Precise Inkjet Fabrication for Large Size OLED Displays

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Abstract

Inkjet is expected to be a promising manufacturing method for large size OLED displays. In this development, inkjet quality was focused and practical solutions were explored. The developed precise ink volume control method with improved inkjet print heads enabled uniform material deposition into pixels to the extent of 0.4% relative error in range. The achieved quality was confirmed using 3.1 inch test panel and complete uniformity of light emission was realized. The approach was applied to a large sized display to demonstrate that the improved inkjet method is scalable for fabricating large sized OLED displays in respects of both quality and productivity.

Introduction

Mask-less, non-contact, and direct-patterning of soluble materials are major advantages of the inkjet fabrication specifically for flat-panel display industries. An inkjet print head, which ejects liquid droplets containing functional materials from multiple number of ejecting nozzles, is scanned along a substrate while putting droplets onto the substrate within a swath. Unfortunately, no matter how the print head is built with precision manufacturing, ejected droplet volume may slightly vary from nozzle to nozzle, resulting in striped dark and bright light emission, which corresponds to ink volume deviation jetted from the nozzles. This kind of nonuniformity is high sensitively detected by the human eye, so that it must be eliminated to a level of visually imperceptible.

To eliminate the striped nonuniform light emissions within the swath and between adjacent swaths, ink volume must be confined within sufficiently-small amount of variation. As printing time delay between swaths causes uneven drying at the swath borders, ink have to be carefully formulated using high boiling temperature solvents. In addition, as same as techniques used in graphical inkjet printers, multi-pass or interlacing may be used to reduce the uncontrolled errors statistically [1].

As the multi-pass method scans print heads many times, it slows down throughput and productivity of the inkjet manufacturing. Despite all these efforts, none of real OLED displays have been presented that attained complete uniformity to the level of visually imperceptible so far.

OLED manufacturing

Figure 1 illustrates a cross-sectional structure of the OLED device. The device region is surrounded by the resin bank to define the emitting area on the anode electrode and precisely confine the deposited ink without overflowing to another region. To accommodate the substrate to the inkjet process, the top surface of the bank is made lyophobic and the inside is lyophilic. Three organic polymer layers: hole transfer layer (HTL), inter layer (IL) and emitting layer (EML) are fabricated by inkjet processing on the anode (ITO) layer. To prevent nozzle clogging and uncontrolled drying, inks are formulated with high boiling point solvent of over 200°C. After depositing ink droplets inside the bank, ink is dried and then baked to form a solid thin film of the organic polymer. The process is repeated to complete stacked layers and a cathode layer is deposited by vacuum evaporation over the EML. The typical total thickness of the polymer layers is about 150 nm. Finally the device is encapsulated by a counter glass. To fabricate a full color OLED display, emitting layer is patterned into RGB sub-pixels with different polymer solution inks. As the inkjet deposits five materials: HIL, IL, and RGB EML, at least five inkjet heads are used.

