O-017

Pixel-Isolated Liquid Crystal (PILC) Mode for Rugged Flexible LCDs

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ABSTRACT

We have suggested Pixel-Isolated Liquid Crystal (PILC) mode for flexible LC display. In our device, the LC molecules are fully isolated in the pixels by the surrounding walls fabricated by various methods. The experimental results of microscopic observation and electro-optic characterization show that our flexible PILC device has good mechanical stability against external point pressure or bending distortion due to the isolated pixel structure.

Keywords: Flexible LCD, Plastic substrate, Roll process, Pixel-isolation, Mechanical stability

1. INTRODUCTION

For the past 10 years, LCD technology has been greatly advanced and leading the flat panel display (FPD) market all around of the world. Nowadays preparing for new generation and replacing the glass substrate by plastic substrate, flexible display devices are widely and extensively studied for the purpose of use in applications such as smart cards, PDA, head mount displays and all kind of mobile display because of their lighter weight, thinner packaging, flexibility, ruggedness and reduced manufacturing cost through continuous roll processing. Among various kinds of flexible displays, plastic LC devices have advantages in their full growth of fabrication technology in FPD and efficient light-control capabilities with low power consumption[1-4]. But due to use the flexible substrates, there exist basic obstacles in fabricating plastic LCD. One is mechanical instability of LC modes, and the other is adhesion of two substrates because flexible displays always experience pressing and bending stresses[5].

In order to overcome the above underlying problems, polymer walls[6] and/or networks as supporting structures have been proposed and demonstrated. However there are some drawbacks in using these methods, such as high electric field in fabrication process, residual polymers in active region which can reduce display quality significantly and increase the operating voltages[7]. For our PILC mode, the LC and polymers are fully separated in horizontal and vertical direction therefore we can minimize the residual polymers in active LC regime.

In this presentation, we will introduce several methods of fabricating pixel isolating structure and demonstrate the mechanical stability of LC mode by measuring electro-optic properties against external stresses.

2. FABRICATION PROCESS

Figure 1 shows typical PILC mode structure. The LC molecules are fully isolated by surrounding polymer walls and layer. We will describe various fabrication method.

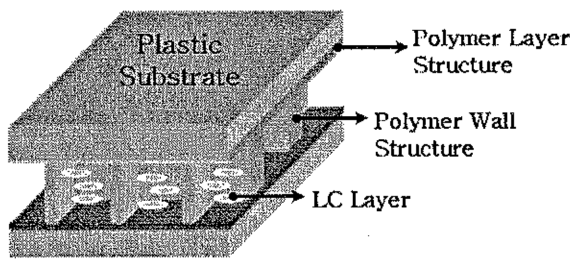
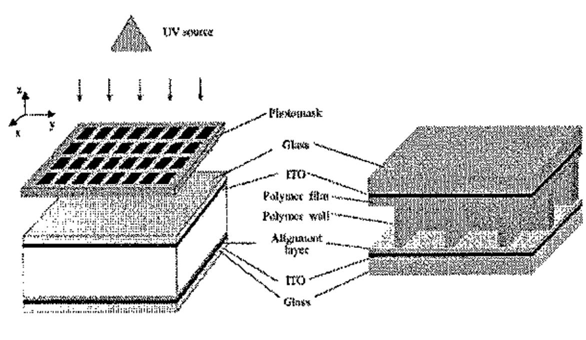


Fig. 1 Schematic diagram of PILC mode

2.1 Fabrication by Two Step UV Exposure

As plastic substrates, ITO-coated PES films were used in our experiment. One of the ITO-coated PES substrates was spin-coated with a homogeneous alignment layer and unidirectionally rubbed. A mixture of nematic LC (LC17) and photo-curable pre-polymer (NOA65, Norland Co.) with a ratio of 75:25 was filled into the plastic cavity at isotropic temperature.

