

P-14: Novel Stability Enhancing Technique for Flexible LC Display by using Rigid Spacer Array and Micro-Contact Printing

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Abstract: In this work, the novel combined technology for maintaining constant gap between two flexible substrates was investigated. The self-gathering adhesive polymer structure to stick flexible substrates was generated by using the rigid columnar spacer array and a micro-contact printing (μ CP) method. The proposed flexible liquid crystal display (LCD) structure showed fine optical properties as well as enhanced mechanical stability for flexible display application under assorted deformations. Moreover, this technique can easily inherit most advantages of traditional LCD technology such as low driving scheme, established process and LC mode selection freedom within a simple fabrication procedure. Therefore, this method can be a powerful candidate for realizing practical flexible display with enhanced mechanical stability and high performance.

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

Introduction

In the developing display technology, the reliable flexible devices to be stable for various deformations and more easy portability are highlighted due to its multi-functional application [1]. In the term described, the flexible display adopts the soft substrates such as plastic. Especially, the LC-based flexible display is viably studied because it is the most dominant and advanced technique in that area [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 performances, it has still remained to solve the problems such as complex fabrication, induced defects from polymer wall or residual polymer and especially narrow display application range from limited LC mode. Especially, the distortion tolerance by bending, cracking of tension, delaminate buckling of compression should be solved to get a high quality flexible liquid crystal display (LCD).

In this work, we focused on the self-gathering adhesive polymer layer by using the rigid columnar spacer array and a micro-contact printing (μ CP) [7] method. The designed pillar spacer array with μ CP bonding method provides the maintenance of constant gap between two flexible substrates as well as good adhesion properties.

This technique of columnar spacer array and μ CP method is more effective for the application of assorted flexible display structure with a simple process [8]. Moreover, the prominent electro-optic characteristics of flexible LCD is guaranteed because the capillary filling effect of designed multi-column spacer array generates a self-gathering structure of adhesive material without overflow.

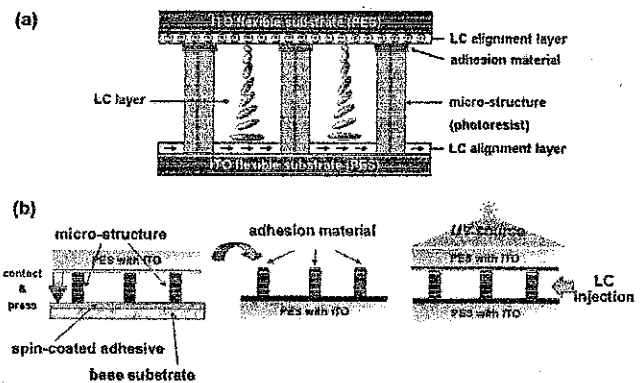


Figure 1. (a) Device configuration of flexible LCD mode based on a micro-structure (b) Fabrication procedure of the device using μ CP method

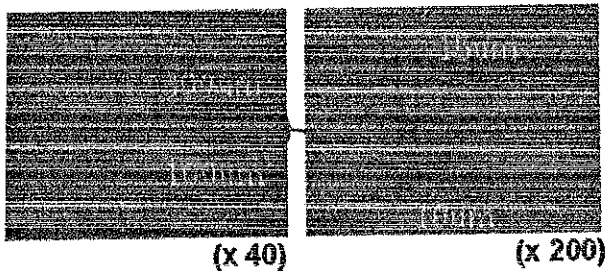
Device Configuration

A schematic diagram of suggested structure is shown in Fig. 1(a). Two flexible substrates are tightly assembled each other by the adhesive material placed on the top of micro-column structure. The pillar array maintains stable and uniform gap of device through whole area by a similar mechanism of the micro-wall structure in previous PILC configuration [5,6]. However in our configuration, unlikely to the PILC case, self-gathering adhesive concept of assembling technique provides LC alignment on the top substrate can be controllable. This assures that we can obtain the freedom for

igning LC mode and easily adopt this method for diverse LC display applications. In this paper, most popular twisted LC structure was demonstrated as an example of diverse application (see Fig. 1 (a)).

