Development of a Linear Nozzle Source for 10.5G White OLED Mass Production System

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Abstract

Here, the Linear Nozzle Source (LNS) applicable to 10.5G substrate (2940mm x 3380mm) deposition with ultra-high film uniformity is reported. By optimizing the nozzle arrangement, the film uniformity within ±1% has been achieved with tact time of 70s, which remained stable through 14 consecutive days of evaluation. It was verified that the source performance remained stable during five repetitive maintenance processes. The material consumption efficiency of the LNS was measured to be 76.4%. The developed LNS is expected to be applied to the 10.5G deposition system and increase the product competitiveness.

Author Keywords

OLED; Uniformity; Material efficiency; Linear Nozzle Source; 10.5G.

1. Introduction

OLED displays are self-emissive, which eliminates the need for a backlight and enables thin and light designs compared to other displays. They offer high contrast ratios for pure black color reproduction and feature fast response times and wide viewing angles, making them ideal for next-generation display industry. These advantages have driven their widespread adoption, from small smartphones to large TV displays. OLED displays are categorized into two primary types: RGB OLED and white OLED. RGB OLEDs are predominantly used in mobile phones and IT devices, whereas white OLEDs are mainly employed in monitors and TVs. However, OLED displays face significant challenges due to high manufacturing costs, which undermine their competitiveness. To address these issues and enhance product performance, optimizing device structures, developing new organic material, and advancing mass production technologies are essential. Notably, organic material costs remain a substantial portion of OLED TV panel production expenses. One of the most effective ways of diminishing manufacturing costs is to develop large-scale production technology, in that efficient material evaporation with less material consumption is enabled as substrate size increases. Also, larger substrates allow for the production of more panels per glass sheet, effectively reducing the cost per panel. To produce competitively priced large-size OLED TVs, the mass production (MP) system must be scaled up. Currently, OLED TVs are manufactured using 8.5G (2200 mm x 2500 mm) substrates. Enhancing the price competitiveness of OLED TVs requires transitioning to production systems that utilize 10.5G (2940 mm x 3380 mm) substrates. To meet this demand, we here developed a linear evaporation source optimized for large-area (10.5G) substrate MP systems.

2. Methods

Linear nozzle sources for OLED TV production must satisfy key performance criteria, including film uniformity of <±3%, operation time of >14 days, and maximized material utilization efficiency. There are two key techniques for linear nozzle sources. The first is a nozzle design technology, which enables the deposition of uniform film with thickness controlled to angstrom level. The second is a heating structure design technology, which ensures precise thickness control and thermal stability. Nozzle design is critical for determining film quality. The focus of this technology is the optimization of the position, size, and angle of individual nozzles through simulation. The nozzle dimensions are adjusted to achieve overall film uniformity, determined by the cumulative evaporation flux of each nozzle.

Heating parts structure design, the second core technology, determines the evaporation continuity and stability. The heating structure of the LNS must be carefully designed by considering properties of evaporation materials. For standard organic deposition, the system must be capable of reaching temperatures up to 500°C. The dimension of the heater including length and size should be selected to heat the crucible to the desired temperature. To ensure evaporation stability during continuous operation and extended lifespan, the heating parts dimension is carefully considered with power supply specification. To prevent material clogging at the nozzle ends, the heating components must maintain nozzle temperatures above the material's evaporation temperature. Additionally, at such operating temperatures, the source components must be designed to withstand repeated thermal expansion and contraction without permanent deformation.

3. Experiment

The evaluation conditions of the LNS were set as shown in Table 1.

Table 1. Evaluation conditions

Contents	Specification	Remarks
Tact Time (sec)	70	
Moving Speed (mm/s)	53.5	
TS (mm)	220	
Open Area (mm)	866 x 2940	
Uniformity width (mm)	2900	
Thickness (Å)	200	1 scan

As shown in Figure 1(a), two sub-deposition sources were symmetrically arranged and paired to enable uniform deposition on a 2940mm wide substrate.

