# Substrate bonding technique using the agar-epoxy composites for flexible LCD

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## Abstract

*We have proposed novel bonding technique of substrates for developing the flexible LCD with high quality. The gel type mixture of agarose and UV curable epoxy developed to obtain tight bonding ability and enhanced electro-optical characteristic simultaneously. This technique can be used to roll-to-roll process for fabricating the flexible LCDs.*

## 1. Introduction

The flexible liquid crystal display (LCD) is the display device adopting novel concept which can be bendable and rolled up like a paper by using thin and flexible substrates. So far the various technologies for fabricating the flexible LCD have been developed, however the reliabilities of device under external deformations were insufficient for the practical applications. To increase the reliability, the cell gap should be maintained same and uniform through whole panel by adopting the stabilizing techniques such as wall-supported pixel-isolated structure [1, 2]. Also, bonding technique of two substrates is necessary for flexible LCD. In case of bonding process for glass substrates, the external seal-line process is applied typically. However, as the size of plastic substrates is expanded, the detached phenomenon is easily occurred by a simple impact like bending. Therefore, the formed micro-structures for the uniform cell gap on bottom substrate have to bond with top substrate by the pixel unit. In the previous bonding method for flexible LCD [3], ultraviolet (UV) curable epoxy was used as adhesive material. But some problem is occurred in assembling process. Because of the low viscosity of UV epoxy, it overflows into the pixels. Therefore, we can't use the LC drop process because UV epoxy reacts with LCs. Also, in the pixel, the existence of excessive adhesive material reduces the image quality and the reliability of device seriously.

In this paper, we have proposed novel substrate bonding technique for manufacturing the flexible LCD which has the micro-structure. As the adhesion layer, we proposed the mixture of agarose and UV curable epoxy. This mixture exists as the gel type and it doesn't react with LCs. Also, we can control the viscosity of adhesive material by temperature so that it doesn't overflow into the pixels. This mixture can tightly bind two substrates after irradiating UV light due to the bonding property of UV curable polymer. Also, we can apply this strong bonding technique to the future roll-to-roll fabricating process for the reliable and high quality flexible LCDs.

## 2. Experimental

Fig. 1 shows schematically the mixture and fabrication process of proposed bonding layer. The gel mixture composed of agar and UV curable epoxy (SK-9, SUMMER OPTICAL) was used as the adhesive material. Fig. 1(a) shows the mixing process of agarose and UV curable polymer. After boiling the agarose solution until 150℃, we added UV curable polymer and EDTA at the cooling process. Fig. 1(b) shows the micro-contact process the proposed bonding

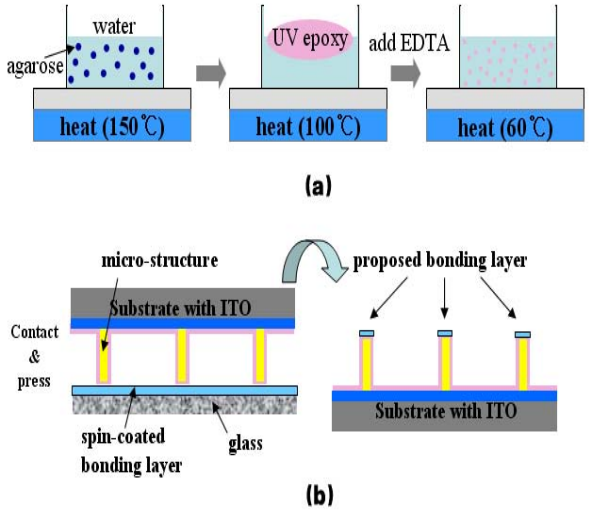


**Fig. 1. The fabrication process of proposed bonding layer: (a) the mixture process of agar-epoxy composites, (b) the micro-contact process.**

material on the polymer wall.