To assemble two substrates, μ CP method is employed as illustrated in Fig. 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 under a simple UV irradiation. Note that multiple adhesion points of rigid spacer array guarantee mechanical stability of device at the edge of each pixel. SU-8 (Microchem) was used as a photoresist material.

[Type A]



[Type B]

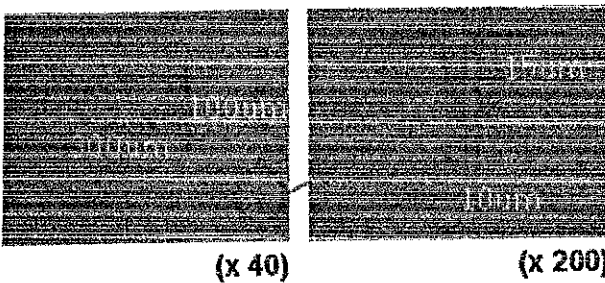
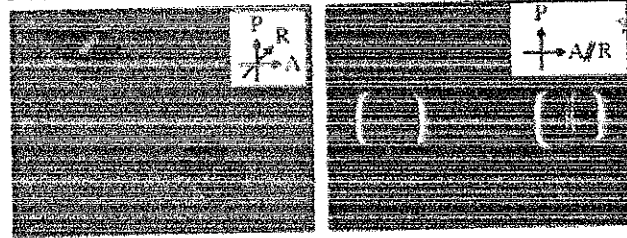


Figure 2. The photographs of designed micro-structure of columnar spacer array. Circled insets in left figures are magnified at the right by 5 times (x40 to x200). Type A array is based on the two pillar structure while Type B does on the four column.

Rigid Columnar Spacer Design

The configuration of designed rigid columnar spacer is illustrated in the Fig.2. We divide the conventional single pillar structure into the sub-parts to prevent overflow of adhesive materials and confine excessive agent in spacer area. By the capillary force between pillars, liquid adhesive slides into the multi-column spacer at the moment of contact and be solidified by UV irradiation providing strong adhesion of two substrates and confined structure of adhesive material. Two types of design were demonstrated to check the mechanical stability and overflow effect variation. Type A rigid spacer have two pillar structures of $15\mu\text{m} \times 40\mu\text{m}$ with $100\mu\text{m}$, $300\mu\text{m}$ of lateral spacing, while type B have four columnar structures of $15\mu\text{m}$ diameter with the same spacing as shown in the figure.

[Type A]



[Type B]

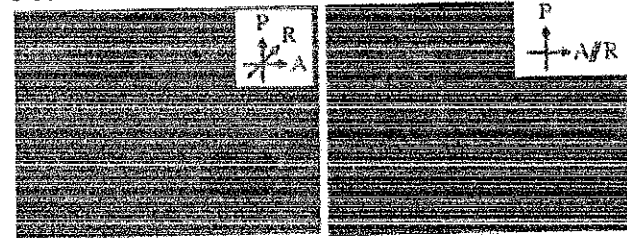


Figure 3. The microscopic images of LC textures under crossed polarizers around the rigid pillar spacer. Rubbing direction is parallel to the analyzer at the right dark images while that is 45 degree twisted to the analyzer at the left.

Results and Discussion

To examine the mechanical stability and the cell gap reliability of suggested configuration, we fabricated the basic planar alignment of LC sample on the popular plastic substrate of PES (polyethersulphone). PES shows a good stability for heat, chemical contamination and mechanical distortion.

In first, we checked the LC textures after fabricating a test sample. The clear gathered structure of adhesive polymer was observed in the microscopic images of LC sample as shown in Fig. 3. From the widely uniform texture images, we can confirm that the multiple adhesion contact points between two substrates by μ CP guarantee a mechanical stability of flexible display as well as a simple process. From the capillary effects, the self-gathering phenomenon was more completed in Type B (see Fig. 3), which we can expect that this structure can be more stable and effective to show better adhesion properties and maintain the cell gap against the external forces. Note that the small boundary effect disturbs the LC alignment around the columnar spacer in the figure.