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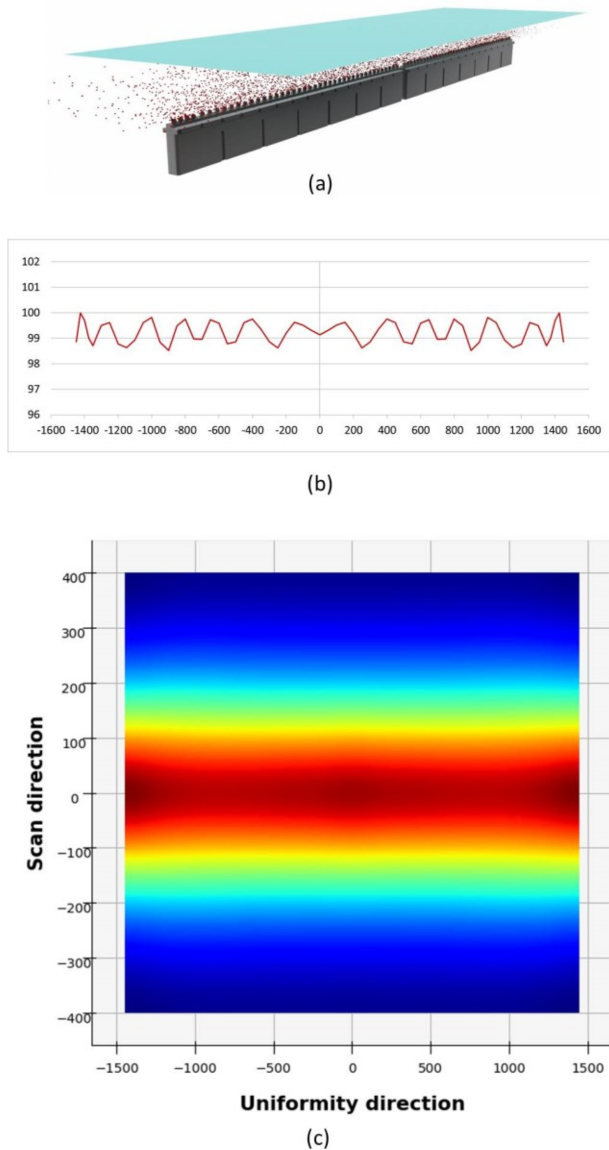

Figure 1. (a) Simulation Schematics, (b) 1D Film Uniformity: 0.7%, (c) 2D Film Uniformity

The sub-deposition source includes two types of heating elements: a top heater, which primarily heats the crucible and upper nozzle area ($0.15m^2$), and two bottom heaters, which provide additional heat to the crucible ($0.55m^2$). The bottom heaters are independently controlled to regulate the deposition rate and to reduce asymmetry between the left and right sides. The deposition rate is separately monitored using QCMs located on the left and right sides of the sub-deposition source. The Direct Simulation Monte Carlo (DSMC) method was applied [2], [3], [4], and the spacing, position, angle, and size of nozzles were simulated to ensure flux uniformity. Table 2 summarizes the DSMC simulation conditions.

Table 2. DSMC simulation conditions

H/W condition	Target to Source (mm)	220
	Open area (mm)	866 x 2940
	Effective area (mm)	866 x 2900
	Tact time (sec)	70
	Scan speed (mm/s)	53.5
	Rate (Å/s)	12.37
Mesh condition	Body (ea)	102
	Node (ea)	115,610
	Element (ea)	231,778
Boundary condition	Dimension (mm)	3020 x 880 x 480
	Cell interval (mm)	5
Material condition	Material	Alq3
	Usage (g/hr)	26.6
	Collision	Collisionable
	Thickness (Å)	200

The nozzle section of the source is divided into an edge nozzle and a single nozzle area. The edge nozzle was designed to compensate for flux at both ends. The size of the source is a critical factor in determining the overall system size, and making compact linear source is critical for reducing manufacturing costs. The results of the design and subsequent simulations based on this concept are shown in Figures 1(b) and (c). The simulation was conducted by generating particles for 200 Å deposition by adjusting the angle, size, and position of the appropriate nozzle at 220 mm of Target to source (TS), resulting in a film uniformity of ±1% or less. From this result, the amount of the material passing through the open area 866mm x 2940mm can be expected, and 79.7% of the particles are predicted to reach the substrate. At TS 500mm, the material usage efficiency is reduced to 53.2%. For a long-term deposition stability, the temperature distribution of the crucible must be uniform. The temperature distribution of crucible was analyzed using the MIDAS program. One LNS consists of two sub-LNS, and each sub-LNS consists of one crucible and nozzle array. Sheath heaters were used as heating elements, consisting of one top heater and two bottom heaters. To perform thermal simulation, power was applied to one top and two bottom heaters. The top heater received 450W, and each bottom heater 50W, to heat the material in the crucible to 420°C. The applied power conditions were obtained through multiple preliminary simulations to achieve the required evaporation temperature. Radiation and contact conditions were also considered in the thermal simulation. Figure 2 shows the temperature distribution of the crucible and nozzle parts heated by the radiation emitted from the heating wire. Additionally, cooling conditions were applied to the water jacket for the simulation to consider clogging issue. Clogging of general organic materials can be prevented when the nozzle temperature is approximately 15°C higher than the evaporation temperature of the material. In order to optimize the temperature distribution, the heating element of the nozzle parts applied 19.1m of heating wire (Top Heater) to a $0.15m^2$ area, and the heating wire of the crucible parts applied 19.7m (Two Bottom Heater) to an area of $0.55m^2$ to be heated. For heating nozzle parts, about 3.52 times larger heat was applied compared to heat of the crucible parts. The heating element length per unit area should be optimized for the material properties. For the LNS evaluation, a chamber with the same width as a 10.5G substrate was manufactured (Figure 3). A load-lock chamber is

applied to enable continuous evaluation, and the tray can move forward and backward at a constant speed by roller driving.