Agar is the mixture of glactan consisted of agarose (70%) and agaropectin (30%). Agarose is a linear polymer composed of alternating residues of D- and L-galactose joined by α-(1→3) and β-(1→4) glycosidic linkages. Chains of agarose form helical fibers that aggregate into supercoiled structures with a radius of 20~30nm. Commercially prepared agarose polymers are believed to contain ~800 galactose residues per chain. The average length of the polysaccharide chains varies form batch to batch and from manufacturer to manufacturer. In addition, lower grades of agarose may be contaminated with other polysaccharides, as well as salts and proteins. This variability can affect the gelling/melting temperature of agarose solution [4]. We used the Chromosomal Grade Agarose (Bio-Rad) of high-gel-strength agaroses type (the gelling temperature: 34~43℃, the melting temperature: 85~95℃).

To mix the UV curable polymer in the agarose solution, it is needed EDTA (ethylenediamime-tetraacetic) as chelating agent. A chemical formula of EDTA is $C_{10}H_{14}O_8N_2Na_2H_2O$ (Fig. 2) and the molecular weight is 372.24g. It helps dispersion of the UV epoxy in the solution. We controlled the included concentration of EDTA and PH of solution for optimization of mixing property.

We formed the wall structure by using the negative photoresist (SU8-2005, MICRO-CHEM) for maintaining the stable cell gap. Conventionally, the process is applied by photo-lithography method.

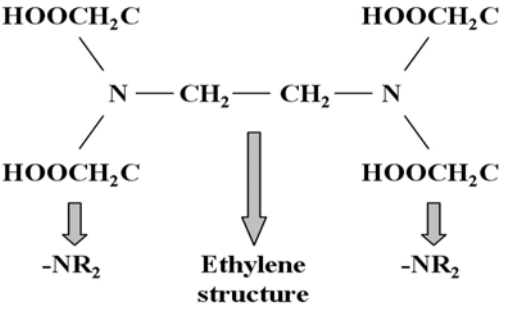


**Fig. 2. Chemical structure of the EDTA**

The interval of polymer wall is 300μm × 100μm, width is 30μm and height is 6.5μm. The used materials in our study polyimide and LC are followed. A commercial polyimide is AL3046 from JSR and a nematic LC is ZKC5085 from Chisso. At the micro-contact process, we coated the bonding material on the glass substrate for micro-contact process. We carried out the coating process above the gelling temperature. The printed bonding layer on wall structure is changed to the gel-state gradually as cooled down. During we put the top substrate on bottom substrate after LC dropping, this gel type mixture doesn't react with LCs. If we heat this sample until 90°C again, the mixture is remelted due to the characteristic of agarose. The mixture has adhesive property when UV is exposed.

## 3. Results and discussion

We made the optimized bonding materials by controlling of the concentration of EDTA and PH of solvent. Also, we transcribed it on the polymer wall by the micro-contact method and it is fixed. To research the surface wettability and adhesion between alignment layer (AL3046) and proposed bonding material, we check the contact angle of bonding material on polyimide. Fig. 3 shows their contact