After μ CP assembling process, the cross section was observed by SEM (scanning electron microscope) to confirm the confined adhesive polymer structure as depicted in Fig. 4 (a). Adhesive material was placed on top of micro-pillar structure, and confined structure of adhesive polymer was monitored within the pixel boundary.

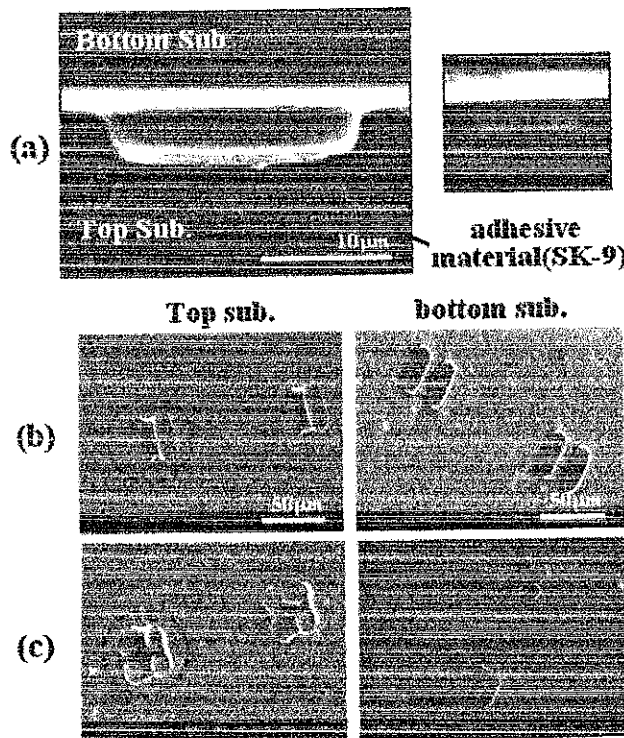


Figure 4. (a) SEM image of cross section after using μ CP method. (b) and (c) is top and bottom substrate after detaching sample, respectively.

Fig. 4 (b) and Fig. 4 (c) show the SEM images of the top and bottom substrates after opening the sample and removing the LCs in inter- and intra pixel regions. The area where the adhesive material was placed to the micro-pillar structure on was obviously observed in the dotted regions of Fig. 4 (b) and Fig. 4 (c). This is consistent with the results of monitoring LC textures in the Fig. 3. As the result, we confirmed the designed rigid spacer can create the self-gathering isolated adhesive polymer structure from the capillary effect.

In next, the sample is fixed in the air with increasing the additional loads to check the adhesion reliability. Table 1 shows the measured maximum capable load without breaking sample in four measurements. In experimental results, our sample stands up the average load of 2.54 and 4.56 N/cm^2 , for type A and type B, respectively. This result can be easily understood by matching the LC texture observations and our general expectation from the pillar design.

Table 1. Adhesion breaking test by increasing weight of the loads. Two types of rigid spacer array was tested by μ CP bonding process.

Experiment	(Dimension: N/cm^2)			
	1	2	3	4
Type A	1.89	3.38	1.89	2.36
Type B	4.35	5.00	5.00	3.01

