Mask-free Fabrication of Color Filter by an All Ink-Jet Printing Process

Fu-Kang Chen, Jhih-Ping Lu, Pei-Ju Su, Chao-Fu Sung*

Yuh-Zheng Lee, Jyh-Wen Shiu and Kevin Cheng*

DTC / Industrial Technology Research Institute, Hsinchu, Taiwan, R. O. C.

Hong-Ye Lin, Li-Chung Chang

AGI corporation, Taoyuan, Taiwan, R.O.C.

**Correspondence Author:*

Fu-Kang Chen, hans@itri.org.tw

Yuh-Zheng Lee, YZLee@itri.org.tw

DTC/Industrial Technology Research Institute, Taiwan, R. O. C.

Abstract

In the past decade, the mask-free process has been developing to be able to make color filters by discharging each color of ink to the predetermined substrate, and then curing the ink to form the color filter pattern. A special feature of this paper is that only the ink-jet printing process is performed for enclosed banks and color resists formation on a bare substrate. The printed sub-pixel size is 130 um wide with a bank width of 15 um. The resulting color coordinates of three colors (red, green, and blue) on the chromaticity diagram are (0.7, 0.3), (0.33, 0.6) and (0.14, 0.09). The rendered excellent color performance of 68% NTSC area was achieved at 3 um thick films. Compared with commercial standard color filter material, acceptable △E value (<3) was achieved for each color in the heat, light, and chemical test. This novel fabrication process is compatible with flexible substrates and can provide low-cost ink-jet printed color filters for the future flexible display.

Introduction

A color filter with three primary colors is a very important component of full color liquid crystal flat panel display (FPD) in modern appliances. In the past two decades, the major fabrication method for color filters has been based on the lithographic process, the same as that for integrated circuits (ICs) manufacturing, but with lower resolution for the former application. However, due to the demand for better entertainment performance, the size of new dream FPDs grows rapidly, and so does the size of substrates and related manufacturing equipment. As the substrate size increases, the complex processes and expensive equipment of the traditional lithographic process will reduce the yield and therefore increase the fabrication cost. In order to solve the aforementioned emerging shortcomings, much effort has been devoted to pursuing a new method for low cost and low waste issues in recent years [1,2]. Ink-jet printing technology is one of the potential candidates because of drop-on-demand discharging, wide format printing capability, and highly efficient material usage.[3-7] It has been intensively verified and gradually realized to make color filter components larger and cheaper. An eighth-generation, mass production ink-jet printing line for producing large size color filters for TV application has been announced recently [8]. Though color resist patterning processes are successfully replaced by inkjet printing technology, the banks for separating R,G,B resist still need to be patterned by photolithography. A fine bank pattern fabricated method is greatly desired for all mask-free color filter panel fabricating.

Coffee ring is a natural phenomenon to form a narrower, thicker ridge in periphery when a drop is dried. The mechanism is described in Fig. 1 [9]. The ridge width is usually around several tens of micrometers and has features which are very suitable for bank design. Therefore, we used the ring shape microstructure as banks for the printing color resist ink, and then finished a 7" QVGA color filter panel by using this all inkjet printing technology.

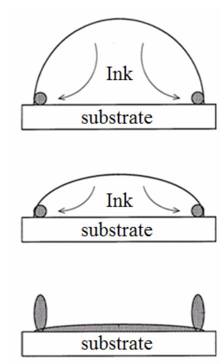

Figure 1. *Mechanism for forming coffee rings*

Experiment

In this study, we used the ink-jet printing method to fabricate a high saturation color filter without using any lithographic process. Besides the three color resists, the bank pattern for confining landing inks was formed by ink-jet printing as well. After routine sonic bath cleaning, a bare glass substrate was treated with proper oxygen plasma. Then, we printed the PMMA solution to be banks on the glass plate, using a 3-Gen printing system integrated by ITRI.

The fabricating illustration of an all inkjet color filter panel is shown in Fig. 2. In Fig. 2(a), first, the PMMA solution was dissolved in anisole with a concentration of 0.8 wt% and then a stripe line with a dot pitch of 60 um was printed onto a cleaned bare glass. In Fig. 2(b), after the ring shape was formed, oxygen and CF4 plasma was subjected to etching out the thinner part inside the ring ridge and making the ridge ink-repellant. The reserved ridge width of each printed PMMA bank was about 15 um. In Fig. 2(c), after forming the stripe-type trenches pattern, the substrate was baked on a hot plate at 100 °C for 30 min, then we deposited red, green, and blue color resists, from AGI Corp., into the resulting banks in sequence by inkjet printing [10-12]. In Fig. 2(d), finally, we finished the color filter plate after baking at 230 °C for 20 min to remove the residual solvent and make the resist cross-linking.

