Carrier Glass Substrates for Electronic Display Fabrication

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ABSTRACT

Non-alkali glass substrates are used as carrier substrates in various electronic device fabrication. In this paper, overview of the requirements for the carrier substrates are described. Thermal shrinkage, stiffness, optical transmittance and residual stress of the glass substrate are important to fabricate display devices, such as flexible OLED display.

1 INTRODUCTION

In these days, divergence of display panel technology has been quite significant. One of the significant technical trend in mobile devices, such as smartphones, is an increase in the number of models which employ organic light emitting diode (OLED) display with flexible substrate, such as poly-imide (PI) resin. For such flexible displays, higher pixel density is desired in the same way as conventional rigid displays and most of the models have the resolution of more than 400 pixel per inch (ppi).

On the other hand, due to its flexibility, there has been a lot of technical challenges in the highly efficient mass production of flexible display panels. In the production process, generally carrier glass substrate is used to support thin PI resin film. PI precursor is coated on the glass surface and cured at elevated temperature [1]. After the curing of PI, electrodes, thin film transistors, insulation layers, organic functional layers, electrical circuit etc. are formed on the PI adhered to the carrier glass. In some cases, PI film with carrier glass is divided into two sheets due to a limitation raised by some special facilities. After the encapsulation process and attaching supporting substrate, the panel is detached from the carrier glass.

Although the carrier glass does not remain in the final products, such as flexible display panels, the influence of the characteristics of carrier glass on the display panel quality and production efficiency should be significant. The reason is that PI film deforms along with the deformation of the carrier substrate. In this study, we focused on two major factors affecting pattern preciseness. One is the thermal shrinkage of the glass at around the temperature where PI on the carrier is cured and low temperature polycrystalline silicon thin film transistor (LTPS-TFT) is activated. The other is the deformation by dividing a large glass substrate into two sheets.

Thermal shrinkage affects the pattern tolerance during repetitive lithography process. Even though the temperature range for PI curing and LTPS-TFT process is lower than that of the glass substrate panel, the duration of the heating is relatively long. Therefore, the effect of structural relaxation of the commercially produced thin glass sheet have to be evaluated because of its complexity of relaxation mechanism of commercially produced thin glass substrates [2].

Deformation of the glass substrate by cutting is caused by residual stress which is introduced by temperature distribution in cooling process of sheet glass fabrication. If large amount of residual stress distribution is remained, a certain deformation occurs because the strain is released by cutting into smaller pieces. This deformation may cause distortion of the configuration of the pixel pattern. Since residual strain depends on the glass fabrication process, we need to assess the condition of cooling process of the sheet glass, if the impact of residual stress is not negligible.

In this paper, we review the requirements and issues for the carrier glass substrate and describe our recent research and development results.

2 FABRICATION PROCESSES USING CARRIER GLASS SUBSTARTES

2.1 Flexible OLED Display

An example of flexible OLED display fabrication process is shown in Fig. 1. At first, precursor of PI is coated on the carrier glass substrate. Non-alkali glass is often used as a carrier substrate. Then, PI is cured at elevated temperature. After cooling down to ambient temperature and formation of barrier layer(s), back plane is formed on the PI surface. Carrier glass is then divided into two or more pieces to adopt the substrate to following process, that is, formation of organic functional layers. Next to the encapsulation, PI substrate is debonded using UV light irradiation. By integrating with other optical films, touch functional sheet, protecting materials etc., PI-based flexible OLED panel is obtained.

2.2 Other Electronic Devices

Application of semiconductor packaging process might be useful to produce a novel flexible display devices. Yang et.al. proposed the application of fan-out panel level packaging (FOPLP) process to flexible transparent electronics [3].

Figure 2 illustrates the typical steps in the FOPLP process[4]. In this particular approach (known as chips-last or RDL-first), the redistribution layer (RDL) is first created on a carrier substrate, and individual dies are then placed and covered with a molding material. The entire package is exposed to ultraviolet (UV) irradiation to deform the molding layer, followed by removal/de-bonding of the carrier wafer, solder bump formation and, finally, singulation of the individual packages. RDL can be formed multiple layers with electric wiring. In such case, repetitive photo lithography is performed.