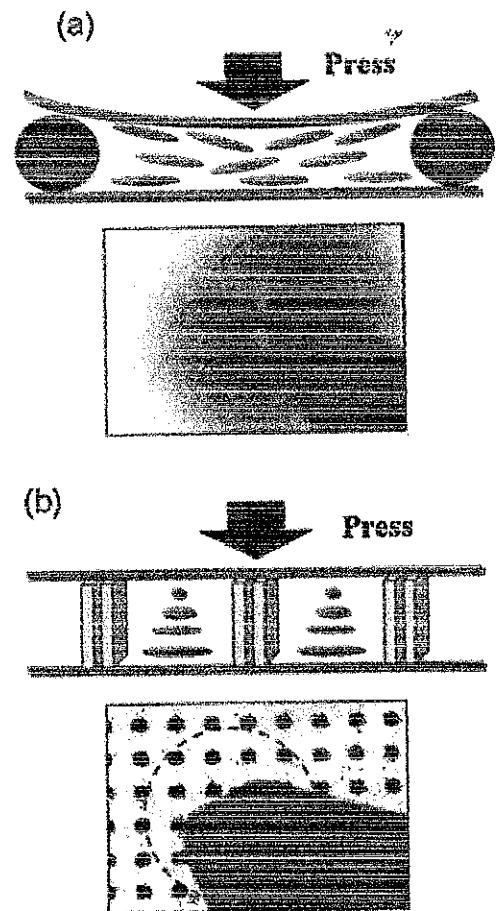


Figure 5. The schematic illustration of LC configuration under external pressure and texture of the sample (a) conventional ball spacer case (b) our rigid micro-structure case

As described earlier, one of the main advantages of our suggested technique is to be adjustable for diverse LC mode which is essential to establish high quality and various flexible displays while the other LC based flexible techniques have restricted LC mode suitability. So, in next experiment, homogeneous LC aligning agent Nylon 6 was used and rubbed in the crossed direction to obtain twisted LC geometry sample. TN is the most general configuration for practical display application as well known. Surely, depending on the LC aligning agent and rubbing direction, we can easily realize different LC mode with our method. A commercial nematic LC (MJ00993 from E. Merck) was utilized in this experiment and its birefringence (Δn) and dielectric constant ($\Delta \epsilon$) is 0.151 and 11.1, respectively. The crystal temperature of used NLC was 101°C and the cell gap was maintained as 3 μm by rigid photoresist micro-structure.

In the mechanical stability test, the micro-structure sample was compared to the conventional ball spacer type. Typical structure is weak to an external pressure due to the lack of substrate supporting system in the pixel area [Fig. 5 (a)], otherwise, our micro-column rigid spacer sustains stable cell

gap through the whole sample as shown in the press test due to the micro-structure and strong bonding [Fig. 5 (b)].

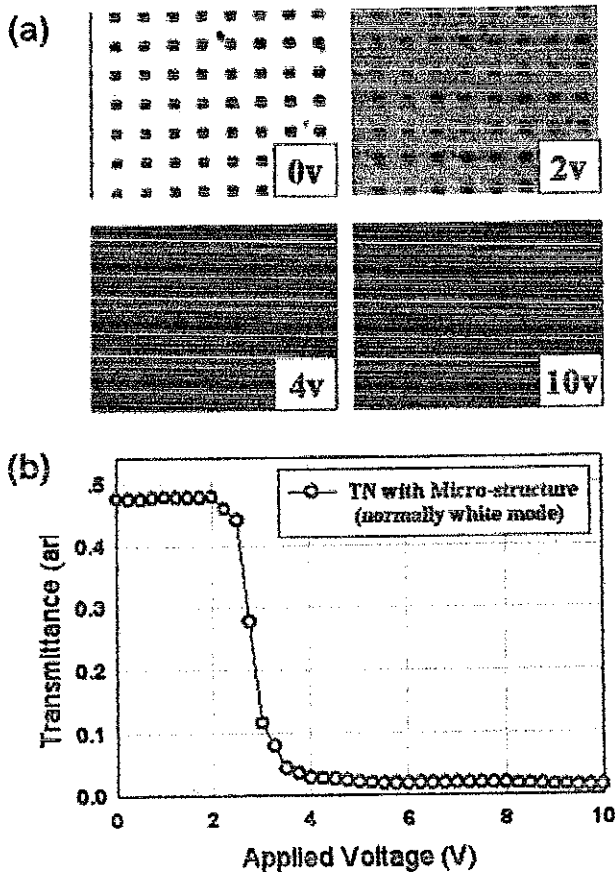


Figure 6. (a) Photograph of LC texture change under various applied voltages. Each image are taken under 0V, 2V, 4V and 10V, respectively (from top left, right, bottom left, right). (b) V-T curve of our TN sample with plastic substrate at normally white mode.