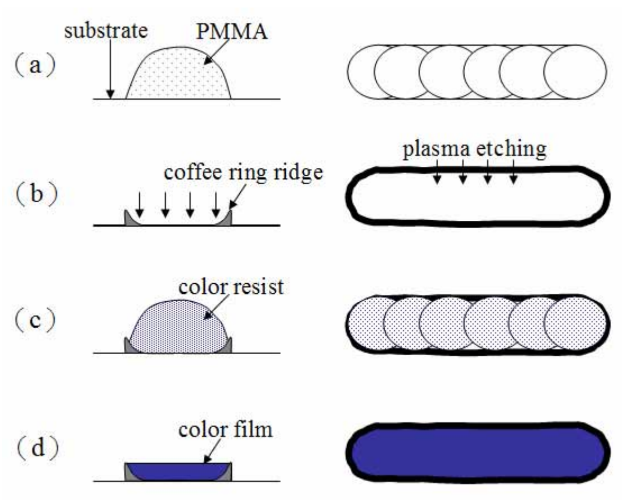

Figure 2. *The fabrication scheme of ink-jet printed banks and color filters.*

Results and Discussion

Fig. 3 shows the optical microscopy photographs of several printing densities for the red color resist. The dot pitch of 100, 60, 40, and 30 um/dot was used in the process. The thickness of color resist increases as the printing density increases. In Fig. 3 (a) and 3(d), discontinuous and overflow defects are observed in the printing pattern, respectively. In the moderate density cases, good printing film quality, with a film thickness of 1.89 um and 3.03 um, is reached for dots pitch of 40 and 60 um/dot, as shown in Fig. 4(b) and 4(c).

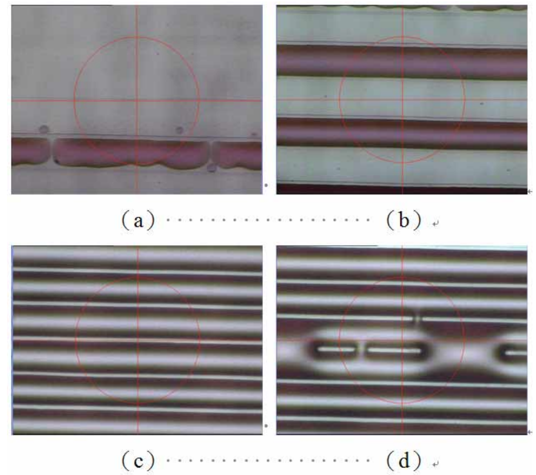

Figure 3. *Optical microscopy photographs of several dot pitch, (a) 100 um/dot; (b) 60 um/dot; (c) 40 um/dot; (d) 30 um/dot, for the red color resist.*

The relationship between film thickness and dot pitch is also shown in Fig. 4. From the results, the thickness of each color film can be predicted and easily controlled from 1 to 3 um by tuning the droplet discharging dot pitch. Besides, we measured the color coordinates for each color filter with various film thicknesses in the chromatic diagram. The RGB chromaticity coordinate measurements were performed on Photal MCPD-3000 Spectro Multichannel Photodetector.

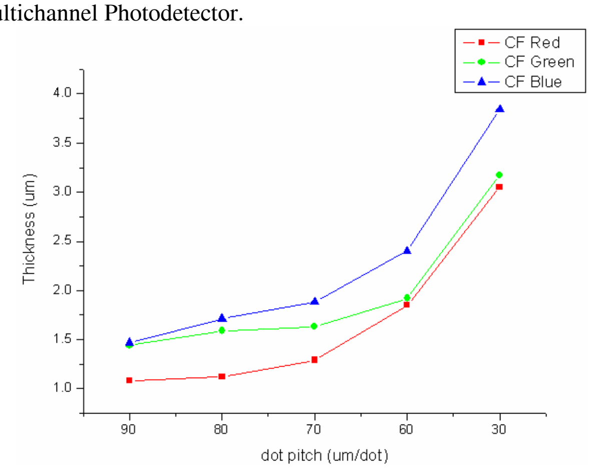

Figure 4. *Relationship between film thickness and printing density for each color resist.*

Fig. 5 shows the optical microscopy photograph of the color filter by use of this proposed method. The printing area is 6x6 cm2 with a sub-pixel pitch of 130 um. The thickness of each RGB resist film is around 2.5 um. The printing quality is good enough for application without any color-mixing due to overflow, splash, and satellite drops.

