Development of Next-Generation Inkjet Printer for High-Resolution QD-OLED Display

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Abstract

In this study, we developed an 8.5 generation inkjet printer that can produce 220 ppi QD-OLED panels which implement red, green, and blue colors using QDs as a color conversion layer. QDs have excellent color reproduction compared to OLED and the high contrast ratio, make it possible to achieve ultra-high definition. If these advantages of QDs are implemented at high resolution, clearer image quality can be obtained. In order to produce panels of 220ppi or higher, more precise head ejection and a stable ink circulation systems are required compared to existing facilities. To this end, we implemented a high-resolution inkjet printing system in three major development directions: inkjet stage correction technology, optimization of head ejection and ink circulation process, and printing pattern S/W technology. We have finally achieved production of 220 ppi (27” 5K) monitor panels, which is at the level of mass production defects.

Author Keywords

QD-OLED; Inkjet printer; 220 ppi; 5K; High-resolution.

1. Introduction

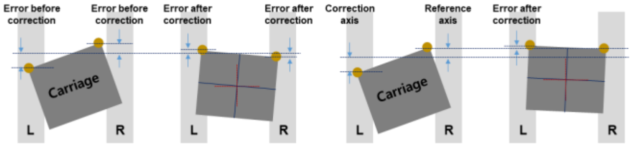
QDs (Quantum dots) have excellent color reproducibility due to its narrow half width characteristic compared to OLED (Organic light emitting diode) and does not suffer from burn-in, so it is attracting attention as a next-generation display [1-2]. In order to apply QDs to large-area display panels, a patterning process is essential. However, when applying existing lithography method, material consumption is very high, and QDs with large surface areas are prone to oxidation, resulting in a decrease in luminous efficiency due to surface defects [3]. Therefore, direct patterning of QDs is not suitable for the mass production processes, so patterning using inkjet printing is applied to the mass production process.

While the large panel market has recently stagnated due to sluggish demand in the TV market, demand for high-resolution monitors for gaming and high-definition video playback is increasing [4]. Therefore, in order to respond to this demand, we used QDs inkjet printing to build a high-resolution monitor production system of 220ppi or more that satisfies 5K at 27 inches. (5,000 pixels).

The Inkjet printing is a method of ejecting the target ink directly at the corresponding location, and it is important to accurately eject the droplets to the desired pixel in the target volume. High-resolution printing requires small droplets that can be ejected onto small R/G/B pixels, but it is very difficult to secure printing quality as resolution increases due to the sensitivity of small volume droplets to the surrounding environment such as air currents and temperature [5].

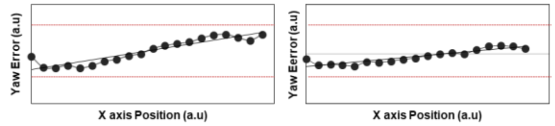
Therefore, in this study, in order to implement a high-resolution printing method of 220 ppi or more in a large area, an inkjet printing system was developed in three aspects: inkjet stage correction technology, optimization of head ejection and ink circulation process, and printing correction pattern S/W technology.

2. Inkjet stage correction technology



(a) Conventional method (b) Improved method

Figure 1. Interferometer correction about axis.



(a) Conventional method (b) Improved method

Figure 2. Calculated Yaw error.

Yaw reference error correction: The position accuracy of the stage (glass) and carriage (head array) of large-area inkjet printing is important. This is because positional errors during printing directly affect the landing accuracy. The axial performance of inkjet equipment is measured using a laser interferometer for verification and correction. In this study, a more precise correction method than the existing method was applied to satisfy high precision. A common correction method is to measure and correct the position error of the left and right drive shafts (Fig.1-(a)), and generally, Yaw (left and right twist) error is large after correction. To improve this, the Yaw error was minimized by measuring the left and right positions simultaneously (Fig.1-(b)) to minimize the yaw on the correction axis based on the reference axis. Through this, it was confirmed that the Yaw value was corrected additionally, improving the Yaw error by 40% (Fig. 2).

3. Inkjet head ejection and ink circulation process optimization technology

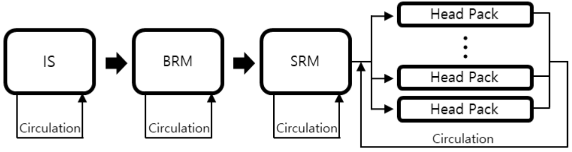


Figure 3. Schematic diagram of ink circulation system

Ink circulatory conditions: The circulatory condition of the Inkjet printing system was established using QDs ink, which is currently being applied to QD-OLED mass production (Fig. 3). The circulatory system consists of the Ink supply (IS), which first introduces ink, the Buffer Reservoir Module (BRM), which acts as a buffer and the Supply Reservoir Module (SRM), which supplies ink to the head packs, respectively. At each stage of the circulation system, a membrane filter is installed to filter out agglomerated particles. QDs ink contains TiO_2 particles to prevent blue light leakage and ensure viewing angle characteristics, so if a sufficient flow rate is not secured inside the circulatory system, TiO_2 particles may settle inside the head and circulatory system, adversely affecting inkjet characteristics. To minimize the influence of particle sedimentation, the flow rate inside the head should be set above a certain level. To ensure flow rates above this value, a pump was installed in the pipe from the SRM to the headpacks and the RPM was adjusted to the optimal level.