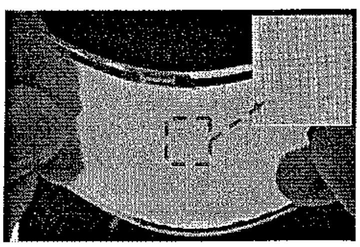


(a) (b)

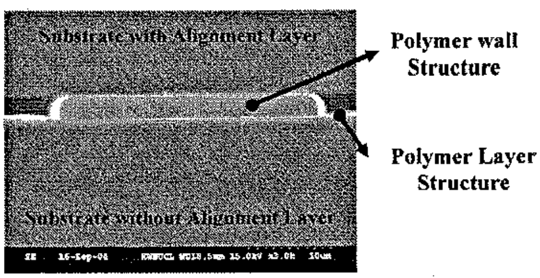
Fig. 2 Schematic diagram of (a) experimental set up and (b) resultant structure after UV exposure

At first UV exposure, the UV was illuminated onto the bare ITO-coated PES substrate through the photo-mask for 90 minutes. A second exposure was performed without the mask for 10 minutes to fully harden the pre-polymers. During these first and second photo-polymerization processes, the anisotropic phase separation occurs in the horizontal and vertical direction, respectively, forming vertical polymer walls and planar polymer layers[8,9]. The LC alignment textures greatly affected by alignment material during second UV exposure due to its surface wetting properties between LC and prepolymer[10]. We used the optimized alignment material to achieve uniform LC alignment.

Fig. 3(a) shows the 3 inch plastic LCD sample using two step UV exposure method. The sample shows uniform texture over the whole sample. By observing under microscope which is represented in inset in figure, we can see 500 μm ×500 μm size of active zone and polymer walls about 30 μm width. Fig. 3 (b) shows the cross section images of the polymer structure in our PILC cell using scanning electron microscope (SEM). The spatially distributed polymer walls fabricated by the first UV exposure act as supporting structures from external pressure and bending keeping the cell gap of the plastic cell. The residual pre-polymers are completely expelled from the bulk LC layer by second UV exposure forming thin polymer layer onto the bare ITO-coated PES substrate which provide adhesion between two plastic substrates.



(a)



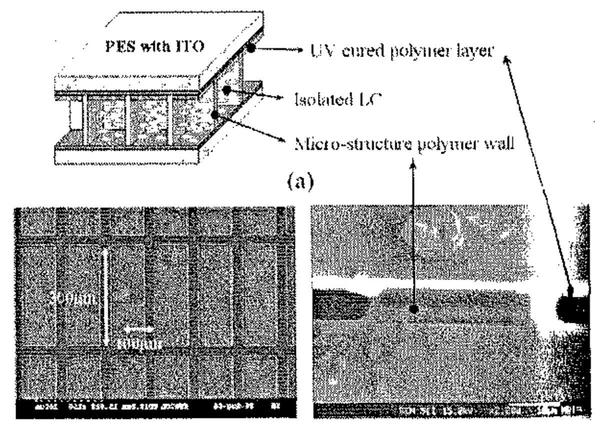
(b)

Fig. 3 Flexible PILC device using polymer walls and layers: 3 inch PILC using plastic substrates (a) and Cross section image using scanning electron microscope (b).

2.2 Microstructures using Photolithography

Although the two step UV exposure method can be used as fabrication method of PILC structure, there remains still some problems in fabrication. Most of the cases, the polymer walls are coincident with black matrix when we apply this method to matrix pixel structure. That means more complex method and pixel structures are needed to obtain pixel isolating structure. Therefore we first prepared the substrate with patterned microstructures using photolithograph. The experimental details are as follow.

We used SU-8 (Micro-Chem) negative photo-resist. SU-8 layers were spin coated on plastic substrate and polymer walls were patterned by UV exposure through a photo-mask (Fig. 4). The alignment layers were spin coated on the patterned microstructures followed by rubbing to control the LC alignment. A solution of LC and prepolymer with weight ratio of 95:5 was dropped on the microstructure and covered by bare ITO substrate. The cell gap of 6 μm was controlled by height of microstructures.



(b) (c)

Fig. 4 (a) Schematic diagram of the PILC structure (b) and(c) are SEM images of the patterned microstructure and cross section of the sample after UV exposure, respectively.

After assembling process, the cells were exposed to UV light of 350nm wavelength to induce phase separation. The resultant structure is almost same as two step UV exposure method except polymer wall material. The adhesion of two substrates are maintained by solidified polymer layers on ITO bare substrate.

2.3 Microstructures using Stamping Method

We fabricated microstructure using stamping method which is applicable to mass production through roll-to-roll process. Fig. 5 shows the schematic diagram of fabrication process. In the first step, we fabricated master structure on glass substrate using SU-8 photo-resist by normal photolithographic method (Fig. 5(a)). The second step is pattern-transferring process to PDMS by stamping. The PDMS is spin coated on a patterned SU-8 structure and covered by bare ITO substrate. After pressing and baking, the substrate with PDMS is separated from the patterned SU-8 structure. The alignment layers were spin coated on the PDMS microstructure followed by rubbing to achieve uniform LC alignment. A solution of the LC and prepolymer mixture was dropped on PDMS and covered

...bare ITO substrate (Fig. 5(d)). The UV exposure was [illegible] onto bare ITO substrate to initiate polymerization.

