

Development of 2-inch Plastic Film STN LCD

Sung Kyu Park, *Member*, Jeong In Han, *Member*, Won Keun Kim, *Member* and Min Gi Kwak

Abstract

Due to distinct properties of plastic substrates such as poor thermal resistance, non-rigidness and high thermal expansion, it is difficult to fabricate plastic film LCDs by conventional LCD processes. Poor thermal resistance and high thermal expansion of substrates induced deformation of substrates surface, mismatch of thermal expansion between ITO electrodes and substrates resulted in defects in the ITO electrodes during the high temperature process. Defects of ITO electrodes and non-uniform cell gap caused by non-rigid and flexible properties were also observed in the pressuring process. Based on in these observations, we used a newly developed material and fabrication process to prevent deformation of substrates, defects of electrodes and to maintain uniform cell gap. The maximum temperature of the process is limited up to 110℃ and pressure loaded during the process is five times less than conventional one. With these invented processes and materials, we obtained highly reliable Plastic Film STN LCDs whose electro-optical characteristics are better than or equivalent to those of typical glass LCDs.

Keywords : Plastic film STN LCD, cell gap, plastic substrates, low temperature process

1. Introduction

The major trend in the electronics display today is to make products more portable by making them smarter, lighter and thinner. One of the essential technologies for this kind of products is a plastic-based display. The potential advantages of using plastic substrates include lighter weight, thinner displays, and reduced incidence of breakage. Also, the plastic substrates enable a new product concept such as curved or flexible displays and have advantages of greater flexibility, reduced sensitivity to flaws and defects compared to glass substrates. However, plastic substrates have considerably poor thermal, mechanical properties, unreproducible shrinkage and relatively high electrical resistance to be applied to large area and more fine graphic display. Because of these different characteristics to glass substrates, it is recognized that modifications of materials, substrates handling practices and processes are necessary to produce plastic film LCDs.

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S. K. Park, J. I. Han, W. K. Kim and M. G. Kwak a re with the Display team, Korea Electronics Technology Institute, Pyungtak, kyunggi 451 - 860, Korea. **E-mail** : skpark@nuri.keti.re.kr **Tel** : +31 610-4085 **Fax** : +31 610-4126

2. Plastic Substrates

2.1 Deposition of indium tin oxide on the plastic substrates

The excellent electrical resistance, optical transmittance and etching characteristics of indium tin oxide (ITO) thin films(1000±100Å) were obtained by depositing on a plastic substrate with a rf-magnetron sputtering. The materials of substrates are polycarbonate(PC) and polyethersulfone(PES) which have gas barrier layer and anti glare coating for Plastic Film LCD. The transmittance spectrum of the ITO films was measured for all samples and bare substrates in the range between 320nm and 1200nm wavelength. The reference used was air, so the data presented in this experiment shows the transmittance of ITO films including the bare substrates. Figure 1 shows the optical transmittance of ITO films deposited on the PES substrates with various oxygen contents. The transmittance of bare substrates was shown for comparison. As shown this figure, bare substrates has transmittance of above 90% in the visible ranges and also, all the ITO samples show about 75~80% in the range of 450~800nm. It is a well known fact that there exist a direct relation between the optical transmittance and the band gap of ITO films. Generally, band gap of ITO films is greater than 3.75 eV even though a range of values from 3.5 to 4.5 eV have also been reported in the literature [1]. The fundamental absorption edge generally lies in the vicinity of ultraviolet region of the visible spectrum and shifts to the shorter wavelength with decreasing carrier concentration. This is because the band gap exhibits an N2/3 dependence due to the Moss-Burstein shift [1-2]. In this experiment, the decrease of carrier concentration was induced by flow of oxygen content resulting in increasing of transmittance and decreasing of sheet resistance. In addition, the increase of transmittance with oxygen content was shown dramatically in the short wavelength range.

