Roll-to-Roll Fabrication for OLED Lighting Using Ultra-Thin Glass Substrate and Encapsulating Stainless Steel Foil

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ABSTRACT

We fabricated OLED lighting on ultra-thin glass using the Roll-to-Roll method. After deposition of the organic layer, the lighting devices were encapsulated with stainless steel foil and then cut. OLED Lighting with this structure had high reliability and did not break when the device was bent.

1 Introduction

Ultra-thin glass has excellent gas barrier properties and transparency and is very useful substrate for OLEDs. Due to the flexibility of ultra-thin glass, the roll-to-roll process is more suitable for handling ultra-thin glass than the sheet process. However, ultra-thin glass is fragile and difficult to handle in the manufacturing process. Yamagata University and Fraunhofer FEP have been working on process improvement for ultra-thin glass [1],[2],[3].

In this study, Yamagata University and Fraunhofer FEP fabricated OLED lighting together. Roll-to-Roll was applied from the transparent electrode deposition process to the encapsulation process. The encapsulation side substrate was made of stainless steel foil and was laminated with the same equipment after the cathode was deposited. The roll sample was cut by Mitsuboshi Diamond Industrial. The ultra-thin glass part was scribed with a special tool [4], and the stainless-steel foil part was cut with a laser. These cutting technologies have achieved high bending strength of ultra-thin glass. In addition to handling, lighting devices using ultra-thin glass had the disadvantage of being fragile. Stainless steel foil has a good gas barrier property and improves the reliability of OLED devices. And OLED lighting with ultra-thin glass encapsulated with stainless steel foil did not break easily.

2 Experiment

The roll glass was G-Leaf manufactured by Nippon Electric Glass and the thickness was 50 um and the width was 30 cm. Stainless steel foil with a thickness of 30 um and a width of 260 cm was supplied by NIPPON STEEL Chemical & Material. Conductive ink and insulating ink were supplied by Fujikura Kasei.

2.1 Device structure

The device structure (cross section in the width direction) is shown in Fig. 1.

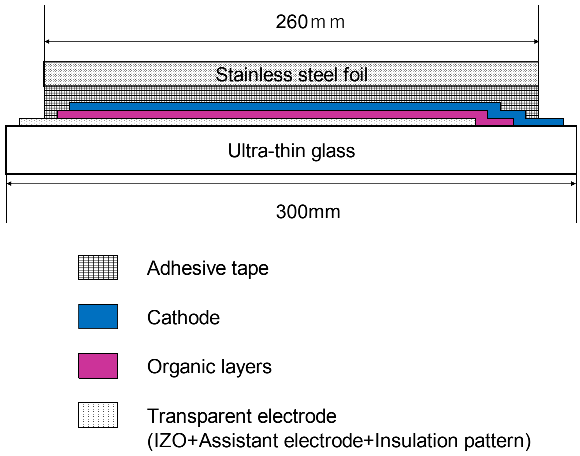


Fig. 1 Device structure

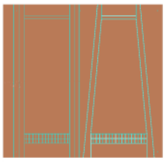
2.2 Transparent electrode

Transparent electrodes were fabricated according to previously studies [1], [2]. The first process was the deposition of IZO on ultra-thin glass. IZO was deposited on a Roll-to-Roll sputtering machine. The thickness of IZO was 100nm and the resistance was about 30Ω.

Next, IZO was etched using the etching paste. The etching pattern cuts off the current route in the line, as shown in Fig. 2. The large rectangle and trapezoidal part were the light emitting area. The etching paste was printed on a special Roll-to-Roll screen printing machine [5] and the paste solved the IZO. This screen printing machine prints in an intermittent roll-to-roll system. Therefore, after printing the pattern shown in FIG. 2, the substrate was moved 320 mm and the next pattern was printed.

The assistant electrode was formed by conductive ink on the same screen printing machine that printed the etching paste. This pattern is shown in Fig. 3. The mesh pattern at the bottom of the figure was the terminal part of the cathode, and current was supplied from the IZO to the long line electrode. The long line electrode was set inside the etched line of IZO and did not touch the small square IZO pattern. The reason why the long line electrode was not extended to the terminal part was to prevent the encapsulation substrate from floating due to the thickness of the associate electrode and the insulation pattern.

The insulation pattern was printed with insulating ink containing particles by the same screen printing machine. Insulation pattern covered most of the assistant electrodes and IZO pattern edges.