Subsequently, we checked out the electro-optic (EO) characteristics of TN structure to assure stable operation of the device in final. In Fig. 6 (a), LC texture change is monitored with various applied voltages. In the normally white configuration, TN sample is placed under crossed-polarizers with one of rubbing direction is parallel to the polarizer. As depicted in the figure, LC textures was get dark as increasing applied voltage and complete dark image was observed at the applied voltage of 10 V. Voltage-transmittance curve of the sample was measured in Fig. 6 (b). From the experimental data, we found that the performance of our flexible TN configuration based on a micro-structure was comparable to that of the conventional one.

As the result, we can conclude that the mechanically stabilized flexible LCD can be acquired by using our assembling technique with a simple fabrication and a LC mode selection freedom. The suggested method can be highly useful to realize the flexible LCD with reliable device

performance. Note that optimization for various device parameters and detailed studies for mechanical stability remain to be explored.

Conclusion

We have demonstrated the stability-enhanced novel flexible LCD by using the micro-column spacer array and the μ CP assembling technique. Designed pillar spacer array creates that the confined structure of adhesive polymer by capillary effect and μ CP bonding supports the good adhesion of two flexible substrates. In addition, suggested techniques can easily adopt diverse LC mode because the control of LC alignment at top substrate is possible, diverse flexible LCD can be realized. As an example, we have demonstrated a flexible TN LC mode sample with the press test and EO measurements. From the experimental results, we can confirm that the much stabilized structure was achieved by a simple fabrication procedure showing the same display performances to the conventional one. In conclusion, this cell gap spacing and substrate assembling techniques based on the rigid spacer and μ CP bonding method are expected to be highly useful for manufacturing flexible display with versatile usage.