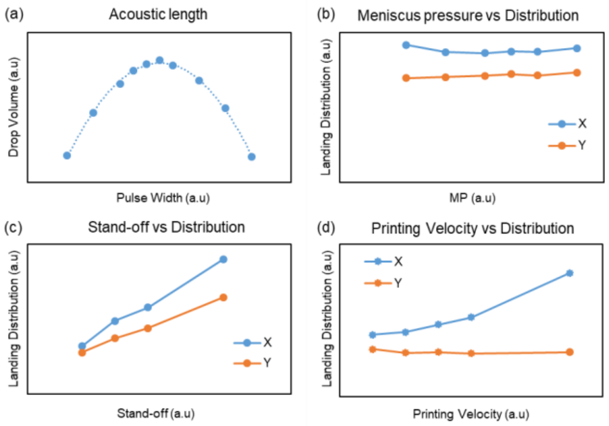


Figure 4. (a) Acoustic length, (b) Meniscus vs Distribution, (c) Stand-off vs Distribution, (d) Velocity vs Distribution

Head process condition: The head process conditions are shown in Fig. 4. The acoustic length where the amount of ejection is maximum was measured, and the waveform was set to the measured value. And the relationship between meniscus pressure and landing distribution was investigated. As a result, the landing distribution was almost constant regardless of the meniscus pressure. The smaller the stand-off, which is the distance between the glass and the nozzle, the better the landing accuracy. So the stand-off value was set to the minimum possible value. When printing, a slow stage speed is advantageous for landing accuracy in Y direction. However, according to the evaluation data, there was no significant difference at speeds below a certain level. The stage speed was set below a certain value that doesn't affect the landing distribution, taking into account the drop-to-drop distance, which determines whether two droplets can be ejected to one pixel in one scan.

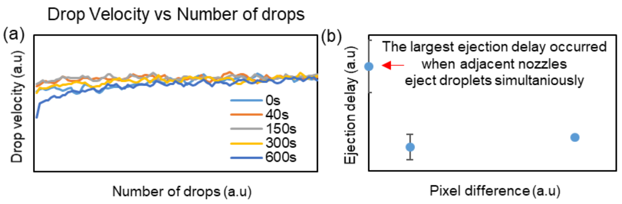


Figure 5. (a) Latency, (b) Cross-talk

Latency & Cross-talk: Fig. 5-(a) shows the latency characteristics of the head. It can be seen that the initial ejection speed is good up to 30 seconds of non-ejection time, but begins to decrease from 150 seconds or more. Printing conditions were set so that the non-ejection time was 30 seconds or less. When simultaneous ejection from adjacent nozzles occurs, causing the largest ejection delay and this phenomenon brings about mislanding of droplets which is called Cross-talk. In this study, the headpack was tilted by 5° to prevent simultaneous ejection from adjacent nozzles. Also, by arranging the heads that make up the pack in steps rather than simply overlapping, we attempted to minimize the overlap of the unique volume characteristics of the heads and thereby the mura defect appearing on the panel could be reduced.

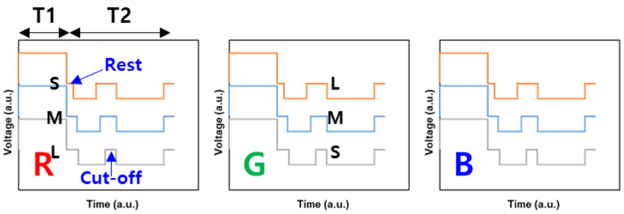


Figure 6. RGB Drop volume variation

Drop volume variation: By changing rest (change in the section where V = 0 when switching from T1 → T2) and cut-off (change in the section where V = 0 in the T2 section) which are controlling the motion of meniscus, we can control the drop volume by 3 levels (S/M/L) for each color. The controlled volume enables total volume in each pixels to be equalized and minimizes mura defect.

4. Printing correction pattern S/W technology

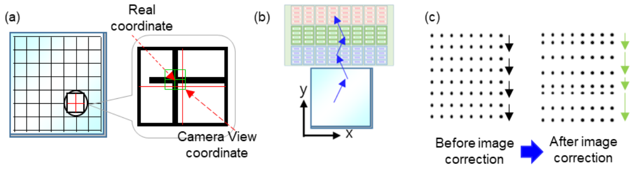


Figure 7. (a) Matrix correction (b) Scale X correction, (c) Scale Y correction

Matrix & scale correction: It takes a lot of time and money to find and correct the mislanding errors in each cause system. In this study, we devised a method to combine the results of multiple errors and correct them. As shown in Fig. 7-(a), the real coordinates of specific points on the glass are measured, then the camera is used to move to the location of the coordinates. The error between the real and the camera view coordinate is mapped. Afterwards, when calculating the coordinates of the real landing position, the results are obtained in an integrated coordinate system corrected through this error mapping, which is called matrix correction.