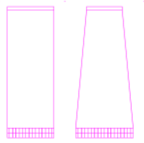


Fig. 2 IZO pattern **Fig. 4 Insulation pattern**

Fig. 3 Assistant electrode

2.3 Deposition of organic and cathode layer, and encapsulation

A thin PET carrier film (75μm) was laminated at NEG on the back side of the glass containing the transparent, structured IZO electrode. The OLED deposition was carried out on the thin glass-PET compound in the RC300 vacuum equipment (Roll Coater with 300mm band width) at Fraunhofer FEP [6]. Figure 5 shows the RC300 tool, left side with open door and schematically on the right side. The thermal evaporation of the organic and metal cathode films was done continuously using organic linear sources and metal point source. The vacuum pressure was kept constant at about 10^{-6} mbar during the deposition and encapsulation. Encapsulation process using stainless steel foil laminated with PSA film (Pressure Sensitive Adhesive) was done in one process using the substrate and interleaf winder in vacuum after the cathode deposition to prevent front-back side contact.

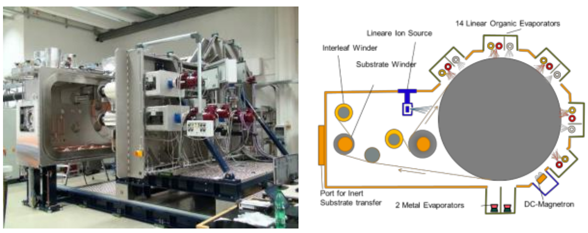


Fig. 5 RC300 vacuum deposition tool.

Fig. 6 shows schematically the used layout and the position of the deposited organic and metallic cathode layers. Large, homogeneously lighting OLED devices of 216mm length and maximal 105mm width were fabricated.

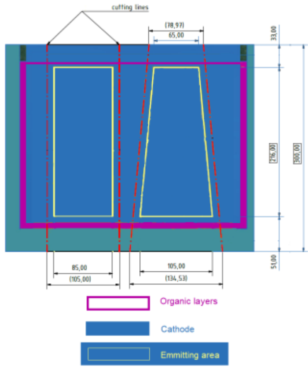


Fig. 6 Position of the deposited organic and metallic cathode layers

2.4 Cutting process

The roll sample was roughly cut at a pitch of 320 mm so that two pieces (one set) of OLED devices would be placed on one sheet. This sheet was cut on the cut line indicated by the IZO pattern and divided into individual devices. First, the glass surface was scribed with a mechanical tool, then the sheet was inverted and the stainless steel foil surface was irradiated with a laser and then separated.

For the scribe on the glass surface, SOLID-D (Fig. 7) manufactured by Mitsuboshi Diamond Industrial, which was developed for cutting ultra-thin glass, and MUGP (Fig. 8), which is a glass cutting machine were used.

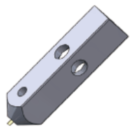


Fig. 7 SOLID-D

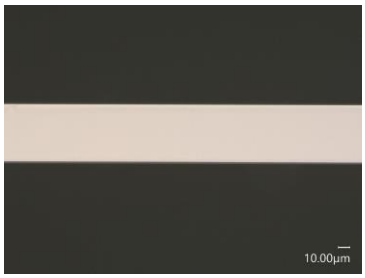


Fig. 8 MUGP Fig. 9 Ultra-thin glass cross section

The ultra-thin glass was scribed using SOLID-D. At this time, a trigger crack was generated at the end point of the scribe line, and a vertical crack proceeded from the end point of the scribe line toward the start point. And it became possible to cut the glass without breaking it during processing [4]. The most feature of this method is no rib mark and lateral crack generated in the glass edge (Fig.9), and it make device can be flexed without glass broken. Next, a laser was radiated onto the stainless steel foil with low power to prevent thermal damage to the glass. The LPM series (Fig. 10) was used as the laser irradiation machine. After laser irradiation, the OLED device was separated to bend to the stainless steel foil side.

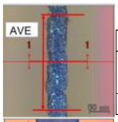
Fig. 10 LPM series

3 Results and Discussion

3.1 Print Results

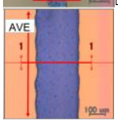
The print results of the assistant electrode and the insulating pattern are shown in Table 1. Since the conductive ink has high thixotropic property, the surface shape of the assistant electrode pattern was rough due to the influence of the mesh of the screen plate. On the other hand, the insulating ink had good leveling properties and the pattern shape was a smooth arch. The volumetric resistance of the assistant electrode was $1.8 \times 10^{-5} \Omega \cdot cm$.

