Flexible Display ; Low Temperature Processes for Plastic LCDs

Jeong In Han

Abstract

Flexible displays such as plastic based LCDs and organic light-emitting diodes for mobile communication devices have been researched and developed at KETI in KOREA since 1997. The plastic film substrate has so poor thermal tolerance and non-rigidness that the fabrication of active devices and panel assembly have to perform at low temperature and pressure. In addition, high thermal expansion of the substrate is also a serious problem for reliable metallic film deposition. In this paper, we investigated particularly on the fundamental characteristics of various plastic substrates and then, suggested novel methods that improve the fabrication processes of plastic LCD panel. In order to maintain stable substrate surface and uniform cell gap during panel assembly, we utilized newly-invented jig and vacuum chuck. Electro-optical characteristics of fabricated plastic LCD are better than or equivalent to those of typical glass based LCDs though it is thinner, lighter-weight, and more robust.

1.Introduction[1)]

There is an increasing demand for displays based on plastic substrates instead of glass substrate. The potential advantages of using plastic substrates include lighter weight, thinner displays, and reduced incidence of breakage. As well, the use of plastic substrates will enable a new product concept such as curved or flexible displays. The advantages of plastic substrates compared to glass substrates are greater flexibility and reduced sensitivity to flaws and defects. However, plastic substrates have considerably low thermal tolerance, unreproducible shrinkage and relatively high electrical resistance to be applied to large area and more fine graphic display. Because of the difference in characteristics between plastic and glass substrates it is recognized that modifications of materials, substrate handling practices and processes used in LCD fabrication, will be necessary to produce Plastic LCDs.

Information Display Research Center,
Korea Electronics Technology Institute,
Pyungtaek, Kyunggi. 451-860, Korea

2. Plastic film substrates

2.1 Deposition of Indium Tin Oxide on the plastic film substrate

The excellent electrical resistance, optical transmittance and etching characteristics of indium tin oxide (ITO) thin films were obtained by deposition on a plastic film substrate with a rf-magnetron sputtering. The materials of substrates are polycarbonate and polyethersulfone which have gas barrier layer and anti glare coating for Plastic Film LCD. Electrical resistance varies from 15/sq. to 30/sq. Electrical resistance of ITO films on the plastic film substrate is more sensitive to oxygen contents than other conditions. Transmittance is higher than 75-80% in the visible range. It is similar to that of ITO glass. Annealing and substrate temperature affect mainly on a etching rate and transmittance at short wavelength range. Wet etching rate was improved in the vacuum annealing at 180℃ and 120℃ in polyethersulfone and polycarbonate substrate respectively. In these experiments, optimum properties of Plastic film substrate are obtained under *0.2% oxygen contents,* vacuum annealing and substrate temperature at 180℃ for polyethersulfone material (at 120℃ for polycarbonate material).

2.2 Characteristics of plastic film substrates

To use plastic film substrates in STN LCD, optical properties, thermal properties and mechanical properties must be considered. Because STN LCD utilizes optical birefringent phenomenon,

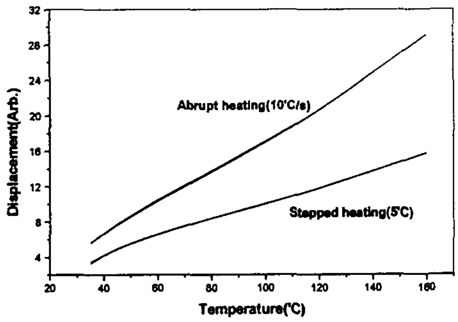

Fig.1 Relationship between thermal displacement

the substrates are required to beoptically isotropic or low optical retardation and high transmission. Thermal properties of plastic film substrates are critical because high temperature is applied in a conventional LCD process deforms and distorts a substrate surface. These processes can cause considerable problems in plastic film substrates such as substrate shrinkage and crack in ITO films due to the differences of thermal displacements between plastic material and ITO film. Fig.1 shows these differences of thermal displacements between abrupt heating and stepped heating. It was accomplished by a dilatometer with measuring a displacement of z-axis in the substrates. The differences of them between ITO film and polymer materials induced distortion of substrates and stress on the ITO film. As shown in Fig.1, thermal displacements could be reduced by stepped heating process. The displacements of substrates with relatively abrupt heating show slopes as steep as twice compared to those of stepped heating substrates. The low thermal displacement induced the lower stress of ITO films on the substrates.