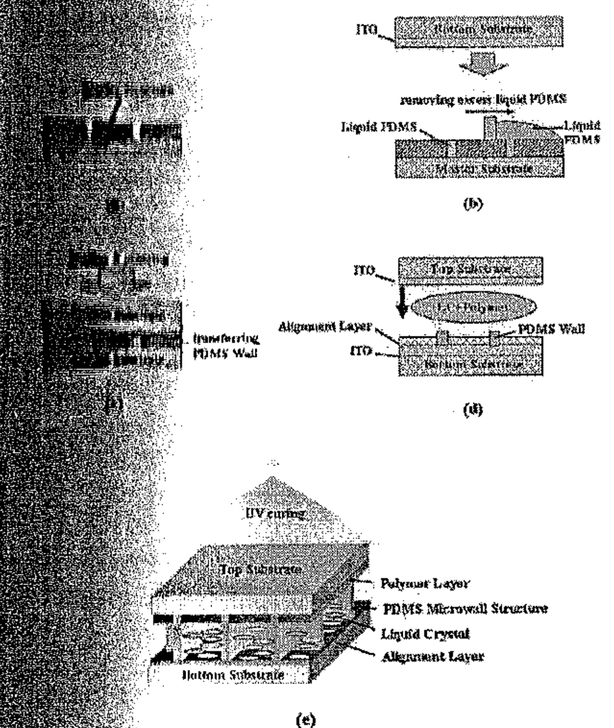


Fig. 5 Schematic illustration of fabrication procedures with stamping method; (a) formation of master structure, (b) coating PDMS layer on master structure, (c) transferring PDMS pattern to ITO substrate, (d) LC+prepolymer drop followed by assembling process, and (e) UV exposure and resultant PILC structure.

As shown in Fig. 5, the stamping method can provide roll process due to by its printability and continuity of fabrication processes. Recently, in order to achieve LC alignment control from both substrates, we combine the stamping method and micro contact printing method. By using this fabrication method we did not need to use LC and prepolymer mixture (Fig. 6). First we fabricate PDMS microstructures using stamping process. And then epoxy is spin coated on glass substrate and

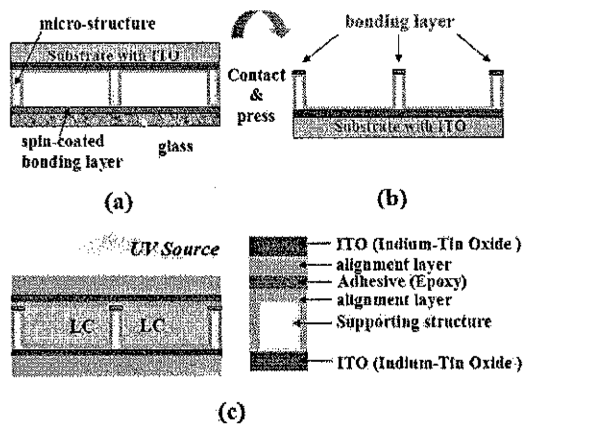


Fig. 6 Schematic diagram of combination process of stamping method and micro contact method; (a) and (b) contact bonding material with microstructure, (c) UV exposure and resultant structure of PILC mode.

then transferred to top side of PDMS microstructures by micro contact method. LC is dropped on PDMS and covered by the ITO substrate with alignment layer followed by UV exposure to solidify the UV epoxy which enhances the adhesion between two substrates.

3. CHARACTERISTICS of PILC MODE

After fabrication of PILC cell, we tested the mechanical stability of LC mode and electro optic responses as bending the plastic samples. We compared the results with normal plastic samples without PILC structure. We prepared a normal LC cell under the same fabrication condition except mixing with prepolymer. The cell gap was controlled by spacers. Fig 7(a) and 7(b) show polarizing microscopic textures of the normal and PILC cells in the presence of an external point pressure with a sharp tip, respectively. Under the same amount of pressure, the alignment texture of normal sample was severely distorted due to the cell gap variation. This means that spacers between tow substrates in the normal cell do not resist LC molecular reorientation induced by the pressure. The distortion of LC molecular propagates over a sufficiently large area as shown in figure and degrades the display quality.