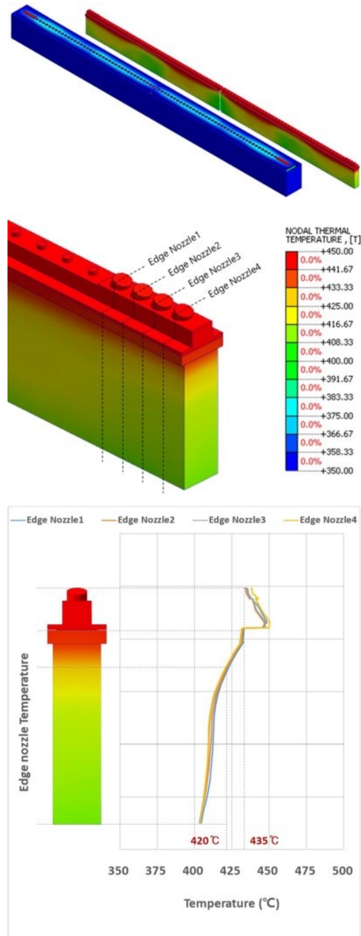

Figure 2. Thermal simulation of Linear Nozzle Source

Wafer samples were attached to the tray at regular intervals, and the thickness was measured using an ellipsometer after deposition. The tray's moving speed (>75 mm/s) was designed to transfer a 10.5G substrate within 50 seconds.

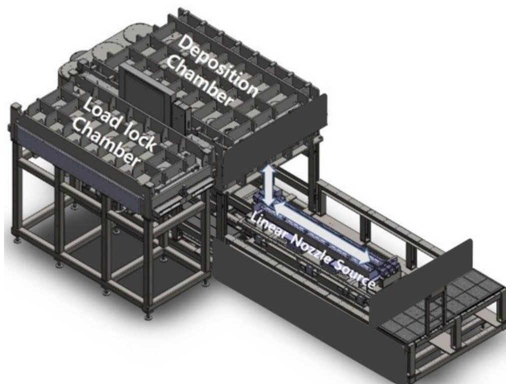

Figure 3. Evaluation Chamber

4. Results

Based on the simulations, the LNS for the 10.5G substrate was designed and made (Figure 4).

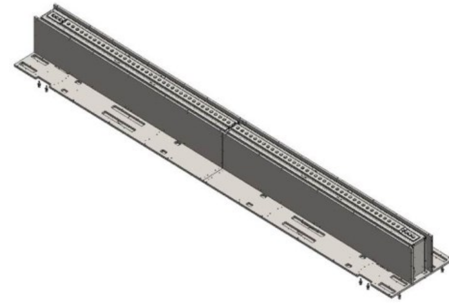

Figure 4. Linear Nozzle Source for 10.5G

The general specifications of the LNS are as follows.

Table 3. General Specifications of the LNS

Contents	Specification
Size(mm)	3000 x110 x 222
Crucible capacity(cc)	16,000
Nozzle to nozzle distance(mm)	2,925
Weight(kg)	94.5
Continuous Operation time(day)	14

The rate stabilization time and stability of the developed LNS were evaluated, and the results are shown in Figure 5.

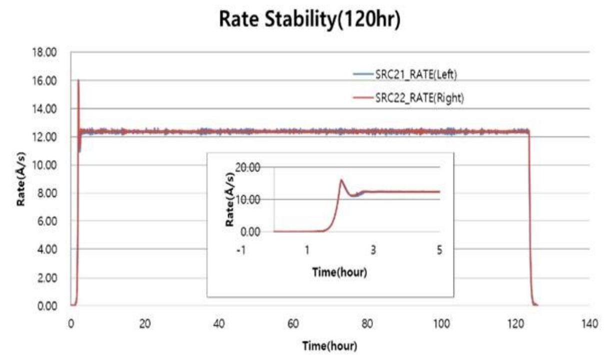

Figure 5. Rate Stability of the Linear Nozzle Source

Evaluations of the LNS were performed using Alq3. After optimizing the nozzle arrangement, film uniformity within 1% (65 measurement points: Si wafer samples, 25 mm pitches) was obtained. Film uniformity of the LNS was evaluated 16 times over 360 hours (Figure 6). Uniformity of less than 0.7% was maintained for 360 hours at a target thickness of 400Å. Material consumption efficiency of the LNS was checked by comparing the film weight (892.5g) deposited on eight substrates (866mm x 367.5mm) for 66 hours with the weight of the material reduced

in the crucible (1161.6g) during the deposition. The material consumption efficiency of the LNS was measured to be 76.8%. The experimental results were measured 2.9% lower than the simulation result (79.7%).

