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Motion stage technology for large size OLED flat panel inkjet printing equipment

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Abstract

In order to adapt to the accuracy requirements of high-resolution OLED RGB inkjet printing equipment, a new type of ultra-precision large-stroke motion stage was developed. Mechanically, both the stepping axis and the scanning axis adopt linear motor direct drive and air bearing guidance, and use a multi-degree-of-freedom fine-motion stage to compensate for the horizontal straightness error and yaw angle error of the scanning axis guide rail. In terms of measurement, multiple sets of laser interferometers are relied upon to provide real-time feedback on the position and attitude of the substrate stage. Through experimental data, the motion stage can achieve sub-micron accuracy. This precision lays a solid foundation for wet film formation in the OLED RGB printing process, effectively guarantees subsequent dry film formation, and achieves mura free for large-size panels.

Keywords: OLED inkjet printing process, Coarse-fine motion stage, Precision measurement

1. Introduction

In manufacturing processes such as OLED inkjet printing, TFT lithography, panel inspection and repair, the size of the substrate becomes larger and larger from G1 to G8.5, or even G10.5 (see Figure 1 for specific dimensions), and the substrate stage's moving range also increases at the same time. In terms of accuracy, with the improvement of substrate resolution, higher requirements have been put forward for parameter indicators such as the positioning accuracy of the substrate stage. Taking G4.5 inkjet printer as an example, the positioning accuracy of the workpiece motion stage can reach 1 micron or even sub micron. In the field of inkjet printing, several companies have done a lot of exploratory work.

David Albertalli [1] of Litrex Company proposed a conceptual design drawing of the G7 inkjet printer for the large-panel industry. The article briefly introduced the drop watcher and printhead module system, but did not describe the mechanical structure of the printer's motion stage in detail. Also from Litrex Company, Tianzong Xu et al. [2] introduced two types of inkjet printing equipment, G2 and G5, summarized the error sources that affect the accuracy of inkjet printing placement in the moving platform, and conducted a detailed study of the compensation methods for various error sources. Jun H. Souk et al. [3] from Samsung Electronics have developed a color filter inkjet printing equipment for TFT-LCD panels, with a panel size of G8. The article contains design drawings and physical drawings of the inkjet printing equipment. The maximum printing speed of the equipment reaches 600mm/s, the droplet placement accuracy is $\pm$15 microns (1 mircron = 1μm), and it is equipped with 24 printheads. The time to complete the full-page printing is 180 seconds.

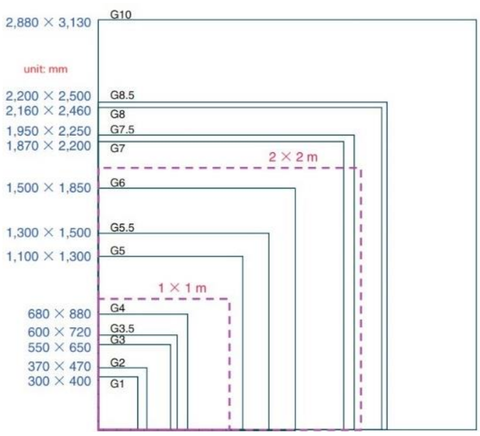


Figure 1. Dimensional drawings of substrates of each generation

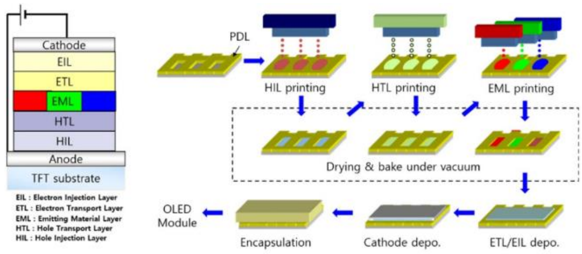


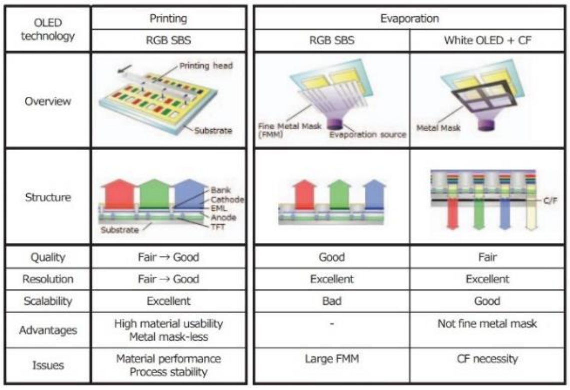
Figure 2. OLED device structure and its inkjet printing process flow [4]