In addition to thermal resistance, it is essential that substrates have to resist variety of chemical solutions utilized in LCD process. We routinely tested it for organic solvents and acids frequently used in LCD process. Table 1 shows chemical stability of plastic film substrates. The mechanical properties of plastic and glass substrates are different and these differences underlie the advantages of using plastic film substrates in portable display devices. Plastic film substrates are less brittle, more flexible and lighter than glass. On the contrary, flexibility can causes some problems in maintaining cell gap, chip bonding process and others.

Table 1. Chemical stability of plastic film substrates

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

3. Fabrication of Plastic Film LCD Module

3.1 Fabrications of cell

Fig. 2 shows the cross-sectional view of a Plastic Film FSTN LCD developed by KETI. It is a transflective cell with a transmissive polarizer, a compensation film on a top substrate and a transflective polarizer on the bottom substrate. As substrate material we use 100 ㎛ thin polycarbonate substrate coated with a 100 nm ITO

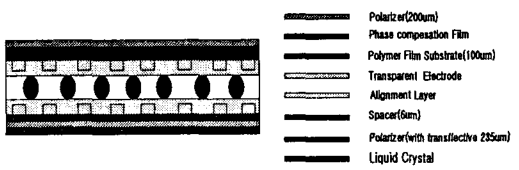

Fig.2 Cross-sectional view of a Plastic Film FSTN

layer showing 30 nm optical retardation at 550 nm. As described above, the surface of plastic film substrates is non-uniform and non-rigidness. It is very important to maintain flatness of the substrate surface. Because most fabrication processes need to fix the substrate on a stage with vacuum press, conventional vacuum zone line damages the flatness of the substrate surface. It can cause problems such as grooves on plastic film substrate, so result in non-uniform coating, exposure and rubbing etc. In order to avoid these problems, we devised a new vacuum chuck with many micro vacuum holes and used it in all the process. 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 temperature below 110℃. Rubbing was done with a velvet coated roller. Because plastic film substrates have more electro-static force than glass substrates, we expected higher pre-tilt angle than that of glass substrates could be obtained at the same conditions. Fig. 4 shows influence of substrates material

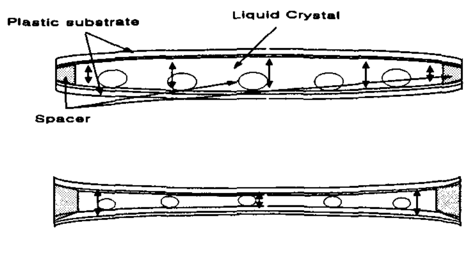

Fig.3 The problems caused by flexibility of plastic film substrate

and number of rubbings on the pre-tilt angle. In this experiments, we obtained higher pre-tilt angle for plastic film substrates than for glass substrates by 1-2 degree at same conditions.

3.2 Cell gap control

Due to the non-flatness and non-rigidness of plastic film substrates, Plastic Film LCD required spacers more immobile in order to maintain uniform cell gap and high mechanical stability. The spacers coated with resin was adopted in this process and cured at 100℃. Also due to the same characteristics of plastic film substrates, it is difficult to make displays have a uniform cell gap by a conventional vacuum filling method. Non-flatness and flexibility of plastic film substrates form a vacant area in the cell and spacers lied in this area flow to the edge of the cell after filling process. So, the areas without spacers have different cell gaps as shown in Fig. 3, and it results in considerable color difference. To overcome this problem, we have developed a pressing and filling methods, which use two flat and transparent substrates as a support. These two supports fix plastic film substrates using surface tension power of water or glycerin lied in between a support and plastic film substrate. We used a glass substrate as a support and this method was adopted to measure the pre-tilt angle and others. The evidence of difference of cell gap was obtained by measuring capacitance of a cell with patterned test electrodes. In glass substrates, the difference of cell gap was about 0.1-0.3m for plastic film substrates. It was 1.5-2 ㎛ with

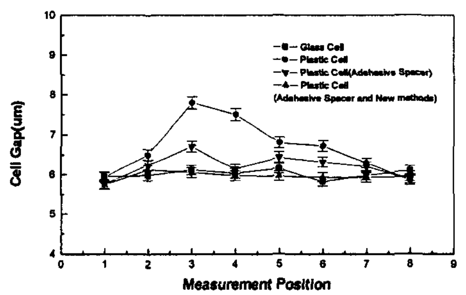

Fig.4 A cell gap measurements

conventional method and the cell gap difference was 0.5 -0.7 ㎛ with adhesive spacers and 0.2-0.4 ㎛ with a new method and adhesive spacers. Fig.4 shows these experimental results. With this new method, we could achieve an uniform cell gap similar to that of a glass

cell. The uniform cell gap was maintained after 20 bending test. It was accomplished by a bending test machine with down head. From maintaining of cell gap even bending, it was considered that the pressure loaded in the process of hot press make the spacers be stuck in the cell. So, even bending strength could not distract the spacers.

