonstrated the hybrid aligned nematic (HAN) LC sample by using conventional plastic substrate of PES (polyethersulphone). In our demonstration, homogeneous LC aligning agent AL3046 (Chisso) was used. PDMS is hydrophobic material, so it plays a role like homeotropic alignment layer. As described earlier, one of the main advantages of our technique is to be suitable for various LC modes which are essential to establish high quality display while the other LC based flexible techniques have restricted LC mode suitability. A commercial nematic LC (MLC00993 from Merck) was utilized in this paper and the cell-gap was maintained by the rigid spacer structure.

3. Results and discussion

Fig. 2 shows the proposed rigid spacer structure and fabricated structure by stamping method using durable elastomeric PDMS (poly dimethyl-siloxane). The negative photo-resist SU-8 (Micro-Chem) is used as master structure. The resultant designed rigid spacer has four columns where the diameter and lateral spacing are 15μm, 10 μm, respectively. The distance between each rigid spacer is 150μm.

In order to assemble two substrates, micro contact printing method is employed. The UV curable optical adhesive polymer SK-9 (Optical Bond) was placed on the top of rigid spacer structure by contacting and pressing. Then the two substrates are assembled by using simple UV irradiation. In conventional rigid spacer case, we had observed flowed adhesive material in the pixel by pressure of top substrate in the texture of LC sample. Because of these reasons, we have proposed the rigid spacer of rectangular shaped structure. Proposed rigid spacer gets together adhesive material between rigid-walls by capillary effect at pressing and contacting process without overflowing.

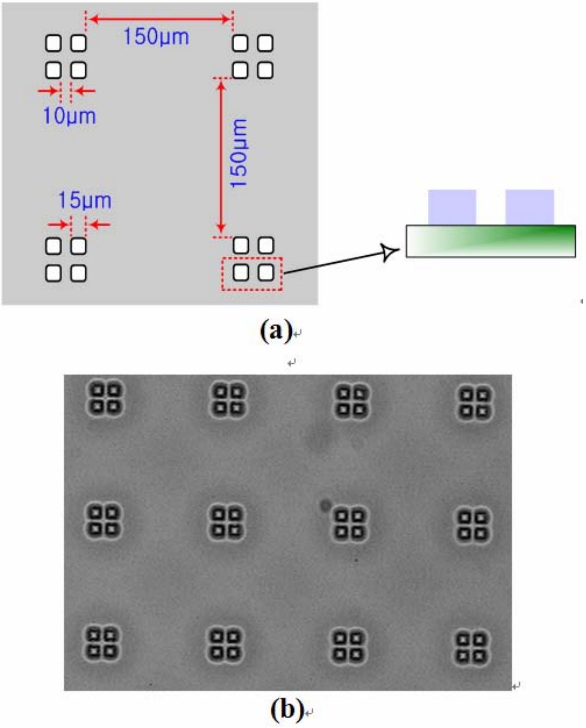


Fig. 2. (a) The proposed rigid spacer structure, (b) fabricated structure by stamping method.

Fig. 3 shows the various microscopic photographs of adhesive material on PDMS surface and rigid spacer region after micro-contact printing. We can see and suppose from the photographs because of the surface wettability of PDMS, the adhesive material may located on rigid spacer as droplet shape, or filled into rigid spacer region.

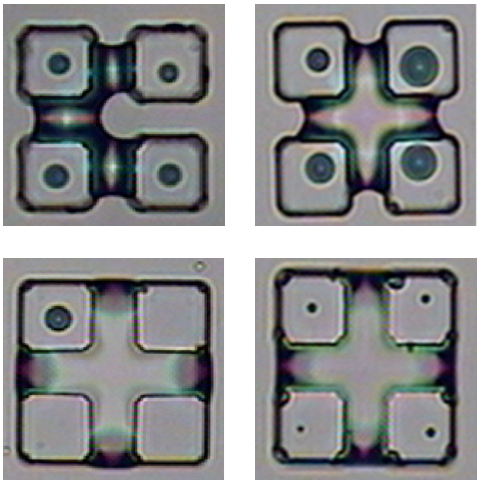


Fig. 3. The various microscopic photographs of adhesive material on PDMS surface and rigid spacer region after micro-contact printing.