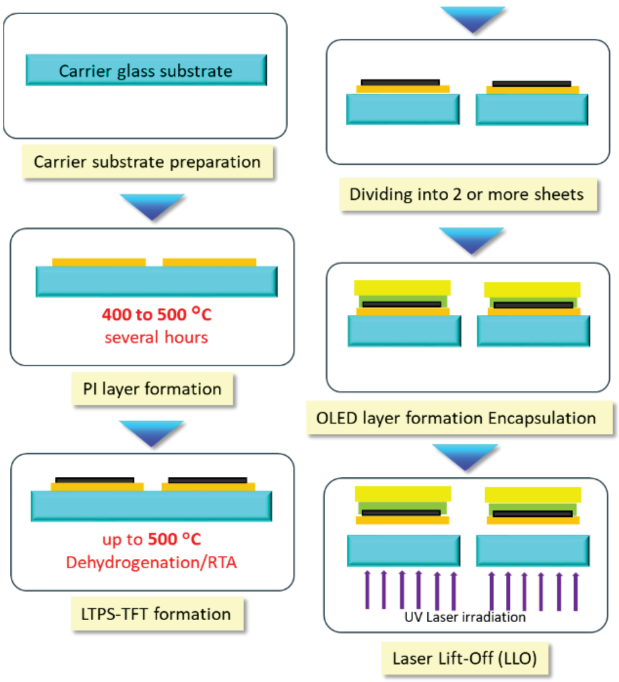


Fig. 1 An example of poly-imide based flexible OLED display fabrication process

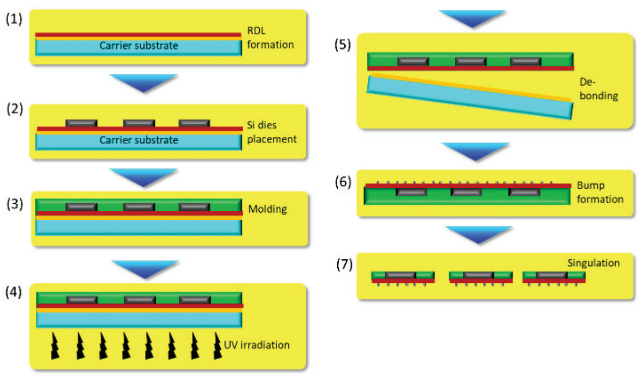


Fig. 2 Schematic illustration of typical fan-out WLP/PLP process (RLD-first)[4]

3 TYPICAL REQUIREMENTS FOR THE CARRIER SUBSTRATES

3.1 Stiffness

Warpage of the laminated substrate may cause problem. In addition to the warpage by CTE mismatch, the effect of gravitational sag must be considered. Amount of gravitational sag can be calculated the formula shown below;

$$\sigma = \beta\left(\frac{\rho}{E}\right)\left(\frac{L^2 \cdot l^2}{t^2}\right) \quad (1)$$

where, σ is maximum bending deflection, ρ is density of glass, E is Young's modulus, L is length of longer side, l is length of shorter side, t is thickness and β is constant. Using this equation, the effect of materials properties on gravitational sag was calculated. According to eq. (1), higher specific modulus, E/ρ should be better to reduce gravitational sag.

3.2 Dimensional Stability

To functionalize the film layers supported on the carrier glass, electric wiring and thin film transistors are formed with highly precise pattern. In the fabrication process of display device, repetitive lithography process are performed. Thermal shrinkage affects the pattern tolerance. Therefore, carrier glass which shows lower thermal shrinkage should be better. Recently, several glass with lower thermal shrinkage characteristics are released. Fabrication process of glass sheet is important to obtain lower thermal shrinkage substrate as well as the thermal properties of the glass [SID 2019].

3.3 Optical Transmittance

In many cases, de-bonding process employs ultraviolet (UV) light (including laser). To avoid negative influence to the device formed by carrier glass, UV light is generally irradiated through carrier substrate. Therefore, optical transmittance of UV light should be high enough to high efficiency de-bonding and less defect caused by insufficient irradiation.

By optimizing sheet glass melting and fining process with using carefully chosen raw materials, transmittance in UV-A region (315~380 nm) can be kept high enough for the UV de-bonding process.

3.4 Chemical Durability

In the fabrication process of electronic displays, there are many steps in which laminated substrate are exposed to some chemicals, such as acidic and basic solutions. In some particular cases, hydrofluoric acid based solution which react with glass network and dissolve glass are used. The carrier glasses must be designed to have sufficient chemical durability against those various chemical solutions.