2. OLED inkjet printing process and accuracy analysis

2.1 OLED inkjet printing process

Inkjet printing (IJP) technology is a process that can directly pattern deposit thin films and can achieve efficient patterning processing on flexible and large-area substrates. Inkjet printing technology has the advantages of high resolution, high degree of automation, low cost, simple manufacturing process, high material utilization, low environmental pollution, and is suitable for large-size screen production. The application of inkjet printing technology to OLED flat panel displays has great potential.

Nowadays, the OLED production process is usually prepared by the evaporation method. The organic material is heated in a vacuum environment to evaporate it and deposited on a glass substrate covered with a mask to form a film.



OLED technology	Printing	Evaporation	
	RGB SBS	RGB SBS	White OLED + CF
Overview			
Structure			
Quality	Fair → Good	Good	Fair
Resolution	Fair → Good	Excellent	Excellent
Scalability	Excellent	Bad	Good
Advantages	High material usability Metal mask-less	-	Not fine metal mask
Issues	Material performance Process stability	Large FMM	CF necessity

Figure 3. Comparison between printing process and evaporation process [5]

2.2 Printing accuracy analysis

The inkjet printing comprehensive accuracy depends on the accuracy of the printhead, the accuracy of the motion stage and the accuracy of the substrate [3]. The error tree of comprehensive accuracy is shown in Figure 4. The height between the printhead and the substrate affects the accuracy of the droplet placement, so the printing height (print gap) is listed as the printhead accuracy.

The accuracy of the printhead consists of two parts. One is the geometric accuracy of the nozzle in the printer. During the printing process, there is a six-degree-of-freedom error regardless of whether the printhead is stationary or moving. As shown in Figure 5, the machine tool slide moves linearly

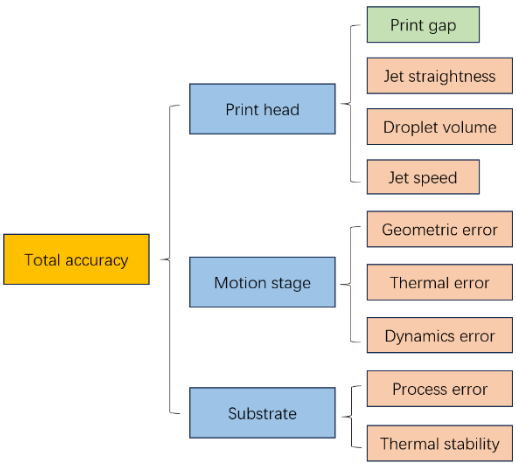


Figure 4. Inkjet printing comprehensive accuracy error tree

along the z-axis guide rail. The silder has three translation errors: positioning error EZZ, horizontal straightness error EXZ, vertical straightness error EYZ, and three rotation errors: roll ECZ, pitch EAZ, yaw EBZ. The second is the physical performance parameters of the printhead: jet straightness, droplet volume/diameter and jet speed.

The accuracy of the motion stage mainly includes the geometric accuracy, thermal error and dynamic error of the printer's motion axis. Since thermal errors are difficult to evaluate and build models for compensation, this article only considers the geometric accuracy of the printer's main motion axes. Like the motion axis of the printhead, the motion axis of the substrate stage also has six degrees of freedom errors. The substrate accuracy consists of the processing accuracy of the previous process and the thermal

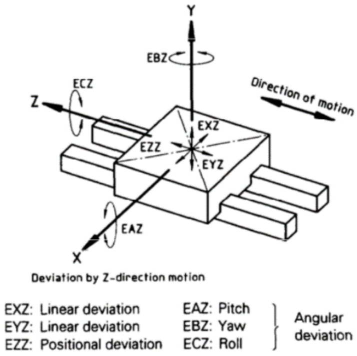


Figure 5. Schematic diagram of the six-degree-of-freedom error of the machine tool slide [6]

deformation of the substrate. To ensure high-quality inkjet printing, substrate accuracy must be strictly controlled.