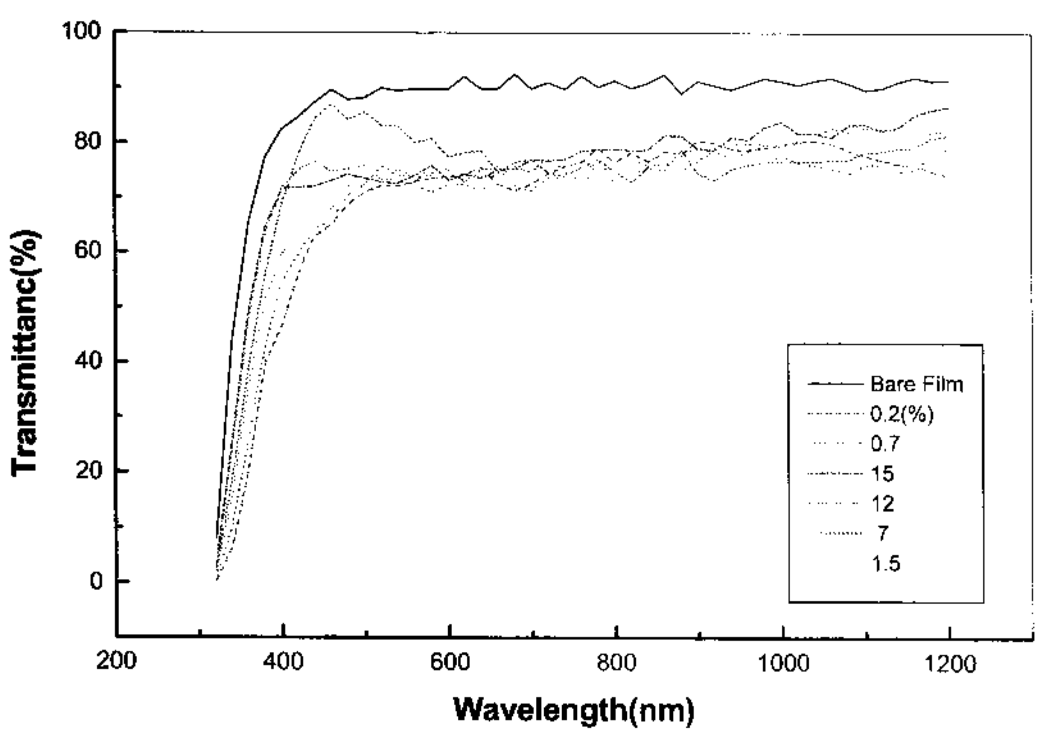


Fig. 1. Dependence of oxygen conten ts on the transmittance

2.2 Characteristics of plastic substrates

Thermal expansion is a distinct property from glass substrates. The coefficients of thermal expansion for PES(44ppm/K) and PC(37ppm/K) are one magnitude higher than that of glass or ITO material [3]. It means that as temperature increase, polymer substrates stretches in all directions at the speed of 37~44 x 10^{-6}m/s. Thermal process on this high elongation substrates is subjected to a tensile force, multiple cracks emerge in the cell fabrication process perpendicular to the direction of the stretching force. Another problem is that, the stretching speed of substrates is too fast for ITO films to catch up with it. This mismatch of thermal expansion can also cause stress of ITO electrode and thus, inducing multiple cracks of these electrodes when temperature increases or decreases. However, it also a well known fact that by decreasing the heating slope, the thermal strains could be reduced significantly, resulting the decrease of thermal expansion from the Hook's law and Poisson's ratio [4]. In addition to thermal properties, it is essential that substrates have to resist various chemical solutions utilized in LCD process. We routinely tested this for organic solvents and acids frequently used in LCD process. Table 1 shows chemical stability of plastic substrates. The mechanical properties of plastic and glass substrates are different and this difference shows the advantages of using plastic substrates in portable display devices. Plastic substrates are less brittle, more flexible and lighter than glass. On the contrary, flexibility can cause some problems in maintaining cell gap, chip bonding process and so forth.

TABLE 1. Chemical stability of plastic substrates

5% HCL	Stable
5% NaOH	Stable
Isopropyl alcohol	Stable
Acetone	Stable
NMP	Stable
Distilled water	Stable
γ-Butyrolactone	Stable

3. Fabrication of Plastic Film LCD Module

3.1 Fabrications of cell

Figure 2 shows the cross-sectional view of a Plastic Film FSTN LCD developed by KETI. The transflective cell is composed of a transmissive polarizer with a compensation film on a top substrate and a transflective polarizer on the bottom substrate. As the material of substrates, we used 100μm thin PC substrate coated with a 1000-1100Å ITO layer showing 30nm optical retardation at 550nm. As described above, the surface of plastic substrates is non-uniform and non-rigidness. It is very important to maintain flatness of the substrates surface. Because most fabrication processes need to fix the substrates on a stage with vacuum press, conventional

