# A Study of Improving PLED Inkjet Printing Quality by Modifying Driving Signal

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## Abstract

Inkjet printing technology has been considered as the most promising process to fabricate full color Polymer Light Emitting Diode (PLED). However, ink droplet directionality of the print head significantly affects the yield rate for the manufacture of PLED displays during the printing processes. Because the physical properties of electro-luminescence polymer solution has a very large difference from the ink used in the commercial desktop printer. The driving signal of a commercial thermal bubble print head is not suitable for a print head designed for PLED. This study investigates how about the driving signal affecting the directionality of a print head for PLED solution's printing. With the specific optical observing system developed by ourselves, a fast and cost effective way to measure the directionality of a multi-nozzle print head become possible. The measuring processes include capturing the image of the ink drop on printing substrate firstly and then analyzing the images based on statistic and optimization theory. Three important parameters of the driving signal are discussed in this study. They are energy input, driving voltage and heating pulse width. The result gets an optimal combination of driving voltage and pulse width, which gives the best performance of droplet ejection directionality.

## Introduction

The inkjet printing technology has been developed since the 1960's and its application has been divided into two major printing types. One is the continuous printing type and the other is the drop-on-demand (DOD) type. DOD type of print heads is commonly used for inkjet printing, especially for many of the industrial applications. Printing technology is not only used for the highly resolution desktop printers but also applied to opto-electronics and biotechnology, etc. Two categories of ink jet print heads that are commonly used are piezoelectric ink jet (PIJ) print head and thermal bubble ink jet (TBIJ) print head. This study focuses on the application to the manufacturing of PLED display panel by the DOD type of thermal bubble inkjet print head.

PLED not only have characters of OLED but also have solubility quality different from OLED. For this reason it can use inexpensive process spin coating for large size area of fabricating. However, spin coating process just can manufacture the mono-color components but not include the full-color components. However, drop on demand printing type could print red (R), green (G) and blue (B) colors exactly on the region for your design of the products. Because of the advantages of easily and large area for manufacturing and with high resolution, it can fabricate inexpensive full-color PLED displays.

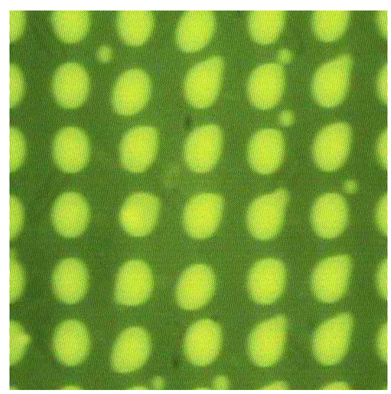

*Figure 1. PLED satellite drops*

It is not easy to apply the drop-on-demand printing technology to the PLED printing process. There is a critical technique in printing PLED process that is how to eject the drops into predicted small regions exactly. It will make color blending even short when drops can't be ejected into the predicted region exactly such as satellite drops and deflection of droplets. Figure 1 shows the satellite drops in PLED printing process and Fig. 2 shows the color blending for the PLED component. For this reason, printing quality of print head such as direction deviation and stability of droplets firing is very important for printing PLED process. There are many factors effect print quality, for example, the driving pulse function has a large influence on the printing quality of print head. This study will use a novel print quality measurement equipment and development the techniques to measure the printing quality of print head. It has been discussed that how to control these operational printing parameters such as input energy, electrical voltage input and heating pulse width, etc, to improve printing quality. Furthermore, it also has been searched for the best printing parameters of PLED printing process in this study.

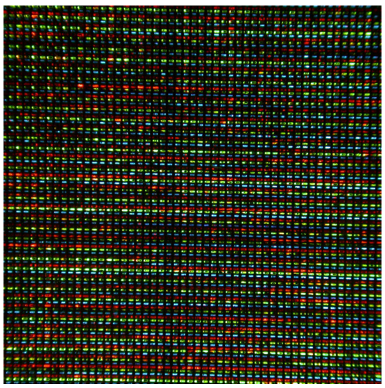

*Figure 2. PLED R, G, B color blending*

## Measurement Method

The experiment procedures are divided into four steps, which including filling of the solution of PF (Polyfluorene) with three different colors of R, G, B, into the cartridge then print the PF Red, PF Green and PF Blue, respectively, on the substrate with the inkjet print head fabricated by ITRI/OES. Next, taking the images of the printed results by quality measurement machine and finally analyzing these raw data form on the captured image. The principle and skeleton of printing quality measurement machine and technology are shown in Fig. 3. A hollow X-Y stage is placed between print head and image capturing set. This stage is used for supporting the print media and equipped an optical encoder with 0.1 µm resolution. Print head is set above the X-Y stage. Below the hollow X-Y stage is another X-Y stage, which is driving the CCD camera and lens. A Laser Displacement Sensor is also mounted on it. The drop flying distance and angle between nozzle plate and surface of print media can be measured from Displacement sensor.