Jet straightness directly affects the placement accuracy of ink droplets. The ink droplet can be regarded as an ideal sphere during flight, and the diameter of the ink droplet can be calculated according to the formula of the ink droplet volume. Substrate pixel density ppi (pixels per inch) represents the number of pixels per inch. The higher the ppi value, the smaller the pixel size. For example, the sub-pixel width of a 202ppi substrate is 34.5μm, while the sub-pixel width of a 300ppi substrate is 20.8μm.

Assuming the droplet physics parameters such as volume and jet speed are under good control, and jet straightness is zero, the primary error is positioning error. However, the droplet jet straightness can not be ignored, the print height multiplied by the tangent value of jet straightness is equal to the droplet placement accuracy. Therefore, in this article, the positioning accuracy of the motion stage and the static placement accuracy of ink droplets are the main sources of error.

As shown in 6a (left), the sub-pixel pitch corresponding to 202ppi is 42μm, the diameter of the 7pl ink droplet jetted from the printhead is 23.7μm, the sub-pixel slot width is

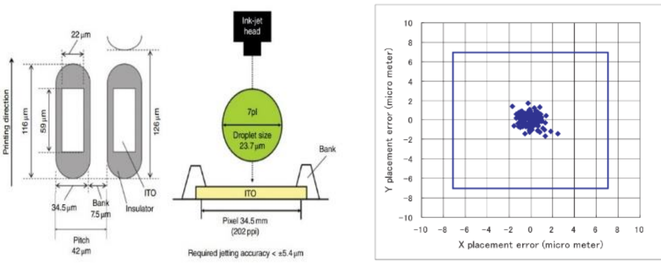


Figure 6. Printhead, ink droplets and sub-pixel slots [7][8][9]

34.5um, and the ink droplet placement accuracy is required to be ±5.4μm.

The ink droplets fall vertically into the sub-pixel slot in the ideal state, without considering the error caused by the straightness of the ejection. Under normal circumstances, there is a jet straightness error when ejecting ink droplets from a nozzle, and this error conforms to a normal distribution. Assume that the ink droplet jet straightness of a certain nozzle is θ and is 3mrad, satisfying the normal distribution 3 sigma, the height h_g from the printhead to the substrate is equal to 500um, and the placement accuracy δ = $h_g$tanθ. The calculated result of δ is 1.5μm. The accuracy of the placement is distributed in two-dimensional space, as shown in Figure 6b (right). The ink droplet placement is in the xy two-dimensional coordinate system, δ_x = δ_y = ±1.5μm. Nozzles that exceed this error range are closed by the printhead control board. Otherwise, ink droplets risk flying out of the sub-pixel slots, causing printing defects [10].

3. Motion stage structure

3.1 Current status of large-size panel motion stage

In the past two decades, with the popularity of LCD TVs, the large-size flat panel industry has developed rapidly. Starting in 2000, the substrate size was only 700mmx900mm. By 2018, the G10.5 generation panel size reached 2940mmx3370mm. The panels are getting larger and larger, and the stroke and accuracy of the substrate carrier and motion stage are increasing at the same time.

In flat panel exposure machines, large-stroke high-precision motion stage are widely used [11][12]. Nikon officially released new FPD exposure equipment corresponding to G10.5 glass substrates in 2018. Compared with the existing G10 exposure equipment, the G10.5 exposure equipment has improved exposure and calibration sequences to achieve faster and more precise exposure.

3.2 Inkjet printer motion stage design

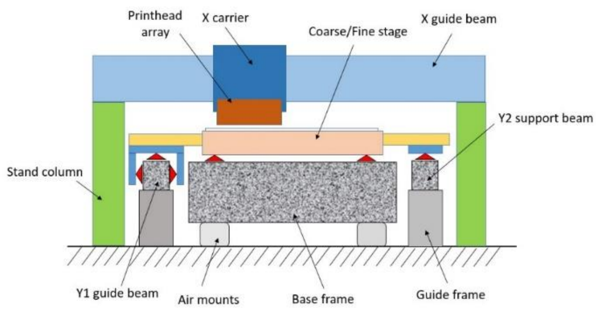


Figure 7. Main structure of inkjet printer motion stage

Design a motion stage that covers the printhead array sliding stage and the glass substrate carrier. The substrate size is 920mm×730mm (G4.5). The printhead array slide stage makes a stepping movement along the X-axis guide rail with a stroke of 1500mm; the glass substrate stage makes a scanning movement along the Y-axis guide rail with a stroke of 2200mm. As shown in Figure 7, the inkjet printing equipment mainly consists of a base frame, guide frame, printhead array, glass substrate stage, air mounts, etc. The glass substrate stage includes a dual-drive servo-controlled coarse stage and a multi-voice coil motor servo-controlled fine stage. The total weight of the substrate stage is 1.2t, the maximum movement speed is 500mm/s, and the positioning accuracy is ±3μm.