4 EVALUATION OF THE DIMENSIONAL CHANGE DURING FABRICATION PROCESS

4.1 Properties of the Glasses for Carrier Substrate

We have developed several types of glasses suitable for the carrier substrate. Table 1 shows typical properties of the glasses. AN100, AN Wizus-FC are glasses for TFT substrate and GL6 to GL8 have higher CTE to mitigate thermal stress caused by the CTE mismatch between the carrier glass and the films formed on it. Young's modulus of those glasses are higher than 77 GPa, thus, deformation during supporting can be suppressed effectively.

4.2 Estimation of the Deformation Caused by Dividing using Numerical Simulation

Glass has glass transition temperature (Tg) and shows discontinuous change in its thermal expansion coefficient (CTE) at Tg. This feature affects the internal residual stress after forming into thin sheet glass when there is in-plane temperature distribution during cooling from the temperature higher than its Tg to lower temperature, typically lower than 100 °C. Therefore, the glass with local residual stress distribution deforms when the sheet is divided into two or more pieces due to stress release. Since there might be a carrier glass dividing process in some types of PI-OLED process, the influence of the deformation of the carrier glass by dividing should be assessed. In this study, we tried to elucidate the effect of temperature distribution during cooling process on the deformation after dividing of sheet glass using a finite element method.

We evaluated the influence of temperature difference on the deformation after cutting using numerical simulation [5]. Conditions of temperature distribution and cutting position were illustrated in Table 2. Figure 3 shows the residual stress and displacement dependence on the initial temperature difference between center and edge part. In this figure, displacement means the maximum distance change from the center of the initial sheet between before and after cutting. Several MPa of stress and several μm of displacement were confirmed to be formed even if the temperature difference was less than 10 °C. In the case of the condition employed in this study, it is expected that about 8 μm of displacement is caused by 1 MPa

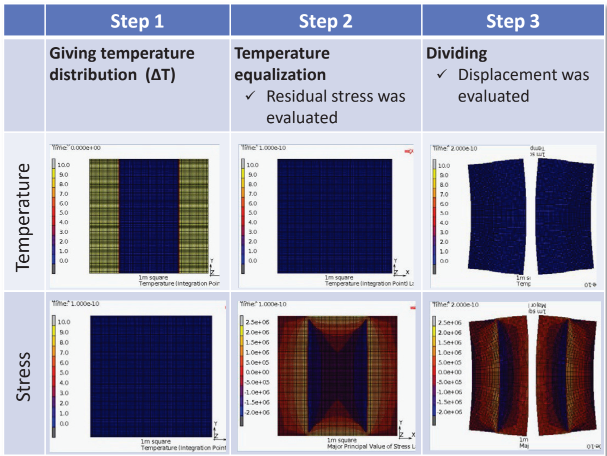
4.3 Evaluation of the thermal shrinkage for the temperature and time of PI-OLED process

The influence of cooling condition during glass sheet fabrication on thermal shrinkage: Figure 4 depicts the plot of thermal shrinkage during the isothermal step in heat-treatment II as a function of the cooling rate of heat-treatment I-a (one-step cooling). As shown in Fig. 2, the specimen with higher strain point (AN Wizus-FC) and slower cooling rate results to small thermal shrinkage. As the results, at the heating temperature and time during PI-OLED fabrication, we found that the thermal history of glass sheet fabrication affected the thermal shrinkage with tens of ppm order.

Table 1 Typical properties of glasses for carrier substrates [5][6]

	AN100	AN Wizus-FC	GL6	GL7	GL8	SLS (ref.)
CTE [ppm/°C]	3.8	3.9	5.9	6.7	8.2	8.3
Young's modulus [GPa]	77	85	77	78	78	72
Strain point [°C]	670	725	700	680	680	510
Alkali content [mass%]	<0.1	<0.1	<0.1	<0.1	<0.1	ca.13

Table 2 Procedure of the numerical simulation for deformation evaluation[5]



