OLED Display Device Fabricated by Inkjet Printing Process

Liu Xin[1], **Ye Yun**[1], **Tang Qian**[1], **Guo Tailiang**[1], **Cao Xianghong**[1], **Yu Yongshen**[1]

[1] College of Physics and Information Engineering, Fuzhou University , China

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ABSTRACT

In this work, a multilayer OLED device is fabricated by inkjet printing process. Optimized bank structure is used to improve the sub-pixel uniformity. By adjusting the process parameters such as plasma processing time and vacuum dry speed, the quality of the film fabricated by inkjet printing is improved. The pixel resolution of OLED display is 119 ppi. It could meet the demand of industrial products.

1 INTRODUCTION

Since Dr. Deng Qingyun invented OLED (Organic Light Emitting Diode) in 1987, OLED has received wide attention due to its high brightness, high contrast, wide viewing angle, fast image response speed, low energy consumption and flexible processing. Nowdays, OLED displays are widely used in small portable devices such as smart watches and mobile phones, and also have taken attractive market share in the high-end TV field. However, due to high manufacturing costs, the market share of large-size OLED displays is still far behind many low-cost competitors. Nowadays, there are two mainstream technologies adopted for OLED displays fabrication. One is to use a vacuum evaporation and FMM (Fine Metal Mask) mask to achieve patterned RGB pixels, and the other is vapor deposited white OLED + RGB color film. But it is not cost competitive with LCD.

Inkjet printing is an important solution processing technology for RGB color pixels. The inkjet printing process has precise droplet landing and ultra-high material utilization, helping to reduce the cost of OLED displays. The simple light-emitting structure and inexpensive process make the inkjet printing process the focus of low-cost OLED panel production technology. In addition, inkjet print processing OLED displays can be easily extended to large sizes based on precise drop control during printing. An inexpensive conventional mask can replace the expensive FMM to meet the requirements of cathode deposition, which can further reduce production costs. Therefore, inkjet printing technology has more advantages in the application and promotion of OLED displays.

Inkjet printing is undoubtedly one of the most promising methods for manufacturing various organic electronic devices, which is easily to fabricate, at low temperatures, low cost and flexible device. But most of inkjet printed OLED are single layer device structures. There are two problems in fabricating multilayer structure of OLED devices by inkjet printing process. Firstly, most small molecules are poorly membrane forming and cannot form a complete film through the solution process. Secondly, due to the problem of the interlayer dissolution, the former layer would be redissolved by the latter layer, which makes it difficult to form a multilayer structure. Despite the limitations of inkjet printing technology, it is still possible to produce high resolution displays with good performance. In this paper, we have successfully demonstrated a 119 ppi OLED device by the inkjet printing process. We used 128 nozzles to print simultaneously by adjusting the waveform of the printer nozzle. By optimizing the inkjet printing process, adjusting the pre-processing and post-processing methods of the substrate, the uniform inkjet pringting film can be obtained, improving the efficiency and lifetime of inkjet printed OLED devices. The inkjet printing process performance of the device is close to the vacuum evaporation device, but the cost will be greatly reduced due to the low cost of solution process.

2 EXPERIMENT

OLED devices were fabricated onto ITO substrates. Prior to the inkjet printing process, the substrate was rinsed with deionized water for 10 mins and blow dry with nitrogen. The substrates were prepared by an O_2 and CF_4 plasma surface treatment. The first layer PEDOT:PSS is poly-(3,4-ethylene dioxy thiophene):poly(styrene sulfon -ate)(CLEVIOSTM P VP CH 4083, purchased from HC Starck). PEDOT:PSS was inkjet printed on a pre-cleaned ITO substrate in the form of a 40 nm film and then baked at 140 ℃ for 10 min. Self-synthesized DB8CBTC material was dissolved in cyclohexanone and butyl benzoate, then inkjet printing to form a 50 nm film, then baked at 120 ℃ for 10 mins. The 2,2',2"-

(1,3,5-Benzinetriyl)-tris(1-phenyl-1-H-benzimidazole)(TPBi, from from Bao Laite Technology Corporation), acting as the ETL and dissolved in methyl benzoate and inkjet printing to form a 40 nm film. All Solvents used in the ink formulations (Cyclohexanone, Butyl benzoate, Methyl benzoate and 1,3,5Mesitylene) were purchased from Aldrich. All the formulations have been fifiltered with a 0.22 mm filter head before fifilling on a clean cartridge of the printer. Inkjet depositions were performed with a Meyer Burger LP50 using a Spectra SX3 printhead composed of 128 nozzles with a pitch of 508 μm and a drop volume of approximately 12 pl.All solutions and annealing were carried out in a low humidity (<1 ppm) and oxygen (<1 ppm) glove box.