Table 1 Print results



Assistant electrode

	AVE	MAX	MIN
Cross-sectional area(um^2)	164	185	120
Thickness(um)	4.3	6.6	-
Width(um)	54	57	46



Insulation pattern

	AVE	MAX	MIN
Cross-sectional area(um^2)	1354	1407	1100
Thickness(um)	8.8	9.3	8.2
Width(um)	294	301	284

3.2 Cutting result

In the roll sample, the ultra-thin glass was 40 mm (20 mm on one side) larger than the stainless steel foil. When there was a gap under the ultra-thin glass, the glass was broken due to bending during scribe. Therefore, at the time of glass scribe, it was improved by setting spacers with the same thickness as the stainless steel foil plus adhesive at the bottom of the start and end positions of the scribe as shown in Fig. 11.

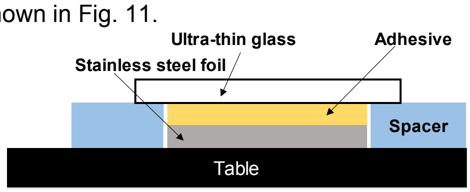


Fig. 11. Setting of spacers

Laser output power was a very important parameter for laser irradiation on stainless steel foil. If the laser power was high, the glass was damaged (Fig. 12), and if the power was weak, it was difficult to divide. The important point was that the processing depth by the laser fits within the thickness of the stainless steel foil. Also, to prevent damage to the ultra-thin glass, only the inside of the stainless steel foil in the width direction was processed. The sample was easily divided by bending the position of the processing line toward the stainless steel foil (Fig. 13). The pretest cut sample did not break when wrapped around a φ40 mm cylinder (Fig. 14).

Fig. 12. Glass damage by laser

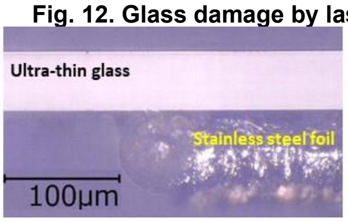


Fig. 13. Cross sectional image of divided sample

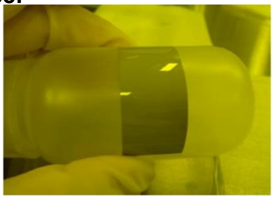


Fig. 14. Bent sample

3.3 OLED Lighting

The rolled devices are shown in FIG. 15, and the divided device is shown in FIG. 16. Large area lighting devices could be fabricated with a roll. When the lighting device emitted, the assistant electrodes and the insulation pattern part appeared to emit due to particle scattering. The cut OLED device has exposed ultra-thin glass on both sides. These parts are very fragile and should be handled with care. As shown in Fig. 17, two stainless steel foils were laminated on the back side of the exposed parts of the ultra-thin glass for reinforcement.

By optimizing the cutting conditions and reinforcing the device, OLED lighting that can be handled with peace of mind was produced. And the true flexible lighting device was completed.

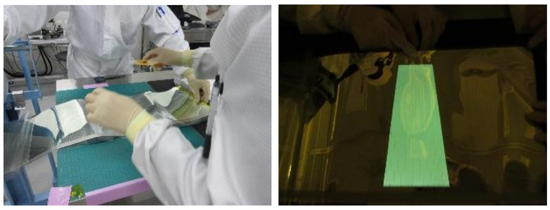


Fig. 15. Rolled devices

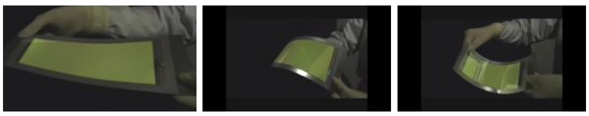


Fig. 16. Divided devices

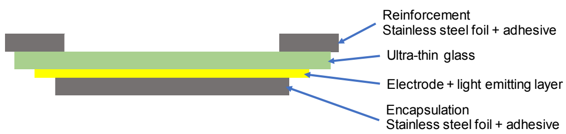


Fig. 17. Reinforcement for the device

4 Conclusions

Large area OLED lighting on ultra-thin glass using the Roll-to-Roll method has been fabricated. This device was encapsulated with stainless steel foil by Roll-to-Roll. And the cutting technology for devices consisting of ultra-thin glass and stainless-steel foil has been established. Stainless steel foil reinforces the fragility of ultra-thin glass, and lighting products can be handled with great peace of mind.

5 Acknowledgement

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