3.3 Chip bonding

The last process of a Plastic Film LCD Module is interconnection of a Plastic Film LCD to a driving circuit. Our Plastic Film LCD was connected with a driving circuit board by thermally activated ACFs included more elastic conductive particles that developed for Plastic Film LCD. Fig 5 demonstrates that transflective type Plastic Film STN LCD developed in this work. A new technology realizing interconnection between Plastic Film LCDs panel and a driving circuit was developed under the new stepped processing condition of low temperature and pressure with ACFs developed for Plastic Film LCDs. Fig.8 shows connection resistance of these new methods and materials. The conduction failure of interconnection of the two resulted from elasticity, low thermal resistance and high thermal expansion of plastic film substrates. Penetration of conductive particles into ITO electrode reduces the contact area and increases contact resistance. This increase of contact resistance in the worst case resulted in open circuit. In this reason, we utilized more elastic conductive particles and measured difference of penetration depth between conventional conductive particles and more elastic ones. Conductive particles with elasticity similar to the plastic film substrate did not damage a ITO electrode on plastic film substrates, and low temperature and pressure stepped process also did not deform the surface of plastic film substrates. As a result, highly reliable interconnection with minimum contact resistance was accomplished. Through these process and newly developed methods, we successfully fabricated 2-inch Plastic Film STN LCD.

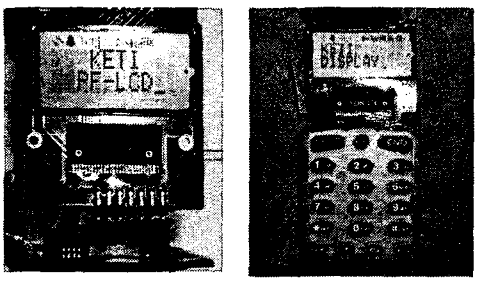

Fig.5 Operation of 2-inch Plastic Film LCDs developed with new methods.

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 temperature operating (10 cycle 200 min./cycle, and -20℃ - 80℃) , and humidity operating (RH 80%, 60℃, 120hr). Bending test was, as described above, accomplished with a bending test machine at the 20. After these test, there is no problem in the operation and external appearance of Plastic Film LCDs

Table 2. Specification of Plastic Film FSTN LCD

Item	Feature	Item	Feature
Size	39 x 24 mm	Viewing Area	35 x 17 mm
Duty Ratio	1/18 Duty 1/5 Bias	Maximum Process	110 ℃
Active Area	T.B.D	Operation	2.4 ~ 3.6 V
Dot Pitch	0.3 mm	Dot Size	0.25 x 0.28 mm
Thickness	0.6 ~ 0.7	Contrast	> 8:1
Weight	0.6 g	Type	Transflective
Mode	NW	Response	< 200 ms

5. Conclusion

The electro-optical characteristics of Plastic Film LCD were better than or very close to those of glass LCD though its thickness was about one third and its weight is about one fifth. Table 2 shows the specification of Plastic Film LCDs. Considering its unique characteristics, Plastic Film LCD is expected to be a strong candidate in display applications for hand held electronic devices in the respects of weight and thickness. We have demonstrated Plastic Film STN LCD technology which includes a new process method, and newly developed vacuum chuck and jig. The key issues of this process are low temperature stepped process and new methods to overcome flexibility and non-flatness of plastic film substrates. As described above, another main problem of plastic film substrates is low thermal resistance. This flaw is critical in the process of main sealing and curing of a alignment layer. So, we used the material have low temperature curing state and optimized curing time. To minimize the shrinkage caused by abrupt heating, temperature increased in many steps.

Reference

[1] R. P. Wenz et al (3M) SID93 DIGEST pp961-964.

[2] T, J. Gardner et al (3M) SID95 DIGEST pp695-698

[3] E. Ohta et al. (Ricoh Co. Ltd), Conference on Solid state device and materail, Sendai 1990 pp.589-592

[4] S.K.Park, J.I.Han, W.K.Kim and M.G.Kwak, Thin Solid Films, 66-67, pp.512-517, 2001

[5] S,K,Park, J.I.Han, W.K.Kim and M.G.Kwak, Jpn. J. Appl. Phys., 41, pp. 533-538, 2002