3.3 Multi-degree-of-freedom substrate stage

When the coarse motion stage moves along the Y-axis guide rail, there are positioning errors, angular errors and straightness errors. The positioning accuracy of the coarse motion stage can reach 1 micron using laser interferometer measurement data compensation. Angle error (Yaw error) and horizontal straightness error can be measured with a laser interferometer. For a guide rail with a length of about 3 meters, the horizontal straightness error reaches tens of microns. To achieve high-quality printing, improve the placement accuracy of ink droplets, and allow large amounts of ink droplets to be accurately and stably ejected into designated sub-pixel slots, a fine-motion stage mechanism is required to compensate for errors in real time. In addition, the fine-motion stage mechanism is required to correct the

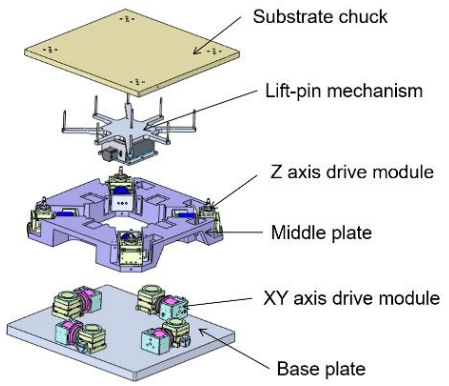


Figure 8. Schematic diagram of fine-motion stage mechanism

angle deviation of the substrate caused during the substrate loading process.

The fine-motion stage can complete six degrees of freedom micro-movement. As shown in Figure 8, the six-degree-of-freedom fine-motion stage is composed of upper and lower fine-motion mechanisms connected in series. The upper fine-motion mechanism is divided into a substrate suction plate, an intermediate drive plate and a Z-direction drive module. Four independently controlled Z-direction drive modules support the substrate suction plate, and use the middle drive plate as a reference object for relative movement to realize Z, θ_x , θ_y micro-movements of the substrate suction plate along the Z axis and around the X/Y axis. Four XY-direction drive modules are installed on the base. The middle drive plate uses the base as a reference object to make relative movements to achieve X, Y, and θ_z micro-movements along the X/Y axis and around the Z axis. There is also a Lift-pin mechanism inside the micro-motion stage. When the glass substrate is loaded and unloaded, the Lift-pin mechanism rises. When printing, the Lift-pin mechanism is in a contracted state.

3.4 Measuring system

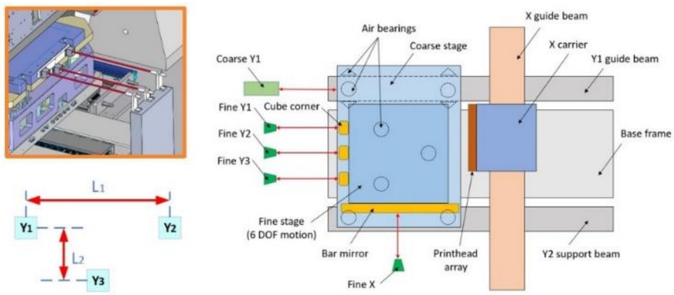


Figure 9. Coarse-fine stage measurement system. The upper left figure shows the spatial geometric position relationship between the three-way laser interferometer and the substrate chuck, and the lower left figure shows the plane geometric position relationship of the three corner cubes.

Precise measurement to realize the precise positioning of the coarse-fine-motion stage in the printing equipment. The coarse-motion stage moves along the guide rail Y1, and the laser interferometer Y1 measures the position of the coarse-motion stage in real time, and feedback the position signal to the motion controller, so as to realize the uniform speed control of the coarse-motion stage.