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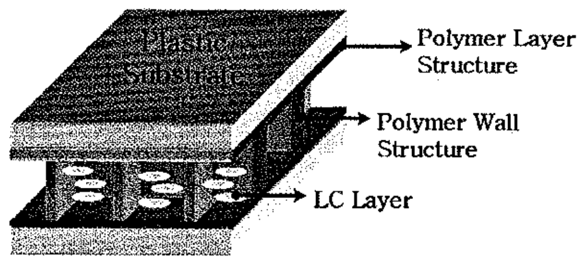

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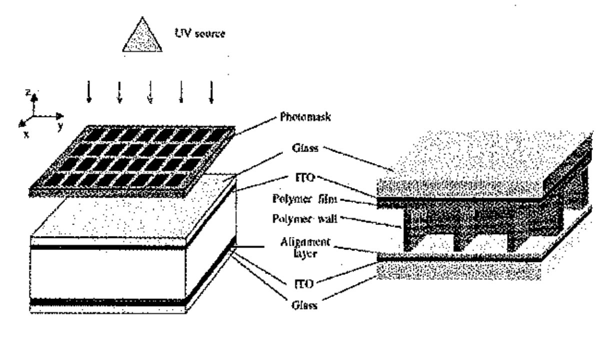

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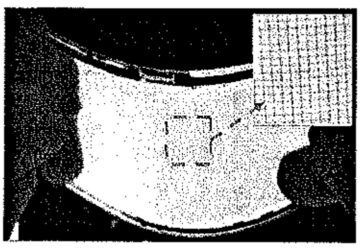

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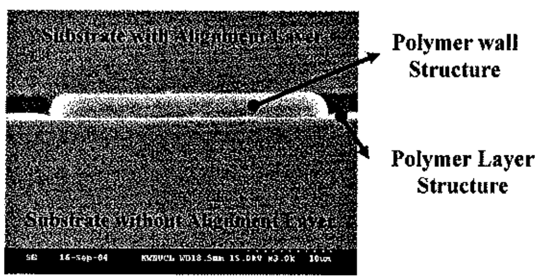

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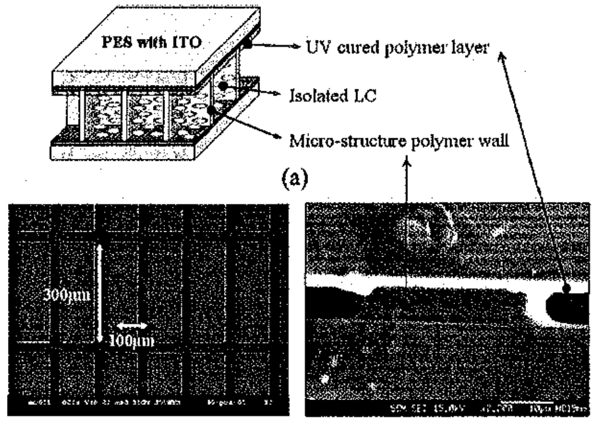

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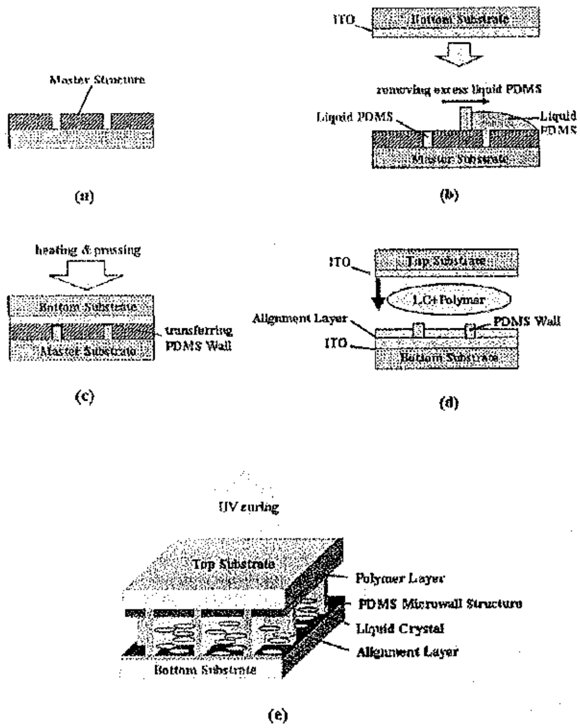