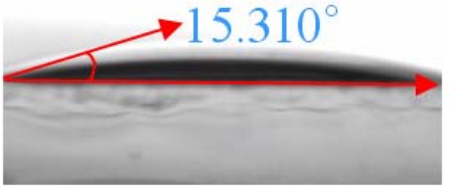


**Fig. 3. The contact-angle between agar-epoxy composites and alignment layer (AL3046).**

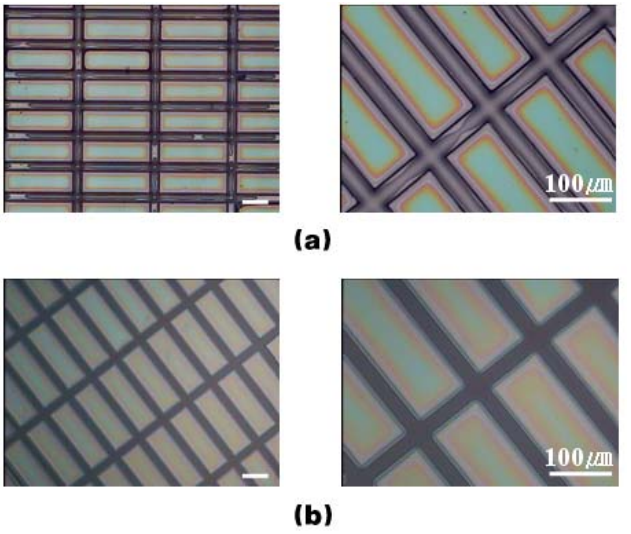


**Fig. 4. Microscopic images of samples: (a) after the micro-contact process, (b) after the assemble process.**

angle. This result provides that the proposed bonding material can easily apply the micro-contact method because the low contact-angle against the surface is shown the high surface energy.

Fig. 4(a) shows the microscopic texture of the transferred adhesion layer on the polymer wall after micro-contact process. Adhesion layer is gradually fixed as temperature is cooling down. To confirm the adhesion property between the top and bottom substrates, we carried out the assemble process with no LC filling process. After putting the top substrate, the UV is irradiated to the sample at 90℃. The UV irradiating condition is considered the remelting temperature of agarose.

Fig. 4(b) shows the microscopic images of the formed adhesion layer on the polymer wall after assemble process. It is fixed on the polymer wall without overflowing into the pixel as shown in the figure. Also, the strong binding of substrates was

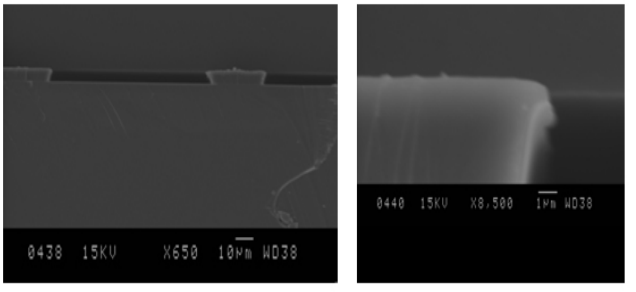


**Fig. 5. SEM images of the adhered section.**

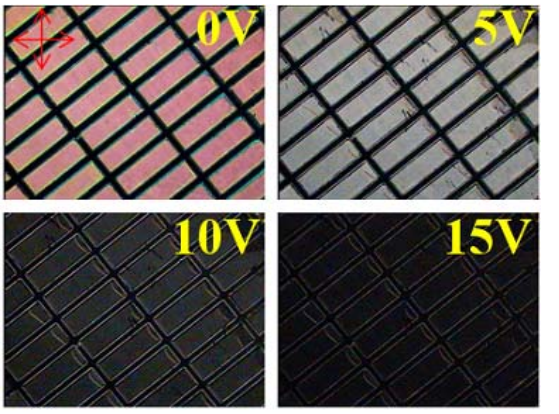


**Fig. 6. Microscopic images of samples.**

confirmed by bending and pressing test. Fig. 5 shows the cross-sectional view of the adhered section using FESEM (Field Emission Scanning Electron Microscopy). It is confirmed that the bonding material is stabilized on the polymer wall. As shown in Fig. 5, there is no overflowing of adhesion material. We fabricated the electrically controlled birefringence (ECB) LC cell by the proposed process. Fig. 6 shows the microscopic textures of the driving test (0V to 15V). The unclean area around near side of the polymer wall is occurred by the pressure from the rolling direction at the micro-contact process. But it is not affected to the initial alignment and driving property of LCs.

In conclusion, the proposed bonding technique can be very useful for flexible LCD applications. The mechanical stability can be secure against external deformations by bonding each sub-pixels of the micro-structure.

## 4. Summary

This method can prevent the overflowing of bonding polymer into the pixels. The adhesion layer on the rigid spacers is stable and no reacting with LCs. This is a great advantage in using all of rigid spacers for the stability and the simple micro-contact method, to be applied in a roll-to-roll system by in the fabrication of flexible LC displays.

## 5. Acknowledgement

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## 6. References

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