The attitude of the fine-motion stage in the inkjet printer space coordinate system is obtained by measuring the laser interferometers Y1, Y2, and Y3. Three corner cube prisms are

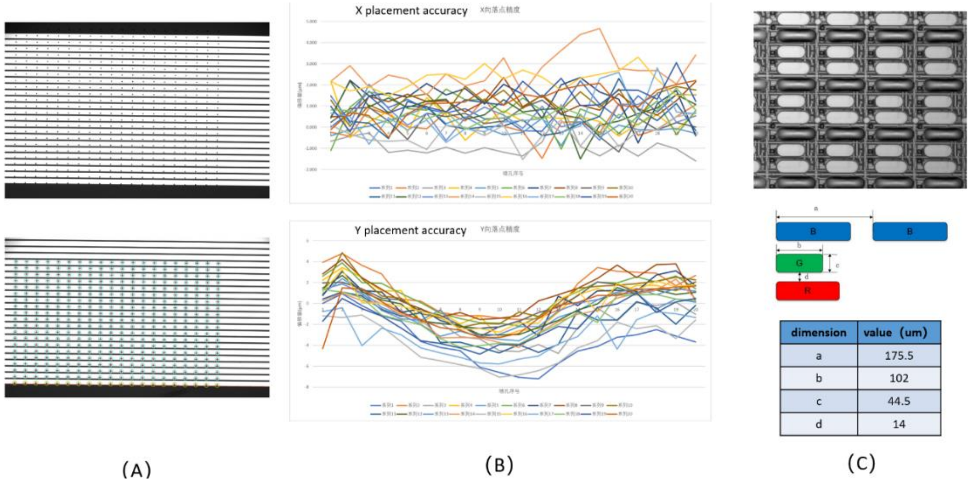


Figure 10. OLED ink printing test results

fixed on one end of the upper plate (substrate chuck) of the fine-motion stage. Details are shown in Figure 9. Real-time measurement of Y axis positioning accuracy、 yaw error around Z axis and pitch error around the X axis. Combining forward and inverse kinematics, the adjustment parameters of the fine-motion stage can be obtained. The specific calculation formula is as follows:

$$y = (Y_1 + Y_2)/2 \qquad (1)$$

$$\Theta_z = \arctan\,[(Y_1 - Y_2)/L_1] \qquad (2)$$

$$\Theta_x = \arctan\,\{[\frac{Y_1+Y_2}{2} - Y_3]/L_2\} \qquad (3)$$

In formula (1), y represents the positioning of the fine-motion stage along the Y axis, and Y1 and Y2 represent the length measurement values of the laser interferometers Y1 and Y2 and the corresponding corner cubes. In formula (2), L1 represents the horizontal distance between corner cube Y1 and Y2. In formula (3), Y3 represents the length measurement value of the laser interferometer Y3 and the corresponding corner cube, and L2 represents the vertical distance between the corner cube Y1 and Y3.

4. Measurement data and print test

The inkjet printing equipment printed substrates at 80ppi, 137ppi, and 144ppi in the clean room of the laboratory. In Figure 10 (A) shows ink droplet placement accuracy test board and image processing software which can calculate the ink droplet's placement accuracy. There are a total of 20 columns of ink droplets in each image, which means that 20 nozzles participate in scanning printing, and each nozzle jets 20 droplets. From the figure, it can be seen that the ink droplets accurately placed in the test area.

Figure 10 (B) shows accuracy curve of ink droplet placement. Top figure shows the placement accuracy of ink droplet in X-direction, with a maximum error is 4.664 µm. Minimum error is -1.597µm. Down figure shows the placement accuracy of ink droplet in Y-direction, with a maximum error 4.845 µm. Minimum error is -7.212µm. The volume of ink droplets used for testing is 3.7pL, and the diameter of ink droplets is 19.2µm. According to the placement accuracy of the Y-direction, ink droplets can accurately fall into the R/G/B sub pixel slots.

In Figure 10 (C), the top figure shows the printing results observed by a high magnification CCD camera. From a local perspective, the ink droplets have accurately and evenly fallen into the R sub pixel slot. The middle figure shows the 144ppi substrate pixel map. The down figure shows the pixel size table of the 144ppi substrate.

5. Conclusion

In this paper, we developed a new type of motion stage whose performance parameters meet the requirements of high-resolution OLED substrate inkjet printing process. The key axis positioning accuracy of the motion stage is ±1 µm, and the repeatable positioning accuracy is ±0.8 µm. The accuracy of ink droplet placement is better than 3 µm.

Acknowledgments

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