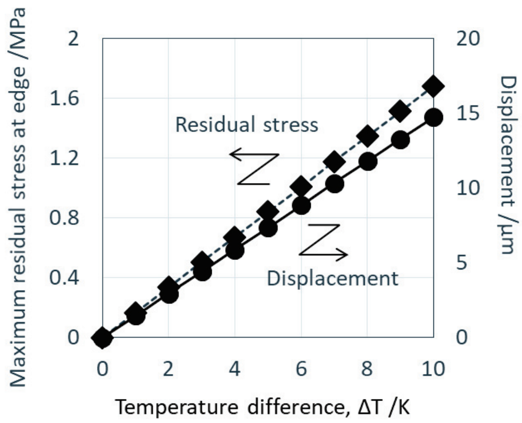


Fig.3 Maximum residual stress at edge and displacement at the corner of the divided sheet[5]

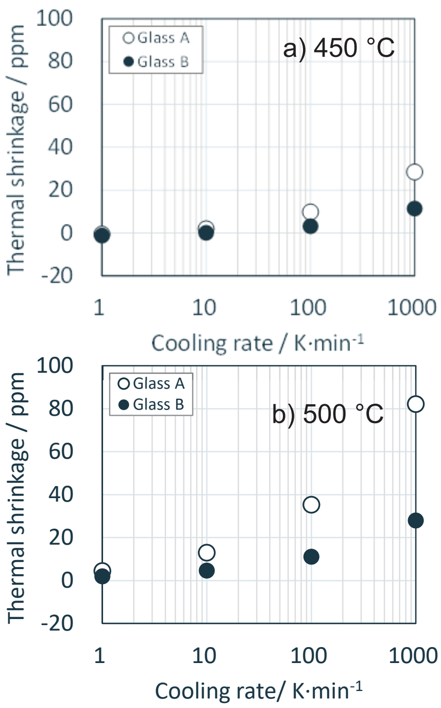


Fig. 4 Thermal shrinkage during heat treatment II as a function of cooling rate in heat during glass sheet fabrication process[5] (Glass A: AN100, Glass B: AN Wizus-FC)

4.4 Evaluation of the Thermal Shrinkage during the Multi-layer RDL Fan-out Process

Higher CTE non-alkali glass carrier is desirable when CTE matching between resin layer and carrier glass is needed. GL6, GL7 and GL8 have much higher CTE than that of conventional glass substrate for TFT-LCD (about 4 ppm/°C). Thermal shrinkage behavior of the GL8 was compared with conventional soda-lime silicate glass (SLS)[6]. Figure 5 indicates the thermal shrinkage of GL8 and SLS when those glasses were heat-treated repeatedly. As clearly shown in the Fig.5, even at 200°C, several ppm of shrinkage was observed in SLS. On the other hand, GL8 whose strain point is about 170°C lower than that of SLS shows almost no shrinkage. Therefore, even the temperature of the heat treatment is low (for example, RDL formation), choice of carrier substrate is important if one needs to fabricate highly fine pattering using photo lithography for more than one layers.

5 CONCLUSION

Glass is still the material occupying important roles in the electronic display field even if it doesn't remain in the final products. Because of the mechanically and thermally stable characteristics, users can obtain the opportunity of the improvement of their flexible display device fabrication and its application by use of carrier glass substrate. This paper can help those who are producing flexible displays to choose the appropriate carrier glass.

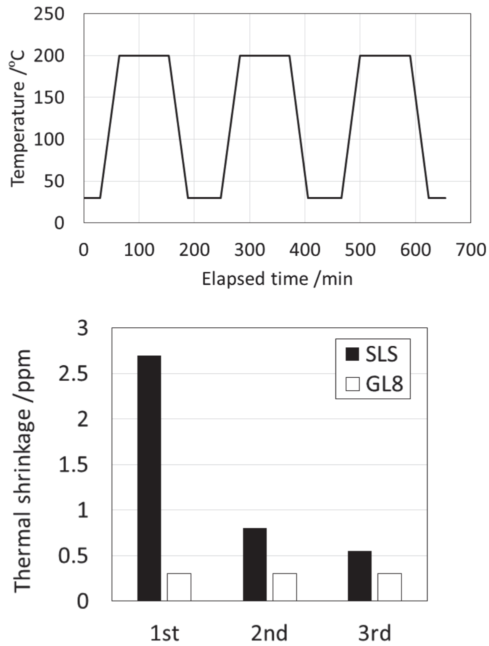


Fig. 5 Thermal shrinkage behavior of high CTE non-alkali carrier glass compared with conventional soda-lime silicate glass[6] (upper: heat treatment profile, lower: thermal shrinkage of GL8 and SLS)

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