The device structure of the inkjet printed OLED is illustrated in Fig. 1(a). Fig. 1 (b) shows the energy design of a multilayer device structure. In each case, the hole injection Layer (HIL), emissive layer (Green EML) and electron transport layer (ETL) are inkjet printed. The electroluminescence (EL) spectra was measured with a Spectra Scan PR655. The current-voltage luminance (J-V-L) relations were characterized with a computer controlled Keithley 2400 Sourcemeter.

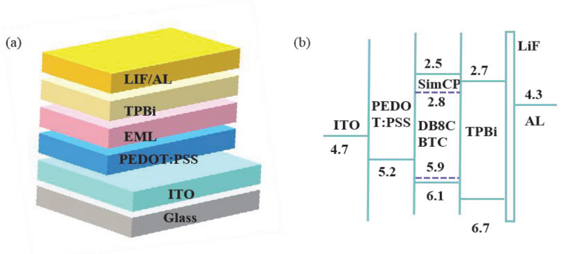


Fig. 1 (a)Structures of the OLED device. (b)Energy levels of the materials used for the OLED stack.

Figure 2 shows the pixel structure of an OLED display. We selected the pixel width of 70 μm and the pixel height of 100 μm. For confining ink in the pixel, photoresist insulating bank which has thickness of 1 μm was formed on the indium tin oxide (ITO) patterned glass. We fabricated inkjet printed OLEDs devices on 54×18 pixel array so as to identify the performance of the devices.

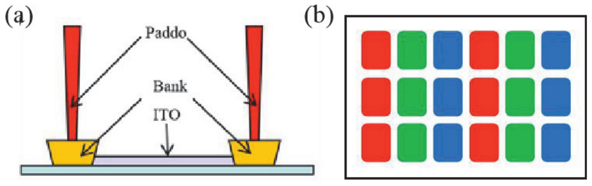


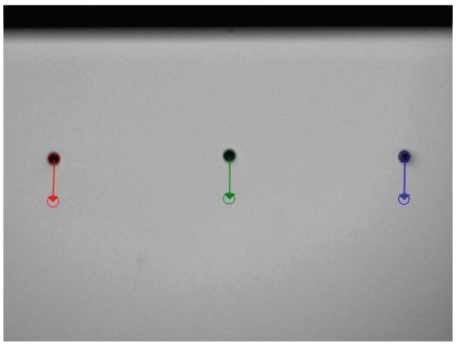
Fig. 2 Pixel Structure

(a)Cross-section of a pixel. (b) Dot-pixel structure.

3 RESULTS

In OLED devices, variations in film thickness have a large impact on device performance. Due to the poor uniformity of the printed film in the bank, OLED devices have uneven luminance, short life and low efficiency. In the study of inkjet printing organic materials for the OLED devices, we found that liquid-solid interfacial wettability and inter layer solution erosion are important scientific issues. On the basis of high efficiency small molecular organic materials, we can obtain a very uniform film by selection printing solvent, controlling the plasma processing time and vacuum dry speed. We can improve the uniformity of the film by increasing the printing speed as soon as possible. And multi-nozzle fast printing meets the needs of industrial production. In this experiment, we increased the printing speed by using multiple nozzles for simultaneous printing.