The measurement starts with the adjustment of nozzle positions and angles, UV light direction and capturing the nozzle image for calculating later. Next step is to print the designed pattern on the substrate media by moving the hollow stage. Firing signal is triggered from position count of stage encoder. After printing finished, it is to move the hollow stage and get all the drop images. Compose images with capturing coordinates and calculate the center point of each printed dots.

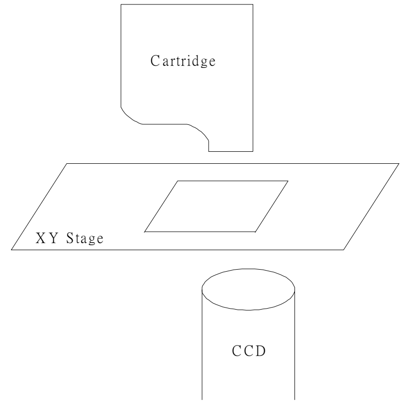


*Figure 3. Sketch of Experimental Setup*

The last step is to estimate the quality of these printed dots. Each nozzle deviation of the average droplet positions from their ideal position can be obtained by comparing each theoretical nozzle position with its corresponding average dot position. With the theoretical position of nozzles, an iterating equation is introduced to evaluate the most possible coordinate of nozzles. Then, the printing quality defined by the value of $q_T$ and is expressed as the following equation

$$q_T = \frac{\sum_{j=1}^{M} \sqrt{(x_j - X_j)^2 + (y_j - Y_j)^2}}{M} \quad (1)$$

where $M$ is the count of active nozzles, $x_j$ and $y_j$ are coordinate of dots center, $X_j$ and $Y_j$ are estimated nozzle coordinate. Printing quality value $q_T$ means how dots relative position fit theoretical nozzle relative position. Dots may out of the limited design range for too large value of $q_T$.

## Result and Discussion

The aims of this study is to discuss the driving signals such as the electrical voltage input, time period of heating pulse width and the overall energy input, etc. All these factors affect the print quality of print head for the liquid solutions of PLED material. It is also important to find the suitable operating parameters by using different kind inkjet print head design to fabricate PLED display. This study is divided into two major topics. One is to discuss the relationships between the voltage input and heating pulse width and printing quality at different input energy. The other is to discuss the relationship between input voltage, pulse width and printing quality at fixed input energy. Figure 4 and 5 show the results of distinct complete composed images by using image-processing skills to calculate the center of every dot.

*Figure 4. Composed dot image with capturing coordinates*

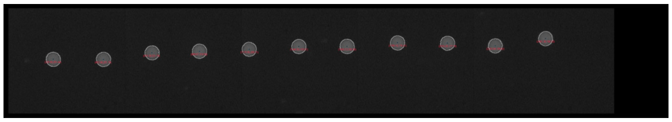

*Figure 5. Calculated the center of each dot*

Following equipment and material will be used in this study:

*Print head:* Print head used for printing the PLED display panel was fabricated by ITRI/OES (Industrial Technology Research Institute/Opto-Electronics and System Laboratories).

*Print solution:* PLED solutions are PF red, PF blue and PF green (Dow chemical).

*Measure equipment:* Measure machine of this study is the printing quality measurement equipment fabricated by ITRI/OES.

**Different Voltage and Pulse Width at Different Energy**

This experiment is about operating the print head for PLED at different voltages input between 10 and 20 volts and heating pulse width between 1 and 6 µs. When measuring quality of print head for PF green experiment, it shows that printing quality is better for printing PF green at voltage between 12 and 14 volts and PW = 3 (except for V = 12 volts), 4 and 5 µs (direction deviation is less than 20 µm) as shown in Fig. 6. The print quality will be bad and it can't even print at voltage of 10 volts or bigger than 14 volts and so it is not suitable for printing the PF Green solution. When measuring the quality of print head for PF Blue printing experiment, it shows that printing quality is good for printing PF Blue at voltage between 12 and 16 volts and PW = 3 (except for V = 12, 16 volts), 4 and 5 µs (direction deviation is less than 20 µm) as shown in Fig. 7. The print quality will be bad, furthermore it can't print at the voltage equal 10 volts or bigger than 14 volts and so it is disadvantageous for printing PF Blue. At experiment of PF Red, it shows that printing quality is good for printing PF Red at the voltage between 12 and 16 volts and PW=3 (except for V = 12 volts), 4 and 5 µs (direction deviation is less than 15 µm) as shown in Fig. 8 When print head being used for PF Red at voltage of 10 volts or bigger than 16 volts, printing quality will be very worst. Moreover, it can't print because that it is not suitable for printing the PF Red solution.

