# Bending effect of flexible liquid crystal display

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## Abstract

*The effects of stress on the IZO/PC substrate and the electro-optical properties of a flexible LCD with micro-structure in bending were investigated. It showed that the IZO/PC substrate and the periodic cross spacers are good enough to be employed in the application of the ECB or polarization rotation LC mode.*

## 1. Introduction

Due to the lightness, robustness, thinness and flexibility, the flexible display has attracted a lot of attention. It can be rollable or bendable in application. It has great potential in the market to replace the flat panel display (FPD) product and to have implications for new designed product. So far, many prototype products have been demonstrated. The layers of display media include: liquid crystals (LC), organic light emitting materials, eletrowetting materials, liquid powder or electrophoretic materials. The flexible LC displays are the most promising since the technologies of liquid crystal display (LCD) have been well developed and the mature products have been sold for many years.

LCD with electrically controlled birefringence (ECB) or polarization rotation LC mode has a high contrast ratio (CR). These modes are the mainstream in the application of today's LCD product. However, more issues should be considered in the flexible display with these LC modes, for example, the variation of the birefringence of the substrate and the cell gap due to the bent applications. Most of the published work concerned focused on the behavior of transparent conducting film [1-3] to date.

In this work, we assembled a test cell with Indium Zinc Oxide (IZO)/ polycarbonate (PC) substrate and with periodic spacers to study its electro-optical property, transmittance vs. voltage (T-V) and response time, in different bent conditions. Besides the test cell, our studies also focus on the bending effect on the conducting layer and the birefringence of the substrate induced by the stress.

## 2. Preparation of Sample

The size of the test cell is 5 cm x 5 cm. The plastic substrates are PC (Teijin's SS120-B30 substrates, 125 μm) with IZO conducting film and functional layers coated on both sides. Both inner sides of substrates were covered with alignment layer (AL 60101, JSR). To promote the homeotropic alignment, the alignment layer was cured at temperature 180 °C for 1 hr. The cell contained the liquid crystal MLC 6882 (Merck). In order to resist the vertical and horizontal strain as the display is bent, the spacer of shape of cross was chosen. Periodic arrays of spacers were fabricated on the plastic substrate by the photolithography, as shown in Fig. 1. The width is 10 μm and both of lengths in horizontal and in vertical direction are170 μm. Pitch is 261 μm in vertical and in horizontal direction. The PC substrates used in this work have a high Tg. It can stand the high temperature in the process.

## 3. Measurement

To measure the birefringence of IZO/PC substrate, the sample was arranged between a pair of crossed polarizers and a beam of red He-Ne laser passing through them was detected. Then we tried to find out the maximum output light intensity as the sample was rotated about the axis parallel to the beam of light. The birefringence can be obtained from the following equation:

$$\Delta n = \frac{\lambda}{\pi d}\sin^{-1}(\sqrt{T}) \quad (1)$$

Where d is the thickness of the sample and T is the maximum transmittance of light. The measured maximum transmittance should be revised in consideration of the transmittance of the sample and the polarizers. The birefringence of substrate was also measured under bending condition.

Resistance of IZO/PC substrate was measured in situ by using Keithley 2010 multimeter directly, and a LabVIEW program controlled bending machine and acquired data synchronously. The arrangement was shown in Fig. 2. The resistances of IZO under different bending conditions were measured. The size of PC/IZO substrate is 30 cm x 7 cm.

To measure the electro-optical property of the test cell, the test cell was wrapped around PE cylinders with five different curvature of radius, 2.5, 5, 7.5, 12.5 and plane. A square wave voltage at the frequency of 1 kHz was applied to it to measure the T-V curve and response time. The measurements of electro-optical property were carried out using a light source of a red He-Ne laser and data acquisition system controlled by LabVIEW.

## 4. Result

The result of the birefringence Δnd of IZO/PC substrate is shown in table 1. Δnd is about 2~3 nm in plane condition. As the substrate is bent in the diameter of 3 cm, Δnd increases to 7~8 nm. The resistance vs. bending diameter is shown in Fig. 3. The change is less than 0.1% under compressive and tensile stress, respectively.