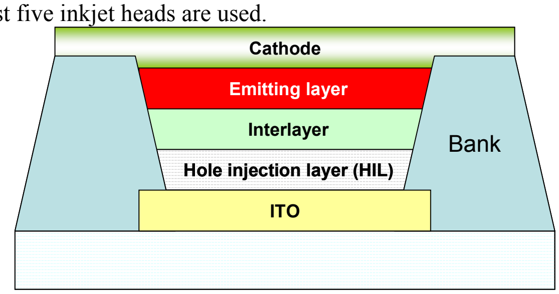

***Figure 1**. A cross-sectional structure of the OLED device*

Epson's piezo inkjet heads called MLP type MACH (Multi-layer Actuator Head) shown in Figure 2 were used in this development [2]. The print head is originally for large format graphics printers; it has two rows of 180 ejecting nozzles in 1 inch swath, i.e. there are totally 360 nozzles in one print head. The print head is designed so as to be densely multi-aligned in a machine to improve throughput. To make the print head adequate for the OLED manufacturing, some structural and material improvements were put to this print head. Firstly, some components of the print head were replaced with parts made of chemical resistance materials. The original print head is well tested for some water base inks for graphical printers, while for industrial applications variety of organic solvents are used to solve the specific functional materials, where they may attack the members of the print head. Even if the print head does not show obvious breakdown, some minute changes may result in small change in ink volume that harms the uniformity of film deposited. In inkjet industrial applications, very small amount of chemical contamination may affect performance and life time of manufactured electronic devices. To avoid these troubles, materials that compose the print head must be carefully selected. Secondly, print head body stiffness was improved to reduce some structural cross talks, which cause deviation of ink volume from the designated values. Thirdly, the nozzle shape was optimized to increase jetting droplet velocity. These improvements led uniform and stable droplet ejection with viscous and viscoelastic polymer solution inks. The typical droplet volume of this print head is 10 pico-liters.

***Figure** 2. Epson's piezo inkjet heads (MLP type MACH) used for the OLED manufacturing*

Experimental

Droplet volume ejected from each nozzle was quantified by measuring polymer volume contained in the droplet. Droplets were ejected onto a flat substrate and dried to form an array of polymer dots. Shape and height of each polymer dot were measured using an optical surface profiler system to obtain the volume of the polymer solute corresponds to droplet volume of each nozzle of the inkjet head. The volume was precisely measured within +/- 0.2% repetitive accuracy. In the printing sequence, the print head can select one of the three different ink quantities at each nozzle and each jetting event using the variable sized droplet technology (VSDT), which is of Epson's original inkjet technology. Based on the acquired droplet volume information of the print head and with consideration for the pixel design, printing sequence was designed as a bitmap that defines deposition map of the three different droplets of VSDT into pixels. The bitmap algorithm generates a bitmap where three droplet volumes are optimally combined so as to veil attributes of the print heads in terms of ink volume deviation and flatten the total amount of droplets in sub-pixels within a panel substrate.

A new test panel was prepared to quantify the light emitting uniformity of the inkjet technology. The panel size is about 3.1-inch in diagonal, which corresponds to three swaths of the print head. In the middle of the panel, there are two lines of pixels where each sub-pixel can be driven individually to measure applied voltage, current, and light emission of each pixel within three swaths. Typical droplet volume and total number of droplets for a sub-pixel used in this development were 10 pl and 35, respectively.

Results

Figure 3 shows green light emission of the test panel fabricated by inkjet process without ink volume correction. Deposited polymer film thickness reflects droplet volume distribution within a print head. The inkjet head runs from top to bottom of the test panel depositing droplets into sub-pixels shown in Figure 3. After putting inks in a swath, head moved to the right for another swath. The multi-pass or interlacing was not used. Hence, obvious dark boundaries between the swaths and a lot of dark and bright stripes in the swath are seen in the panel, which represent the trend of droplet volume distribution of the print head.

Figure 4 shows light emission with ink volume correction. The dark and bright stripes shown in Figure 3 are completely eliminated and uniform light emission from the OLED has been achieved.

***Figure** 3. Green light emission of the test panel without ink volume correction*

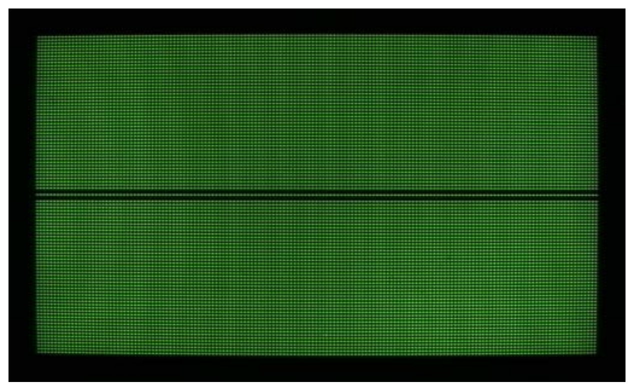

***Figure** 4. Green light emission of the test panel with ink volume correction*

The pixels on the two black lines that lies horizontally in the test panel images are for individual pixel to pixel measurements of light emission characteristics. Figure 5 shows measured light emitting power along the pixels for the individual measurement. The data covers just three swaths of the printing process. Without the ink volume correction, the emitting light power spreads in about 50% of the average value. On the other hand, with the ink volume correction, the measured emitting power lies within the range of 4.7% driven at a constant voltage.