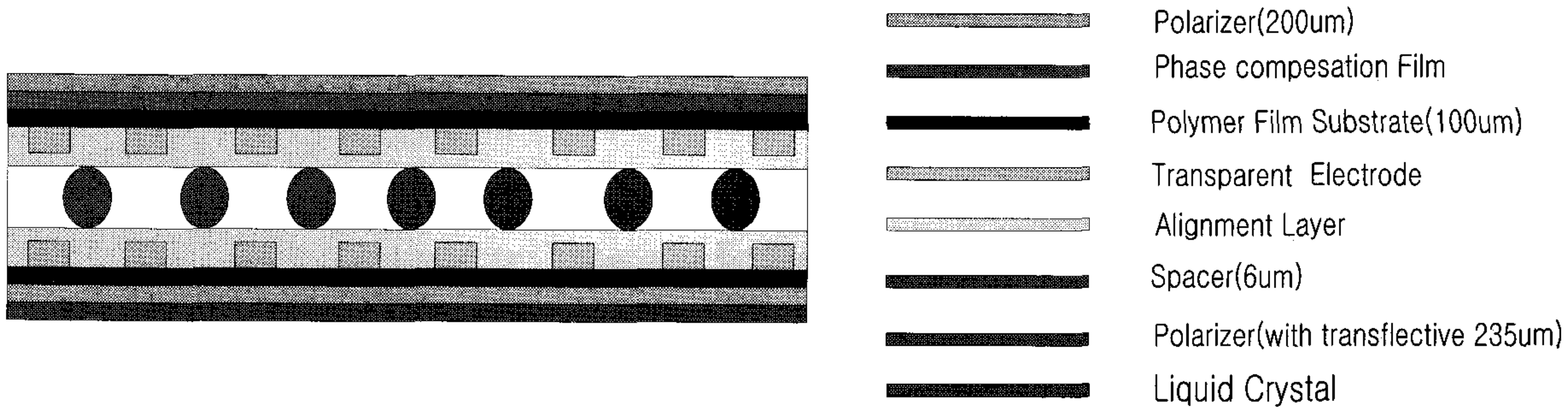


Fig. 2. Cross-sectional view of a Plastic Film FSTN LCD

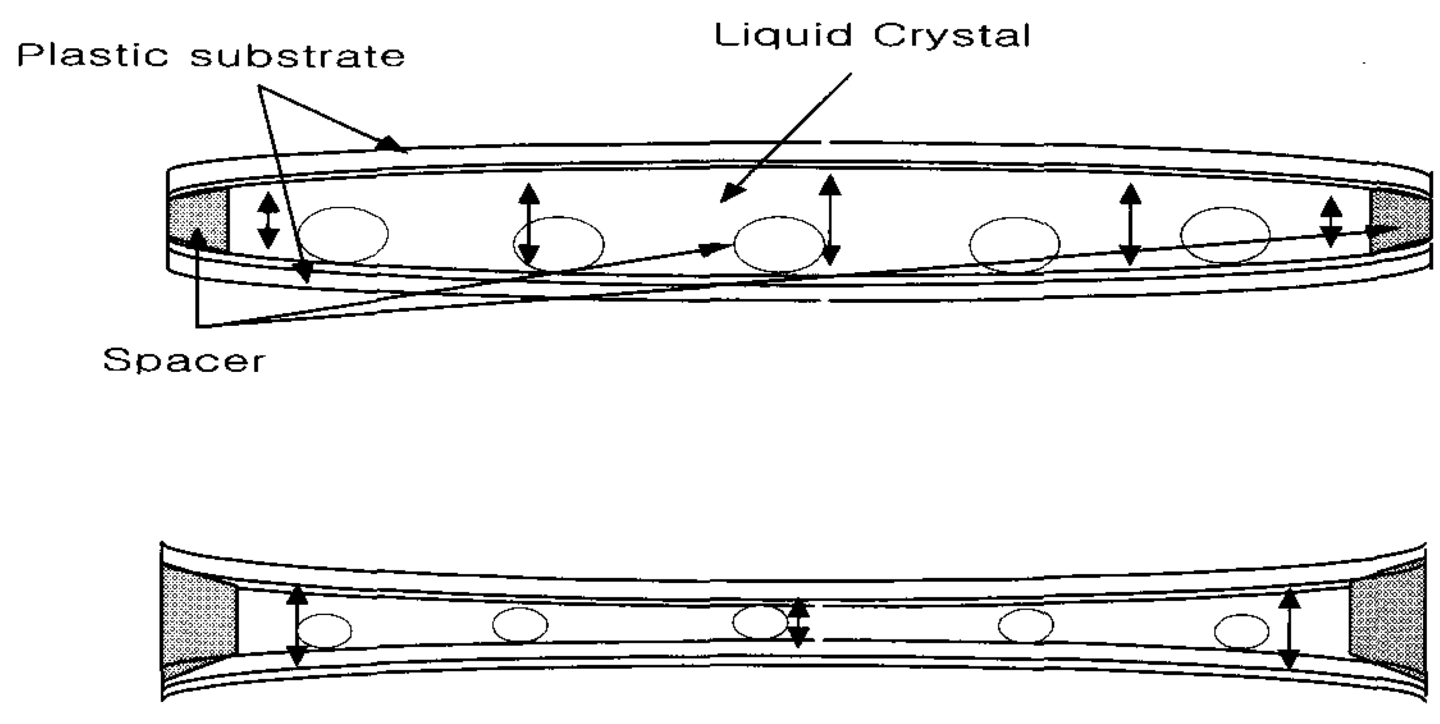


Fig. 3. The problems caused by flexibility of plastic substrates.

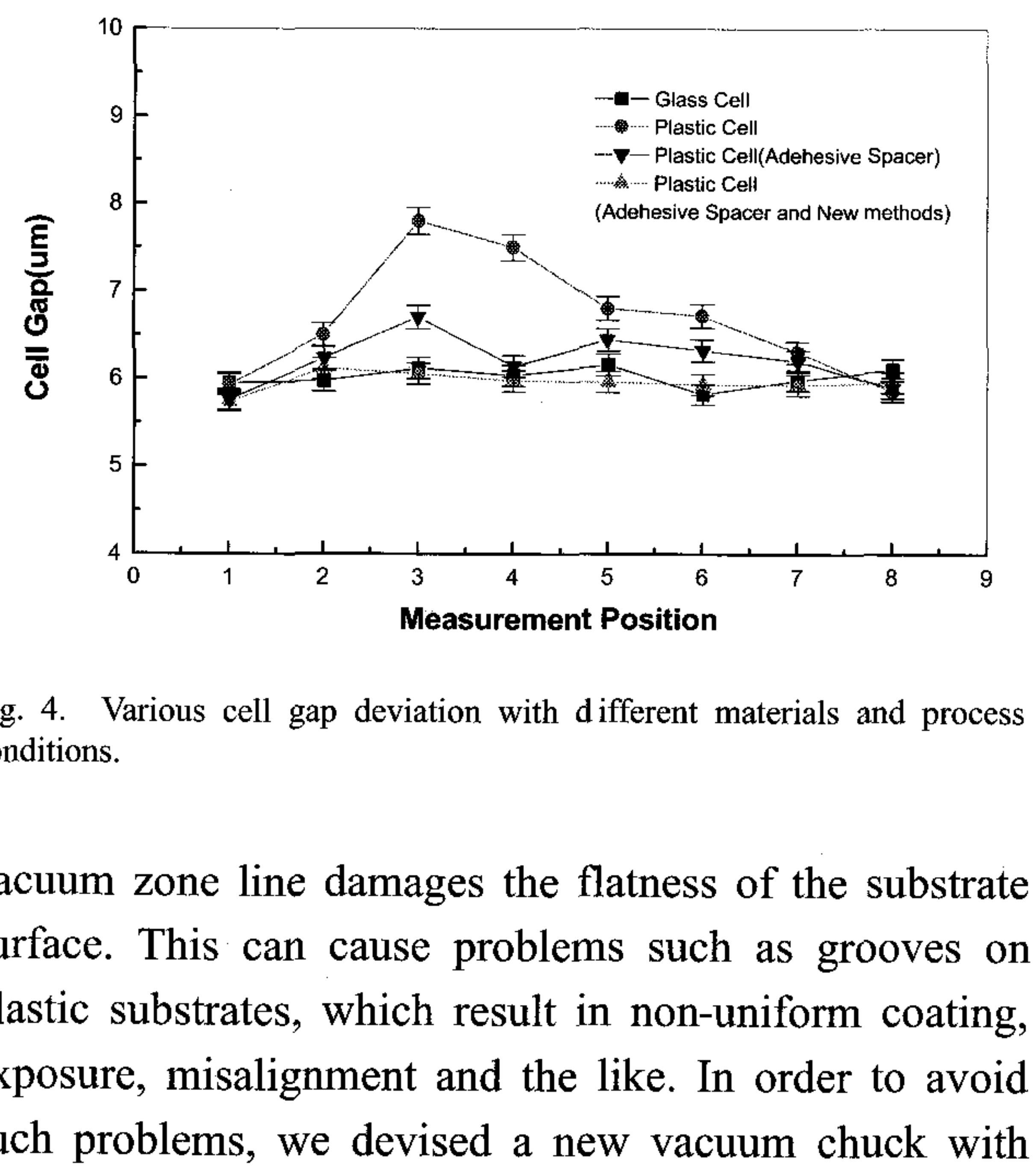


Fig. 4. Various cell gap deviation with different materials and process conditions.

vacuum zone line damages the flatness of the substrate surface. This can cause problems such as grooves on plastic substrates, which result in non-uniform coating, exposure, misalignment and the like. In order to avoid such problems, we devised a new vacuum chuck with many micro vacuum holes and used it in all the processes. The ITO electrode was patterned by photolithography process, alignment layer was printed by flexographic printing and the printed polyimide was cured in an oven at a temperature of below 110°C. Rubbing was done with a velvet coated roller.