Fig. 4 shows the T-V curve of the test cell in different diameters. The shape of the curve indicates that the practical cell gap is larger than the optimum one. There is no horizontal shift between these curves. It implicates that the cell gap is almost the same. The curves almost coincide in the bent condition, and the transmittance of the one in the plane condition is a little difference with them. It may come from the angle inaccuracy between the polarizer axis and the optics axis of the test cell. The response times of test cell in different diameters are range from 17.57~18.26 ms. The variation is less than 4%. It also confirms that there is no significant variation in the cell gap.

## 5. Summary

The resistance variation and the birefringence of the commercial PC/IZO substrate in the bent condition are small enough to be employed in the application of the ECB or polarization rotation LC mode. For the application of curved display, the periodic spacers of cross shape are good enough to maintain the cell gap and a stable electro-optical performance. We will study the cell gap variation of the flexible LCD with periodic spacers of different dimensions and shapes in different bent conditions to figure out the optimum specification of the spacers in the future.

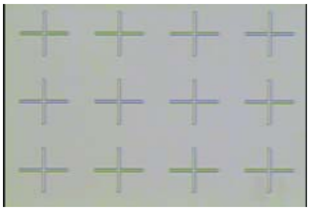

**Figure 1 The picture of spacers was observed by the microscope. The width is 10 μm and lengths in horizontal and vertical direction are 170 μm. Pitch is 261 μm in vertical and horizontal direction**

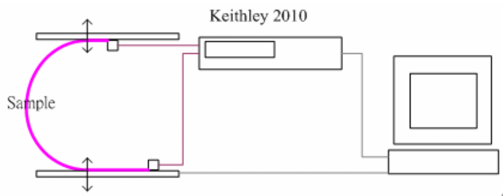


**Figure 2 The set-up of resistance measurement under bending condition**

**Table 1 Δnd in plane and curved condition**

| sample | Sample1 Δnd (nm) | Sample2 Δnd (nm) |
|---|---|---|
| plane | 2.47 | 2.94 |
| Bending at diameter of 3 cm | 7.39 | 7.94 |

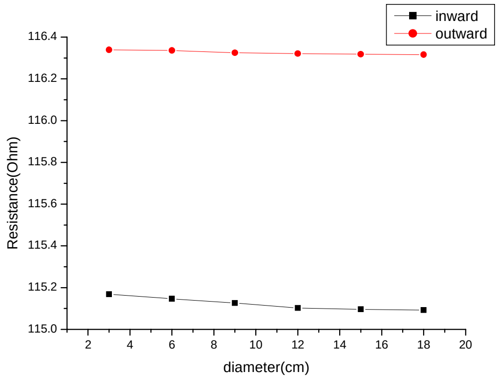


**Figure 3 The resistance under bending condition**

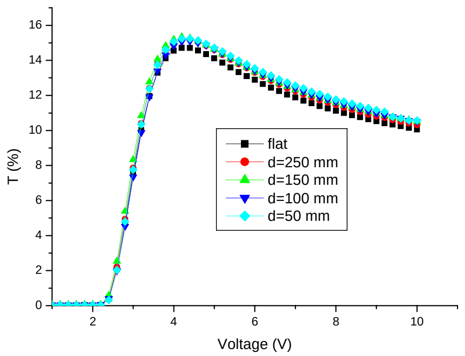


**Figure 4 T-Vcurve in different diameters**

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## References

[1] Cairns, D.R., Whitte II, R.P., Spacerin, D.K., Sachsmann, S.M., Pain, D.C. and Crawford, G..P., Appl. Phys. Lett. **76**, pp. 1425-1427(2000)
[2] Piet C.P. Bouten, 17-5 Eurodisplay (2002)
[3] S. K. Park, J. I. Han, D. G. Moon, and W. K. Kim, Jpn. J. Appl. Phys. **42,** pp. 623-629 (2003)