Conclusion from the above experiments reveals that the voltage input with much influence for printing quality than heating pulse width. It consists with the research of Chen et al. (1997). Their results show that the threshold operating voltage for ink ejection decreases with the input pulse width increasing. In addition, increasing the operating voltage causes a little volume change of the ejected droplet at a fixed input pulse width. Therefore, the droplet volume is only slightly affected by the variation of heating pulse when the operating voltage is kept at a constant value. Print quality will be affected acutely by changing input voltage, and it shows that voltage influence is bigger than pulse width according to following equation. The input energy has more significant influences than other parameters for the printing quality and it can be explained from the relationship of the following equations.

$$P=(R_h*V^2)/R_t^2 \quad (2)$$

and

$$E=P*PW \quad (3)$$

where $R_h$ is the heater resistance, $R_t$ is total resistance, V is the input voltage, PW the heating pulse width, P is power, and E is the energy input.

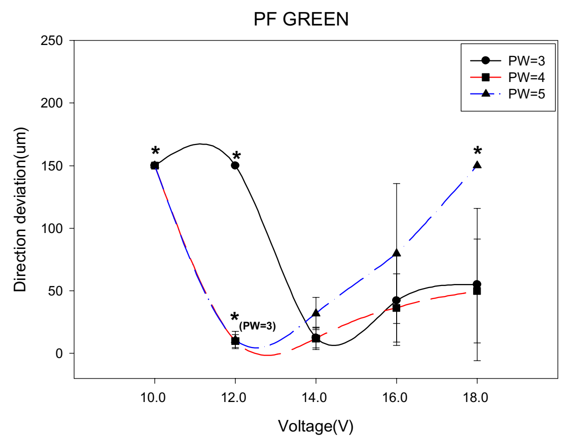


*Figure 6. Experimental results of PF Green at different input voltage and energy*

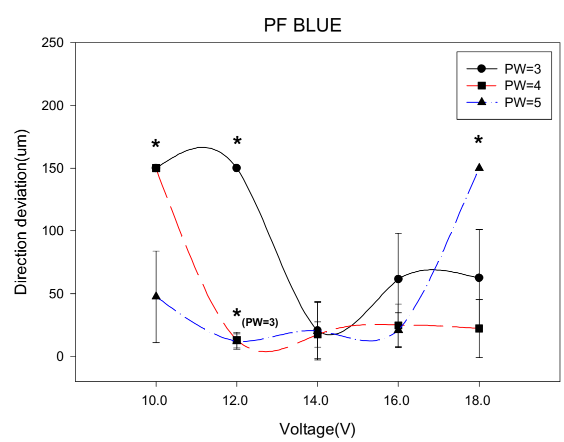


*Figure 7. Experimental results of PF Blue at different input voltage and energy*

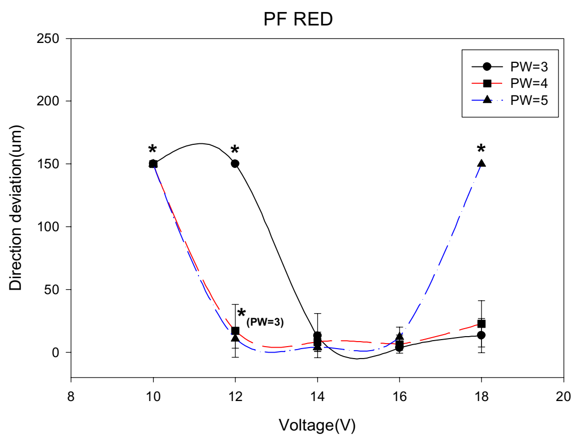


*Figure 8. Experimental results of PF Red at different input voltage and energy*

**Different Voltage and Pulse Width at Fixed Energy**

The experiments in this section are to change the time period of heating pulse width from 1 to 6 µs at fixed energy input for 10, 15, 20, 25 and 30 µJ, respectively, for the PLED solutions' printing. Firstly, printing quality for printing PF Green whose deviation of droplet ejection directionality less than 50 µm is good at the operational condition of E = 15 ~ 20 µJ and PW = 3~5 µs, as shown in Fig. 9. Printing quality for printing PF blue is good (direction deviation of print head is small than others, direction deviation les than 40 µm) at E = 15 ~ 25 µJ and PW = 3 ~ 5 µs, as shown in Fig. 10. Printing quality for printing PF Red is good (direction deviation less than 20 µm, which is the best among three of the PF solutions) at E = 25 ~ 30 µJ and PW = 3~5 µs, as shown in Fig. 11.