3.2 Cell gap control

Due to the non-flatness and flexible properties of plastic substrates, it is difficult to make displays with a uniform cell gap using conventional vacuum filling method. Non-flatness and flexible properties of plastic substrates may form a vacant area in the cell and spacers lying in this area flow to the edge of the cell during a filling process [5]-[6]. So, the areas without spacers have different cell gaps, as shown in Fig. 3, and thus it bring about considerable color difference. To overcome this problem, spacers are immobile to maintain uniform cell gap during the filling process. The spacers coated with resin cured at 100°C was adopted in this process and we have developed a specific pressing and filling methods, which use flat and transparent substrates as support. The evidence of difference in cell gap was obtained by measuring capacitance of a cell with patterned test electrodes. In the case of glass substrates, the difference of cell gap was about 0.1-0.3μm. However, in plastic substrates, it was 1.5-2μm with conventional method, 0.5 -0.7μm with adhesive spacers and 0.2-0.4μm with a new method and adhesive spacers. Figure 4 shows these experimental results. With this new method and materials, we could achieve a uniform cell gap similar to that of a glass cell. The uniform cell gap was maintained after ±20° bending test. It was considered that the pressure loaded in the process make the spacers to get stuck in the cell. Therefore, even the bending strength does not distract the spacers [7], [9]. As described above, another main problem of plastic substrates is low thermal resistance. This flaw is a critical factor in the process of main sealing and curing of an alignment layer. To solve these problems, we used the materials with low temperature curing state and adjusted duration time and decreasing slops of temperature.

3.3 Chip bonding

The last process of a Plastic Film LCD Module is the interconnection of a Plastic Film LCD to a driving circuit. Figure 5 demonstrates that transflective type Plastic Film STN LCD modules developed in this work. The conduction failure of interconnection of the two resulted from non-rigidness, low thermal resistance and high thermal expansion of plastic substrates [8]. Penetration of conductive particles into ITO electrode due to non-rigidness of substrates reduces the contact area and increases contact resistance. This is regarded as the main reason for the conduction failure and depicted in Fig. 6. Figure 6(a) shows high deformation of conductive particles on the glass substrates enlarging the contact areas. Fig. 6(b) shows penetration of conductive particle into ITO electrode. This increase of contact resistance in the worst case resulted in open circuit. Therefore, we used more elastic conductive particles made by a kind of polymer materials coated with Ni and Au. Conductive particles with elasticity similar to the plastic substrates did not damage an ITO electrode on plastic substrates, and low temperature and pressure with stepped process also did not deform the surface of plastic substrates which bring about reduction of thermal expansion rates. To realize reliable interconnection between Plastic Film LCDs panel and a driving circuit, we used stepped heating and pressure process with ACFs developed for Plastic Film LCDs. Figure 7 shows connection resistance of the joint area with these new methods and materials. Therefore, highly reliable interconnection with minimum contact resistance was accomplished.