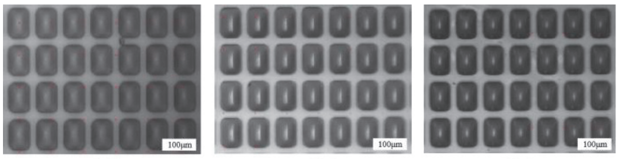
Important technical specifications for inkjet printers/printheads include the positioning accuracy of droplets, inkjet droplet volume, and printing reliability. The target position of the drop is determined by the geometric pattern of the display, the drop volume is primarily determined by the diameter of the printhead. Since the pixel size of the display screen is generally on the order of micrometer. The smaller and more precisely positioned the droplets, we can get the higher pixel resolution. Inkjet depositions were performed with a Meyer Burger LP50 using a Spectra SX3 printhead composed of 128 nozzles with a pitch of 508 μm and a drop volume of approximately 12 pl.We adjusted 128 nozzles for simultaneous printing by adjusting the piezoelectric waveform of the printhead. The movement of the printer during operation causes the ejected ink to have a horizontal velocity component. When the pressurization rate is decreased, the ink droplet ejection speed is reduced, and the flight path is affected by the lateral velocity component. Obviously, the pattern will shift toward the moving direction of the printer. On the contrary, when the pressurizing rate increases, the ink droplet exiting speed increases, and the head-to-tail speed difference increases, causing the liquid column to be easily broken, resulting in a large amount of satellite ink. drop. Within a certain range, when the pulse duration decreases, the pressure waves generated in each cavity cancel each other, the velocity and size of the ink droplets decrease, the ejector energy of the ink droplets decreases, and the pattern is also prone to lateral shift. The pressure waves in the ink chamber are not completely superimposed, so that the pressure waves of different portions of the ink droplets are different in intensity, so that a large speed difference causes the ink droplets to split and the satellite ink droplets to increase.



	v (m/s)	V (pl)	X (μm)	Y (μm)	Angle (°)
→	3.08	± 18.1	147	444	-1.14°
→	3.09	± 19.4	658	435	-0.51°
→	3.06	± 15.3	1167	438	-0.52°

Fig. 3 Droplet analysis

Figure 4 shows an example of printing a HIL+ EML+ ETL multilayer film on a 119 ppi bank substrate. In inkjet printing, the key to film uniformity typically involves plasma processes, adjust printing process parameters and vacuum drying systems. When the processing conditions are not suitable, the inkjet printed film exhibits a slight U-shape along the outline of the short pixel axis, has a minimum at the center of the pixel, and is curved upward toward the edge of the pixel. Some accumulation can be observed at the edge of the pixel. By selecting a suitable pretreatment gas and duration, it helps to form a uniform film. By changing the speed of vacuum drying, the pinning point can be prevented from moving down the bank during the drying process. The same process applies to the subsequent layers of EML and ETL.



（a） （b） （c）

Fig. 4 Images of wet pixels immediately after the printing

(a) Print the HIL layer (b) Print the HIL+EML layer (c)Print the HIL+EML+ETL layer

4 DISCUSSION

Fig. 5 shows the lighted pixel pictures with microscope. Flatness of organic layer inside of the pixel is a very important parameter for inkjet printing OLED displays. By controlling the process parameters such as plasma processing time and vacuum dry speed, we were able to obtain very uniform pixels and improved the efficiency and lifespan of the devices.

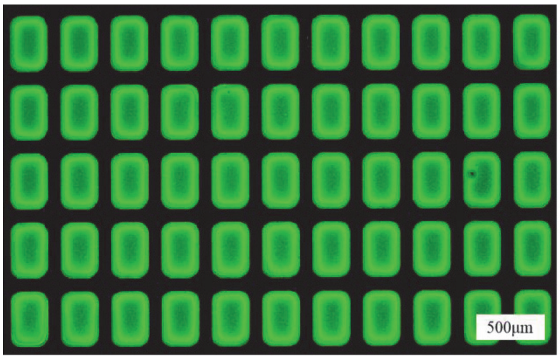


Fig. 5 Inkjet printed OLED in pixel well.

5 CONCLUSIONS

In our study, we have shown that 119 ppi resolution devices can be printed by simultaneous multi-nozzle printing. And the inkjet printing process can be used for small-sized, medium-sized and large-sized displays. We demonstrated that the quality of the film produced by the multi-nozzle simultaneous printing technology is suitable for industrial production.

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