Figure 5. *Optical microscopy photograph of a color filter fabricated by all ink-jet printing.*

In Fig. 6, the color region of this printed color filter is about 39.5% of the color space defined by the National Television System Committee (NTSC), as the thickness of each RGB film is 1.5 um. When the thickness increases to 3 um, the covered color space can span to about 67.8% of the NTSC. This result nearly satisfies the standard specification of 70% of the NTSC for TV application.

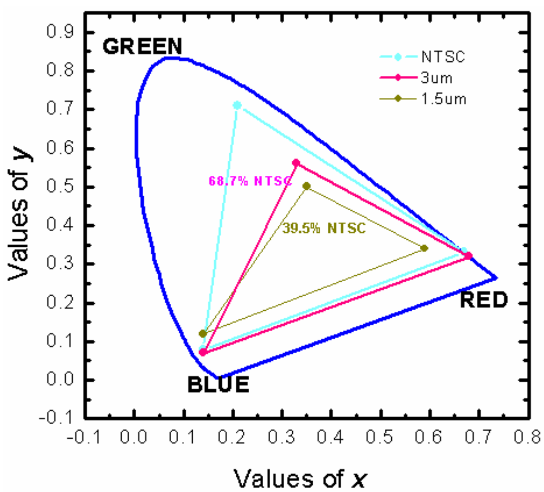

Figure 6. *Color coordinates for the printed color filter with around 1.5 um and 3 um of each color film in the chromaticity diagram (CIE 1931).*

Conclusion

In summary, we have successfully demonstrated an excellent solution processing high saturation color filter by all ink-jet printing technology. The thickness of RGB color film can be fine-tuned by dot pitch to achieve 1 to 3 um by only one swath printing, without any color-mixing problem. The color region of the three primary colors (red, green, and blue) on the chromaticity diagram reaches 67.8% of the NTSC in our preliminary result.

References

[1] R. W. Sabnis, Displays 20 (3), 119 (1999).

[2] E. Elizur and D. Gelbart, Journal of Graphic Technology 1 (2), 1 (2003)

[3] K. Cheng, T.-Y. Yang, V. Wang, C.-C. Lai, K.-H. Wu, and J. Chen, NIP 17: International Conference on Digital Printing Technologies (2001), pp. 739.

[4] T. Satoi, US Patent No. 5989757 (1999).

[5] S. Shiba and H. Sato, US Patent No. 6245469 (2001).

[6] A. Kashiwazaki, K. Shirota, K. Nakazawa, S. Shiba, and M. Hirose, US Patent No. 6312771 (2001).

[7] C.-J. Chang, S.-J. Chang, F.-M. Wu, M.-W. Hsu, W. W. W. Chiu, and K. Chen, Japanese Journal of Applied Physics, Part 1: Regular Papers and Short Notes and Review Papers 43 (12), 8227 (2004)

[8]http://techon.nikkeibp.co.jp/article/NEWS/20061012/122215/?ST=fpd (2006).

[9] Robert D. Deegan, Olgica Bakajin et al., Nature, Vol.389, (1997)

[10] T. Shimoda, in SID'03 DIGEST (2003), pp. 1178.

[11] W. W. W. Chiu, K. Cheng, C. F. Lu, F. Hsieh, and J. Chang, NIP 19: International Conference on Digital Printing Technologies (2003), pp. 303.

[12] K. Cheng, W. W.-W. Chiu, C.-S. Jang, C.-C. Lai, Y.-K. Ho, and J. Chang, NIP 19: International Conference on Digital Printing Technologies (2003), pp. 309.

Biography

Fu-Kang Chen received his Bachelors Degree in Mechanical Engineering from Chung Hua University in 2000. He is now a process integration & verification engineer in the Printing Science Department, Panel Integration Division II, Display Technology Center of Industrial Technology Research Institute at Taiwan. His work has primarily focused on the industrial ink-jet printing processes development, especially in PLED (polymer light emitting diodes), Color Filter, and Liquid Crystal Display by ink-jet printing