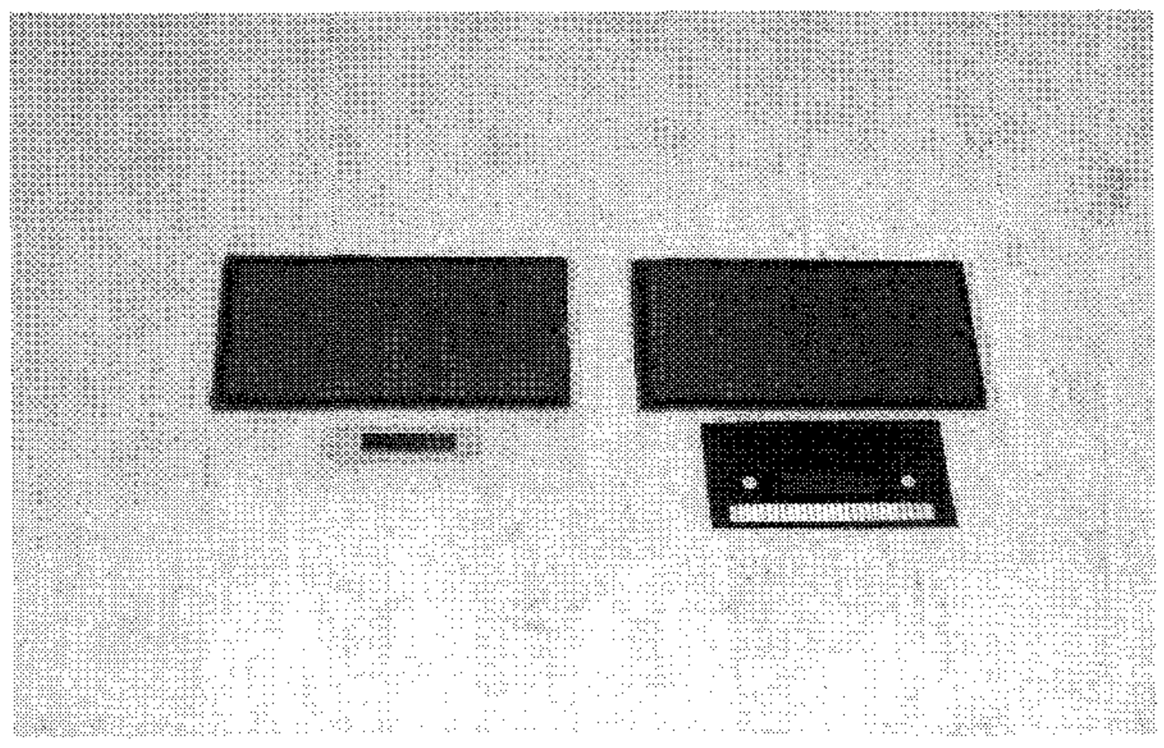
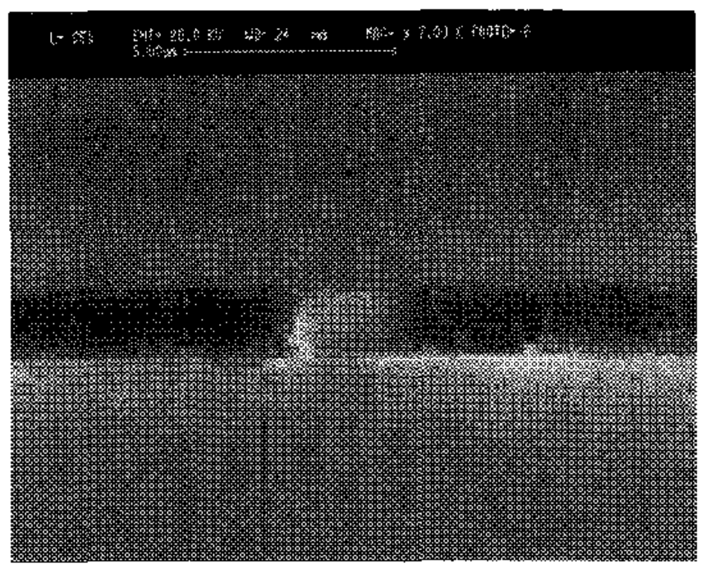
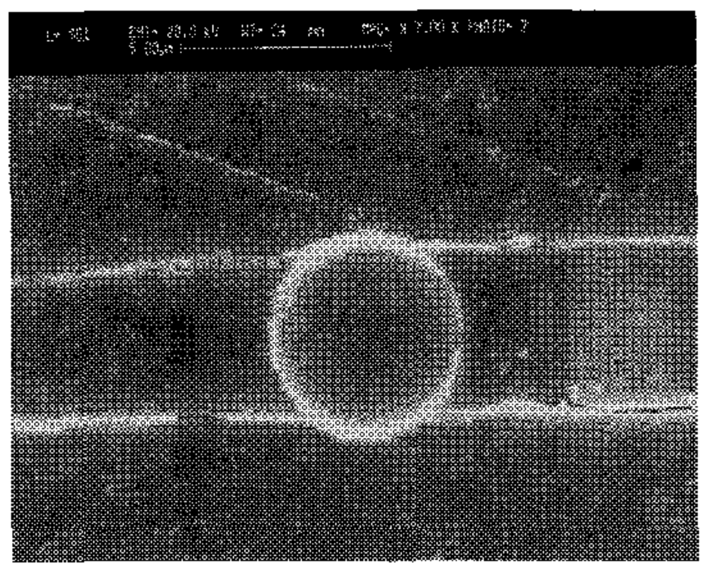


Fig. 5. Plastic Film STN LCD Modules.