Using the same bitmap as that used to fabricate the test panel, polymer dots were formed on a flat substrate to measure the ink volume jetted into the sub-pixels. The quantitated ink volume deviation of sub-pixels was about 6% in the case of without ink volume correction and it was improved to only a range of 0.4% when the developed ink volume correction was applied.

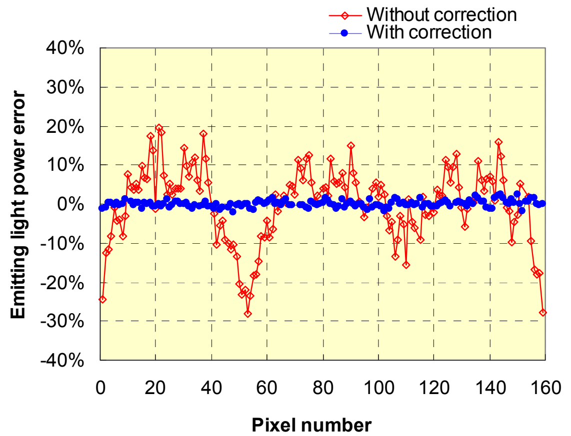

***Figure 5.** Emission light power for three swaths with and without ink volume correction of the test panel*

As a result of the development, we applied the improved inkjet method on fabrication of an active matrix color display (AM-OLED). The specification of the manufactured AM-OLED display is shown in Table 1. The backplane of the display was a low temperature poly-Si TFT (LTPS). The device structure was bottom emission and pixel resolution is 60ppi, which corresponds to a resolution of 37-inch full HD display.

Uniform light emission from the OLED display was achieved by the improved inkjet method in the same way as the test panel.

Table 1: Manufactured AM-OLED Specifications

Display Size	14-inch diagonal
Resolution	60ppi
Aperture ratio	40% (R:G:B=1:1:1)
Color	6-bit full color
Luminance	200cd/m^2
Driving Method	LTPS TFT based Active Matrix
TFT-OLED	Bottom-emission

Summary

In this work, we have developed the improved inkjet method specialized for manufacturing of OLED displays. It is important that ink volume from inkjet head nozzle is controlled correctly to fabricate large sized OLED displays with uniform light emission. The inkjet head was improved suitable for deposition of polymer solution inks. Droplet ink volume of each nozzle was quantified by precisely measuring the polymer solute content with the optical surface profiler system. The volume measurement accuracy was within +/- 0.2% in repeated tests. The accurate ink volume correction was done with the VSDT in accordance with the ink volume information obtained from the measurement.

The developed technology was applied to a newly designed 3 inch diagonal test panel to confirm the accomplished quality level. As a result, uniform light emission from the OLED display was achieved. The technology eliminates the use of multi-pass or interlacing inkjet printing, where a large number of nozzles are used to fill a pixel to reduce the volume error statistically, and the use of additional external signal compensation. Consequently, the developed technology reduces the cycle time and device cost and increases productivity. The developed technology was successfully expanded in applicable display size from 3 inch to 14 inch in the same manner, hence, it verified the scalability of the inkjet OLED manufacturing method.

Acknowledgements

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References

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Author Biography

Shinri Sakai is a research manager in the Corporate Research and Development Division of Seiko Epson Corporation. He received his B.E. and M.E. in mechanical engineering from the Tokyo Institute of Technology, Japan, in 1983 and 1985, respectively. He worked on inkjet print head development and is now working for OLED device development using inkjet technology. He also received PhD in material science and engineering from the Tokyo Institute of Technology in 2005.