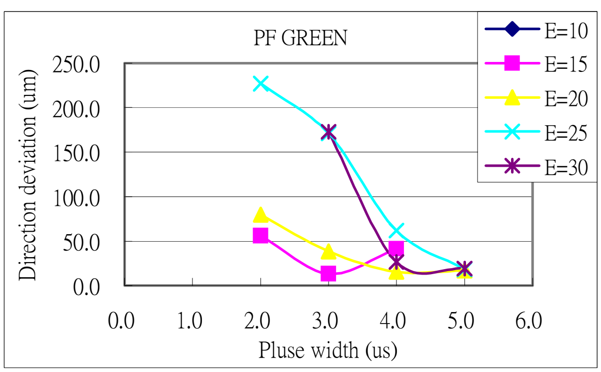


*Figure 9. Direction deviation of PF Green at fixed input energy.*

Concluding of the above experiment results show that changing of the energy input has great effect on print quality i.e. printed direction deviation. However, it can't explain the whole results if we only concern energy, according to experiment results that excellent print quality should cooperate input energy and printing pulse width. Furthermore, it will be excellent at the heating pulse width between 3 and 5 µs and it is getting worst when heating pulse width is bigger than 5 µs or smaller than 3 µs. For this reason, we conjecture that it needs even more high voltage to drive print head if printing pulse width is too small, however, a suddenly high voltage input will cause the printing unstable or non-printing condition or even damage the micro heaters within the inkjet print head. Besides, it needs just very low voltage input to drive the print head when heating pulse width is highly enough and it will have negative effects on the print quality that makes the deflection of droplet ejection.

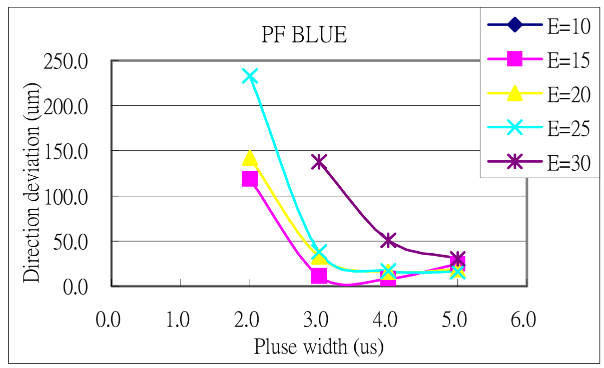


*Figure 10. Direction deviation of PF Blue at fixed input energy*

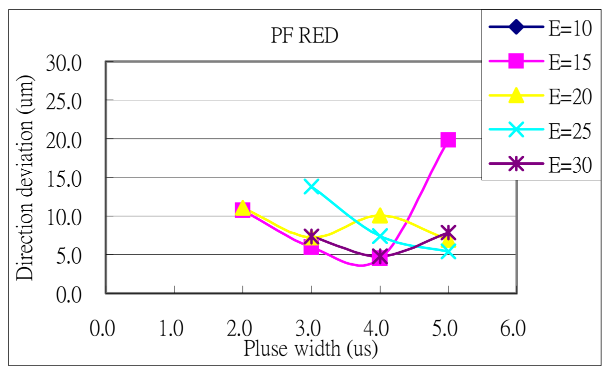


*Figure 11. Direction deviation of PF Red at fixed input energy*

## Conclusion

The input energy, input voltage and printing pulse width play an important role of printing PLED process by thermal bubble inkjet print head. There is an excellent print quality that needs for print head and these parameters be operated in coordination. For example, the best operational parameters of PF green is 12 volts, 4 µs for voltage input and heating pulse, respectively, with the minimum droplet direction deviation within 10 µm. For the best operational parameters of PF blue are V = 11.3 volts and PW = 4 µs with the minimum droplet direction deviation of 8.2 µm and V = 14 volts and PW = 5 μs at the minimum droplet direction deviation of 4 μm for PF Red's best operational parameters.

This study presented importance and influences of the operating parameters on the printing quality. As above description, it is strongly recommend that selecting of the suitable parameters should follow these steps. Firstly, it is to adjust the heating pulse width between 3 and 5 μs for searching the best parameters. Secondly, it is to adjust the voltage. In addition, we can follow the waveform control idea cited by Cheng[4] to get better parameters for print head.

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