(a)



(b)

Fig. 6. SEM pictures of joint structure configuration for glass and plastic substrates.

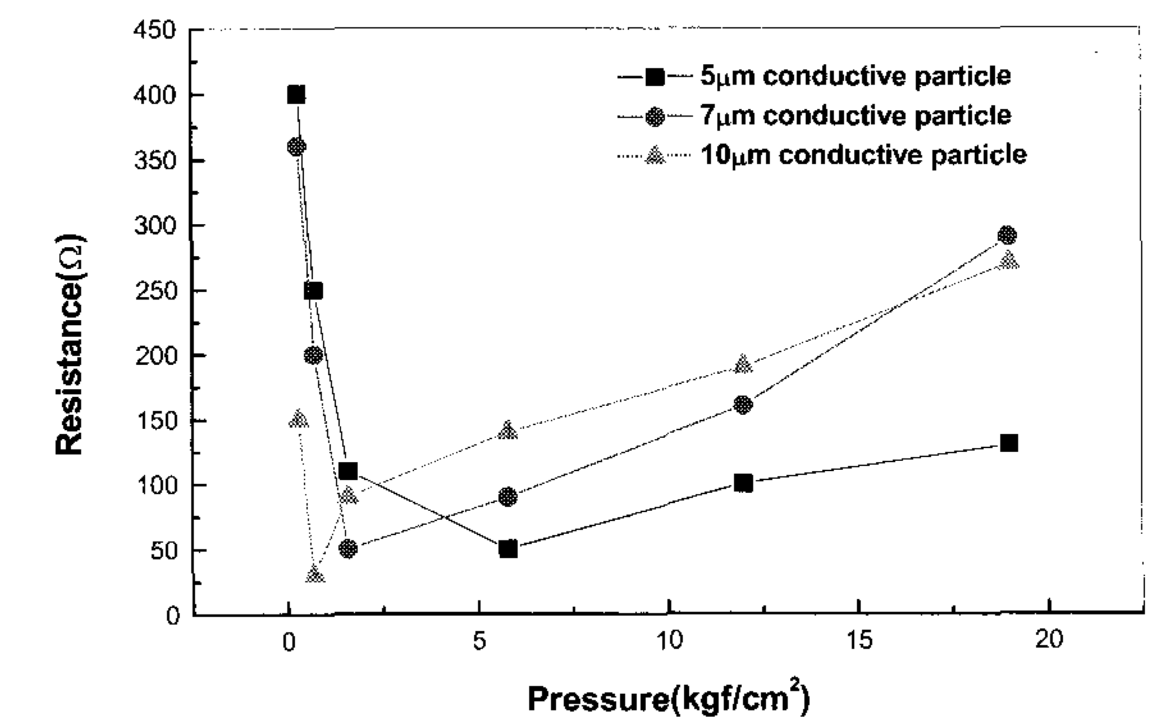
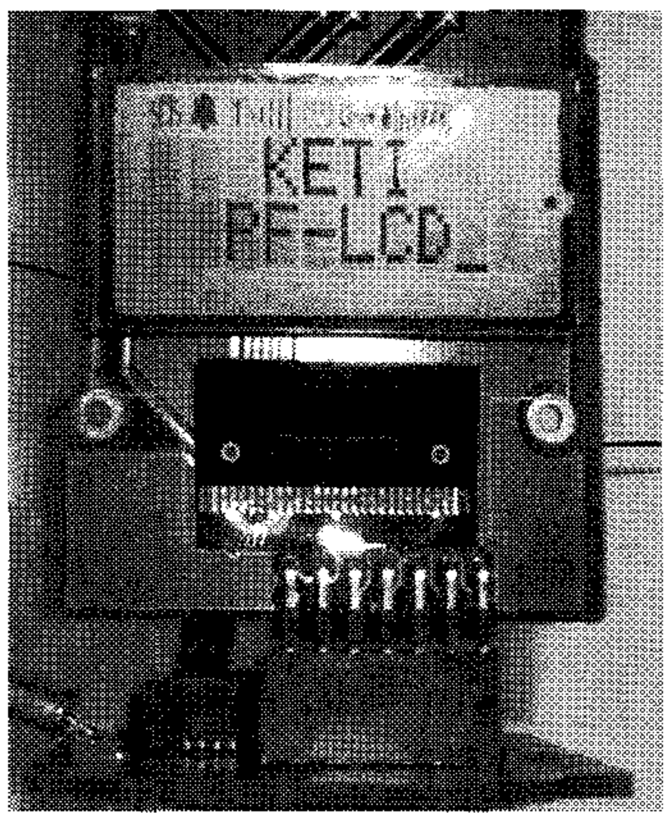