If the pattern is printed at equal intervals in X and Y over the entire area where the workbench moves, landing positions have errors compared to the target position. Scale correction is a very useful way to correct the X and Y by measuring errors for each section. In the case of an X direction, the errors can be reduced by moving the position of the worktable or head in the opposite direction by the amount of errors (Fig. 7-(b)) For Y direction, it is possible to reduce errors by reflecting them in the printing pattern image (Fig. 7-(c)).

5. Production & evaluation of 27” 220 ppi monitor

As described above, we developed inkjet stage correction technology, optimization of ink circulation and head process, and printing correction pattern S/W technology to improve landing accuracy. Based on this, we produced an 8.5 generation (8.5G) 27” 5K 220ppi panel. In the case of blue, it was formed using lithography process. Printing was performed on four types of pixel structures based on differences in aperture ratio, lifespan, reflectance, and white angular dependency (WAD). After inkjet printing, the glasses were passed through UV curing process.

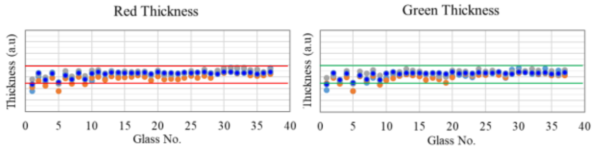


Figure 8. Film thickness of type 3 pixel

Film thickness: In the Fig. 8, the film thickness for type 3 pixel is shown according to the order of glass produced. In the initial process, if the thickness was lower or higher than the target, it was adjusted by changing the number of drops. It was able to obtain a thickness distribution value that satisfied the target through a mixing algorithm through volume calculation for each nozzle.

Starting position correction: Because large-area inkjet printing accompanies structural deformation and positional distortion of cameras, work tables, head carriages, etc., the final ejection start position must be adjusted based on the result of test printing on a dummy glass for accurate ejection. We checked the location and direction of the mislandings of the test printing pixel through auto optical inspection (AOI), and adjusted the starting position in the direction opposite to the mislanding.

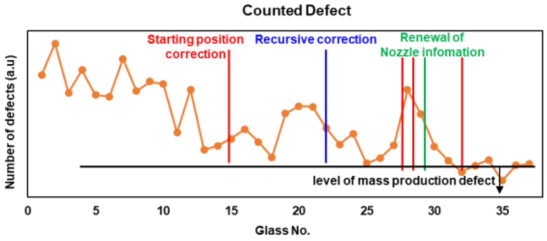


Figure 9. Change in number of defects

Pixel defect inspection by AOI: Fig. 9 shows the change in the number of defects by printing order. After UV curing, the substrate is imaged and if the shade differs by more than a certain value, it is detected as a defect. In the beginning of AOI, the number of defects was much higher than the mass production level. To improve this, starting position correction was performed based on the 12th panel measurement standard, and it was confirmed that the defect level was significantly reduced. Starting with the 19th glass, the number of defects increased again. By applying recursive correction to recalibrate the corrected nozzle, the accuracy of the Y-direction correction value was improved, and by updating the nozzle information to adjust the change in nozzle ejection amount over time, the number of defects was reduced to the mass production level.

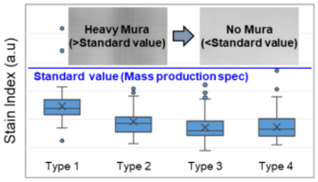


Figure 10. Mura index of 220ppi monitor

Mura index of 220ppi monitor: Fig. 10 shows the mura index of four types of pixels. If the mura index is above the standard value for mass production, the mura defect can be seen with the naked eye. However, if the mura index is below the standard value, the mura defect are not visible. Although there were differences in the four types of pixels, they all met the mass production standard or less and no mura defect were identified in the image.

Figure 11. A prototype of 27" 220 ppi 5K monitor

6. Conclusion Section

In this study, we developed Inkjet equipment for manufacturing high-resolution QD-OLED panels and evaluated printing of 27" (220ppi, 5K) monitor panel. We improved equipment stage precision, optimized printing process conditions and circulation system, and developed pattern S/W to strengthen corrections. Through corrections to reduce mislanding of ejected droplets during the process, we succeeded in producing panels at a level that satisfies the mass production. From the perspective of mass production facilities, improvements are still needed in terms of maintainability and productivity. However, it is significant in that it proved the feasibility of the high-resolution monitor printing mass production process using 8.5G equipment.

7. References

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