Acknowledgement

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TABLE OF CONTENTS

Session 15: Emissive Displays

Thursday, September 21 / 9:50 am – 12:00 pm /
Governance Chambers

Chair: Shigeo Mikoshiba, University of Electro-
Communications

- 15.1: Invited Paper: Development of 0.3 mm Pixel Pitch High-Resolution AC-PDP for Super Hi-Vision Broadcasting System** 199
Keiji Ishii, Yoshikuni Hirano, Yukio Murakami
NHK Science & Technical Research Laboratories
Masaki Yoshinari, Tasuku Ishibashi,
Toshihiro Komaki *Pioneer Corp.*
Naoya Kikuchi *Noritake Co., Limited*
Isao Sumita *NBC, Inc.*
- 15.2: Ultra-Bright High-Frequency Flexible Plasma Displays** 203
Carol A. Wedding, Edwin F. Peters, Jeff W. Guy,
Thomas J. Pavliscak, Oliver M. Strbik III,
James C. Rutherford, Daniel K. Wedding,
Victoria W. Kurtz *Imaging Systems Technology*.....
Donald K. Wedding *University of Toledo*
- 15.3: Application of Embedded Carbon Nanotubes for Field Emission Displays** 207
Sara Darbari, Yaser Abdi, Shams Mohajerzadeh,
Javad Koohsorkhi *University of Tehran*
- Poster Session**
Tuesday, September 19 / 4:30-6:30 pm / Student Center,
2nd Floor Hallway
- P-1: Design of Large Area OLED Displays Utilising Seamless Tiled Components** 211
Mark Aston *TEW Engineering Ltd.*
- P-2: Characteristics of Ultra-Wide-View TN-type TFT-LCD**..... 215
Dano Lin, Andy Chao, Chia-Hua Yu, Tean-Sen Jen
HannStar Display Corp.
- P-3: Hybrid Projection QR-LPD 3D Display Design** 220
Wallen Mphemo *Chalmers University of Technology & National Chiao Tung University*
- P-4: Measuring Birefringence at RGB Wavelengths** 223
Baoliang Wang, Andrew Leadbetter,
Richard Rockwell, Doug Mark *Hinds Instruments, Inc.*
- P-5: Evaluating Tristimulus for Dim Levels of LED Projector** 227
Ming-Lin Li, Jong-Woei Whang, Neng-Chung Hu,
Jong-Woei Whang, Neng-Chung Hu
- P-6: Uniform Back Light Unit by Specular Reflection** 231
Jong-Woei Whang, Yi-Lung Lin
National Taiwan University of Science and Technology
- P-7: An Analytic Approach in Designing Film STN LCDs**..... 235
D.-K. Yang, F. Zhou, S. Hurley, L. Shi
Kent State University
- P-8: Innovative Design of Illumination System for LED Projectors** 239
Jong-Woei Whang, Heng-Che Chen
National Taiwan University of Science and Technology
- P-9: Reduction in the Operation Voltage of a Polymer Electroluminescence Device with a Photo-alignment Layer** 243
Jun-Hee Na, Wonsuk Choi, Jinyool Kim,
Sin-Doo Lee *Seoul National University*
- P-10: A Large Organic Electroluminescent Display using Bimorph MEMS Devices** 247
James C. Rutherford, Carol Ann Wedding
Imaging Systems Technology
Donald K. Wedding *University of Toledo*
- P-11: LCD Response Time Estimation**..... 251
Pierre Adam, Pascal Bertolino,
Jean-Marc Chassery *Laboratoire des Images et des Signaux de Grenoble*
Fritz Lebowsky *STMicroelectronics Grenoble*
- P-12: A Novel Electrode Design for High Transmittance In-plane Switching Liquid Crystal Displays** 255
Zhibing Ge, Xinyu Zhu, Thomas X. Wu,
Shin-Tson Wu *University of Central Florida*
- P-13: Innovative Design to Increase Lumens for Projectors Illumination** 259
Shih-Chi Chien, Jong-Woei Whang,
Neng-Chung Hu, Horng-Ching Hsiao
National Taiwan University of Science and Technology
- P-14: Novel Stability Enhancing Technique for Flexible LC Display by using Rigid Spacer Array and Micro-Contact Printing**..... 262
Se-Jin Jang, Ji-Hong Bae, Min-Soo Shin,
Yoonseuk Choi, Hak-Rin Kim *Hanyang University*
Sang Il Kim, JunHyung Souk *Samsung Electronics*
Jae-Hoon Kim *Hanyang University and Samsung Electronics*
- P-15: New Type of RGB Matrix: 3 Operations and Any Moving of a Substrate by Manufacturing** 266
Valentin A. Tsvetkov *Moscow State University of Instrument Engineering and Computer Sciences*
- P-16: Low Temperature Fabrication of Flexible Liquid Crystal Display by an Imprinting Technique** 270
Yeun-Tae Kim, Jong-Ho Hong, Sin-Doo Lee
Seoul National University
- P-17: High-Resolution 3D OLED Demonstrator** 274
S. Hentschke, Zh. Yordanov, J. Börcsök
University of Kassel
A. Wedel *Fraunhofer Institute of Applied Polymer Research*
- P-18: Super-PVA Mode with Varying Tilt Angles and Azimuths**..... 278
Woo-Jung Shin, Taeyoung Won *Inha University*
Cheol-Soo Lee *Sanayi System Co., Ltd.*
- P-19: Analysis of the Discharge and VUV Radiation Characteristics of a Ultra-High-Resolution PDP Cell by 3-D Computer Simulation**..... 282
Yoshikuni Hirano, Keiji Ishii, Yasushi Motoyama,
Yukio Murakami
NHK Science & Technical Research Laboratories
- P-20: Continuous Pinwheel Alignment (CPA) Mode for LCD Pixel Structure**..... 286
Sang-Young Cho, Tae-Young Won *Inha University*
Cheol-Soo Lee *Sanayi System Co., Ltd.*
- P-21: Patterning of Alignment Layers for Multi-Domain Liquid Crystal Structures** 291
Hak-Rin Kim, You-Jin Lee, Jong-Wook Jung, Min-Soo Shin, Myung-Eun Kim, Jae-Hoon Kim
Hanyang University