Fig. 7. Dependence of stepped loaded pressure and particle size on a connection resistance



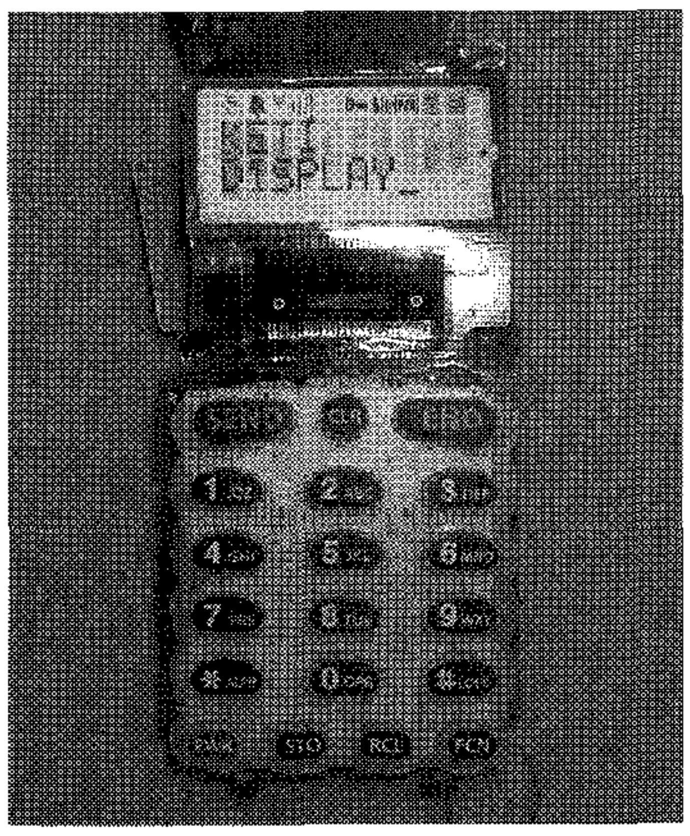


Fig. 8. Operation of 2-inch Plastic Film LCDs developed with new methods.

4. Electro-optical Characteristics and Reliable Test of Plastic Film LCD Module

Electro-optical characteristics of Plastic Film LCDs were measured by measurement equipment of LCD characteristics. They are better than or equivalent to those of typical glass LCDs. Response time is less than 200ms, contrast ratio is higher than 8:1 in reflective mode and viewing angle is wider than ±60°. Reliability test was accomplished in the environment and bending. Modes of environment test were thermal shocks test, high and low temperature storage. The items and conditions were shown in Table 3. Bending test was accomplished with a bending test machine [9]. The reproducible bending angle is more than ±20° in vertical direction. After these tests, there is no problem in the operation and external appearance of Plastic Film LCDs. Table 2 shows the specification of Plastic Film LCDs developed from this research. Figure 8 shows reliable operation of 2-inch Plastic Film LCDs developed through this research.

5. Conclusion

We have demonstrated Plastic Film STN LCD technology that includes a new process method, materials and newly developed vacuum chuck. The important issues of these processes include low temperature stepped process and new methods to overcome flexibility and non-flatness of plastic substrates. The electro-optical characteristics of Plastic Film LCD were better than or very similar to those of glass LCD even though its thickness was about one third and its weight about one fifth. Considering its unique characteristics, Plastic Film LCD is expected to be a strong candidate in display applications for hand-held electronic devices in respect to weight and thickness.

TABLE 2. Specification of Plastic Film FSTN LCD

Item	Feature	Item	Feature
Size	39 x 23.8mm	Viewing Area	35 x 7.1mm
Duty Ratio	1/18 Duty 1/5 Bias	Dot Size	0.53 x .64mm
Active Area	T.B.D	Maximum Process Temp.	110°C
Dot Pitch	0.53 x 0.64mm	Operation Voltage	2.4 –3.6V
Thickness	0.6 – 0.7mm	Type	Transflective
Weight	0.6g	Contrast Ratio	> 8:1
Mode	NW	Response Time	< 200ms

TABLE 3. Reliability test items and conditions.

Items	Test condition	Duration
Thermal shock test	-20°C ~ 80°C 30 / 30 min.	100 cycles
High temperature storage	80°C 40% RH	500h
Low temperature storage	-20 °C 20% RH	500h

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