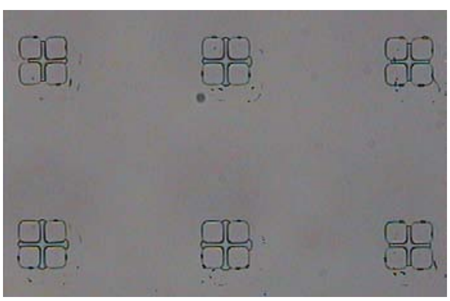
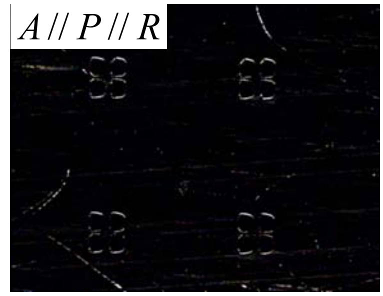


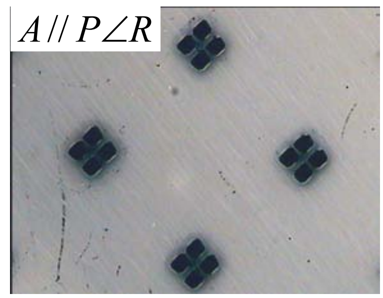
Fig. 4. The microscopic photograph of the top substrate. The adhesive material SK-9 is located in rigid spacer by capillary effect.

Fig. 4 shows the microscopic photograph of the top substrate after detaching sample. We can see the adhesive material is located in rigid spacer region by capillary effect, so there is no overflowing into pixel.

Fig. 5 shows alignment textures with proposed rigid structure under parallel polarizers. From the texture, we confirmed that the self-aggregated polymer structure maintains the stable cell-gap against the external deformations and holds the top substrate tightly. We got uniform and good alignment texture especially around rigid spacers without defect that is from overflowed adhesive material. It means adhesive material SK-9 which has low surface wettability preferred to place into rigid spacers region rather than surface of spacers. Stable HAN mode was achieved as we expected.



(a)

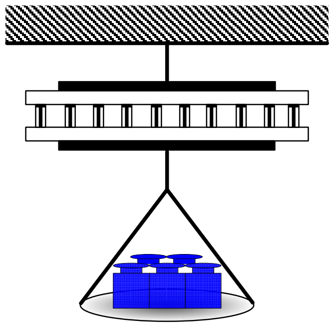


(b)

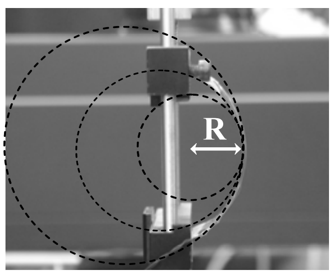
Fig. 5. The photographs of LC alignment texture under parallel polarizers.

In order to check the bonding strength of the proposed rigid spacers between two plastic substrates, we measured the maximum tension to preserve cell-gap of the sample. We fixed one substrate and add weights to the other substrate until the sample took apart as shown in Fig. 6 (a). We carried out the experiment several times and the averaged tension was 4.34 N/cm^2. This result can prove tightly bonding of top and bottom substrates.

And also, we measured bending capability of the sample by measuring E/O properties with changing degree of bending as shown in Fig. 6 (b). From the experiment, our method (Type I) could tolerate even with hard bending of R = 1.5 cm (R is the radius of bending curvature), while the sample with only the micro-structure which has seal line (Type II) is broken after engaging bending action of R = 3.2 cm as shown in the table 1 which proves that this technique supports stable cell-gap of the device under high external bending forces. From these results, we can conclude that the proposed technique can be useful to realize the flexible LCD with reliable device performance.



(a)



(b)

Fig. 6. Experimental set up for mechanical stability. (a) Bonding strength test, (b) Bending deformation test (R is the bending radius).

R	∞	4.6 cm	3.2 cm	2.1 cm	1.5 cm	0.5 cm
Type I	**good**	**good**	**good**	**good**	**Poor**	**break**
Type II	good	good	poor	break	-	-

Table 1. Bending test as increasing the degree of bending. Type I and II are plastic samples based on our tight bonding method, and only micro structure which has seal line, respectively.

4. Summary

We have proposed bonding technique of plastic LCD with new rigid spacer array using stamping method. A self-aggregated structure of UV epoxy provided tight bonding of two plastic substrates. It is expected that our proposed method is applicable to the fabrication of large plastic LCDs with a good mechanical stability and a superior visibility using the cost-effective roll-to-roll process.

5. References

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