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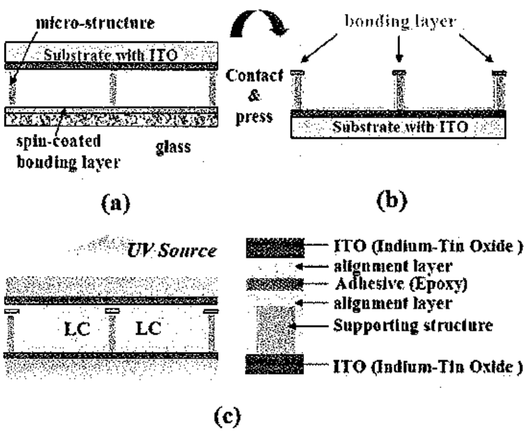

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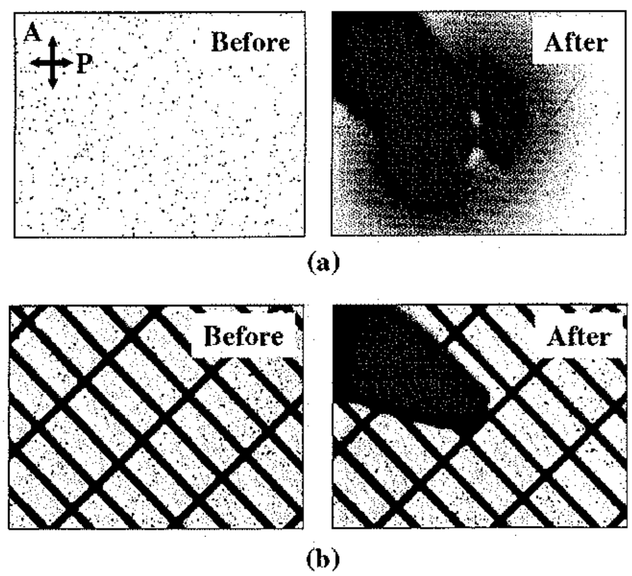

Fig. 7 Microscopic textures of normal plastic cell and PILC structure before and after point pressure on (a) normal cell and (b) PILC cell.

However, the PILC cell showed no appreciable changes since the LC molecular reorientation is restricted in pixels by the vertical polymer wall structure and can not propagate to other pixels. These polymer walls act as supporting structures to maintain the cell gap from external pressure and bending. The dispersed small dot in the figure are glass spacers.

To investigate how the above results affect the display qualities, we measured electro-optic properties of the normal and PILC cells under external bending.

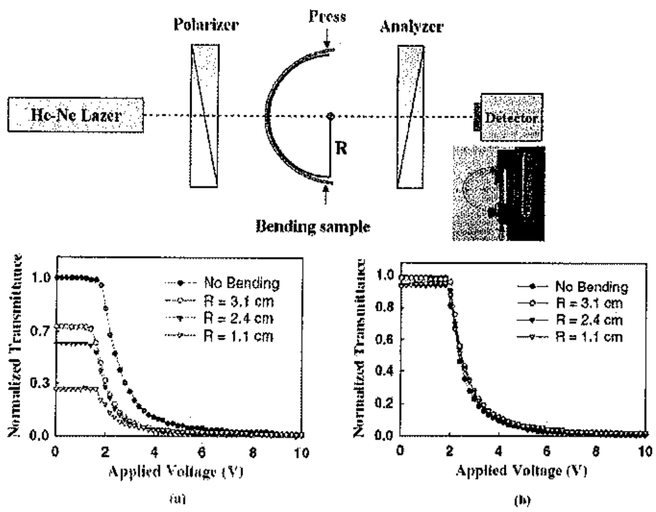

Fig. 8 Transmittance curves vs applied voltage (a) for normal cell and (b) for PILC cell at various bending states. (Upper schematic diagram shows experimental setup.)

We measured transmittance curves as function of applied voltage with various degrees of bending as shown in Fig. 8. The degree of bending is represented by the curvature of cell (*R*). For the normal plastic LC cell, as shown in Fig. 8(a), decreasing *R* decreases the transmittance at 0V which reflects significant change of cell gap. Whereas, PILC cell shows almost same V-T characteristics except for a minor decrease in the low voltage regime. It is clear that LC molecule's orientational distortion due to bending stress is effectively suppressed in the PILC structure with respect to normal plastic cell. Moreover, the PILC sample has no appreciable shift of the threshold voltage different from the polymer network or dispersed structures in which the threshold voltage increases as polymer concentration increases[7].