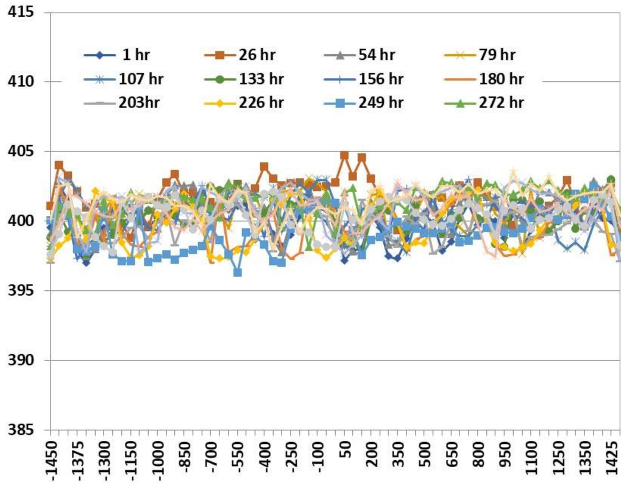

Figure 6. Film Uniformity evaluation for 360hrs.

OLED mass production equipment requires periodic maintenance for work such as material filling and replacement of the shield inside the chamber, and the source performance must be maintained consistently before and after preventive maintenance (PM). To check the differences in performance after PM, the uniformity changes were traced by repeatedly venting the chamber, removing and re-installing the crucible from the LNS and pumping the chamber 5 times over 120 hours. (Figure 7).

PM	1st(1hr)	2nd(26hr)	3rd(54hr)	4th(79hr)	5th(107hr)	8th(120hr)	Avrage U/F
Max. Thick	401.84	402.75	401.37	402.30	402.31	401.15	401.35
Min. Thick	397.08	398.44	397.14	397.67	397.15	397.81	398.19
Average	399.53	400.71	399.51	400.06	399.59	399.33	399.79
U/F	0.60%	0.54%	0.53%	0.58%	0.65%	0.42%	0.39%
400Å STD	0.12%	0.18%	0.12%	0.02%	0.10%	0.17%	0.05%

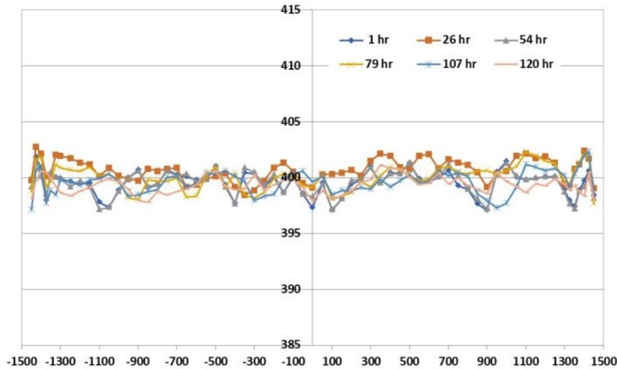

Figure 7. Uniformity changes between PM.

In the first repeated reproducibility test of the LNS, the uniformity was measured to be ±0.60%, and after 5 times PM operations, the uniformity was measured as ±0.42%. During the repeated processes, the deviation of the average thickness was ±0.05%.

5. Conclusion

A source for a 10.5G substrate was developed. The film uniformity was maintained below 1% for 14 days, and the rate was stably controlled (<±2%) at the target deposition rate (T/T 70 sec.). Under the same conditions, the material consumption efficiency was measured to be 76.8%. In addition, it was confirmed that there was no change in the film uniformity even after PM. Although OLED TVs have many advantages over LCD TVs, their market share does not exceed 2.5% [5] in the overall TV market due to their high price compared to their competitors. We are confident that this technology will increase the competitiveness of OLED panels. The developed technology can be used for Perovskite Solar Cells and Organic Solar Cells that require large-area deposition technology.

6. Impact

The deposition system for 10.5G is expected to play an important role in increasing the cost competitiveness of OLED TVs and increasing their market share.

7. Acknowledgements

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