Figure 9 is prototype of 3 inch size of LC sample with PILC structure. The resolution is 124 × 76 with a pixel size of 500 × 500 μm^2 and polymer walls are well formed throughout the sample. The electrodes were patterned on the lower substrate. To make a full-color display device, red, green and blue color filters were formed on the upper substrate.

Fig. 9 Three inch size LC sample using plastic substrates with pixel-isolated liquid crystal structure.

4. CONCLUSION

We introduced the fabrication of PILC cell using plastic substrates. PILC mode can provide the mechanical stability against external stress. PILC mode also provide the stability of electro optic properties of LC display which can be used for displays with free form factor. Moreover our fabrication process can be easily applied to roll-to-roll process which can reduce the cost and tact time. Fig. 10 shows the schematic diagram of roll process using our fabrication method. We believe the pixel isolating structure is one of the promising technologies for solving the underlying problems in fabrication of flexible liquid crystal display and this technology can realize thin, light, rugged and robust plastic LCDs

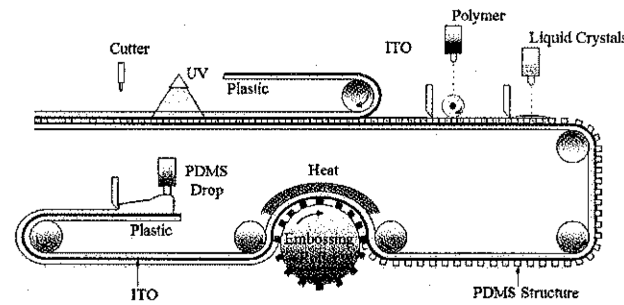

Fig. 10 Schematic diagram of the continuous roll processing for fabrication of flexible LCDs

5. ACKNOWLEDGEMENT

This work was supported by the Korea Research Foundation Grant Funded by the Korean Government (MOEHRD, Basic Research Promotion Fund).

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2008 Taiwan Display Conference

台灣顯示科技研討會

論文集

- 時　　間：97年6月11~12日(星期三、四)
- 地　　點：台北國際會議中心 102、101CD 會議廳
- 主辦單位：國際資訊顯示學會中華民國總會
  Society for information Display Taipei Chapter
  國立臺灣大學、工研院、國立交通大學

SID Taipei Chapter

工業技術研究院
Industrial Technology Research Institute

June 12, 2008, Thursday

Registration (outside of TICC Room 102)

V. Emerging TFT/Backplane Technology (9:00-11:45), TICC 102

Session Chairs: Yung-Hui Yeh (ITRI); In-Cha Hsieh (National Chung Hsing University)

9:00 **ZnO TFT for use in LCD**
Prof. Takashi Hirao, Kochi University of Technology, Japan

9:30 **Oxide TFT for Active Matrix Display**
Dr. Jang-Yeon Kwon, Samsung Advanced Institute of Technology, Korea

10:00 **Amorphous Oxide TFT Technologies and Modeling**
Dr. Hsing-Hung Hsieh, National Taiwan University, Dept. of EE

10:30 Coffee Break

10:45 **Develop Printable Solution Processes for Oxide Semiconductors**
Prof. Chih-Hung Chang, Oregon State University, USA

11:15 **Flexible Amorphous Si Thin-Film Transistors on an Engineered Parylene Template**
Prof. Dong-Sing Wuu, Vice Dean, college of engineering, National Chung-Hsing University

VI. SID 2008 paper review by SID-sponsored students, 11:45-12:30, TICC 102

12:30 lunch time

VII. LC/Flexible LCD (13:30-15:00), TICC 102

Session Chair: Wen-Jun Zheng (National Sun Yat-Sen University)

13:30 **Optoelectronic devices based on liquid crystals**
Prof. Andy Ying-Guey Fuh, Dean, college of science, National Cheng-Kung University

14:00 **Pixel-Isolated Liquid Crystal (PILC) Mode for Rugged Flexible LCDs**
Prof. Jae-Hoon Kim, Hanyang University, Korea

14:30 **Flexible Liquid Crystal Displays SIG**
Dr. Chi-Chang Liao, Manager, Industrial Technology Research Institute (ITRI)

15:00 Coffee Break

VIII. 3D Displays (15:20-16:20), TICC 102

Session Chair: Cheng-Huan Chen (National Tsing Hua University)

15:20 **Overview of Recent 2D-3D Convertible Displays**
Prof. Byoungho Lee, Seoul National University, Korea

15:50 **3D Display Technologies**
Chao-Hsu Tsai, Manager, Industrial Technology Research Institute (ITRI)

IX. Closing, 16:20, TICC 102