New Materials for Inkjet LCD Color Filter Manufacturing

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Abstract

Inkjet printing technology can reduce the LCD color filter manufacturing cost more than 50 %. Uniform color filter patterning can be achieved only with proper ink and barrier materials. We developed new ink and black matrix materials for inkjet color filter. The ink materials have low volatility while they have very high solid content. The black matrix materials have very precisely controlled surface energy so that the inks can fill the pixels evenly and completely. We controlled the ink drop volume and ink material to minimize the thickness difference between the black matrix and the color pixel. Micron-order jetting position accuracy was achieved. We successfully printed 14.1" color filters using our ink and black matrix materials.

1. Introduction

Photolithography has been the most widely used process for LCD color filter manufacturing. The cost of LCD color process decreased mainly due to the effect of panel size-up and improved photoresist coating methods from spin coating to slit coating. However, display industry analyses forecast the difficulty of further cost down simply via panel size-up. It is estimated that the unit price of color filter changed only slightly in the years 2004, 2005 and 2006, compared the rapid price down by around 20 % in the years 2001 and 2002 [1]. (see Figure 1.)

New color filter manufacturing technologies has been actively sought to replace the costly photolithography. Inkjet printing has been developed since the first published idea in 1984 [2]. Due to the technology development for office and industrial inkjet printing in the last decade, now much matured inkjet technology is the most promising candidate. Inkjet printing deposit color materials directly into pixels thus it can reduce the color filter process steps, maximize the material usage and minimize the waste, which can reduce the LCD color filter manufacturing cost more than 50 %.

For the inkjet printing technology, ink and black matrix barrier materials should be well designed. The ink materials have low volatility while they have high solid content. As a result, the ink materials do not dry at the inkjet nozzle and have minimum volume shrinkage after pattern jetting. The black matrix materials have precisely controlled surface energy in order to be filled by the ink materials evenly.

A printing machine has several micron-order position accuracy was developed in-house. Gohda and others also reported that their machine's drop placement accuracy was about 5.4 micron [3]. Jetting parameters were optimized to remove satellite drops and make stable ink jetting. Printing quality should be extremly high. Even 1 ppm misfire rate cannot be accepted to meet the quality standard.

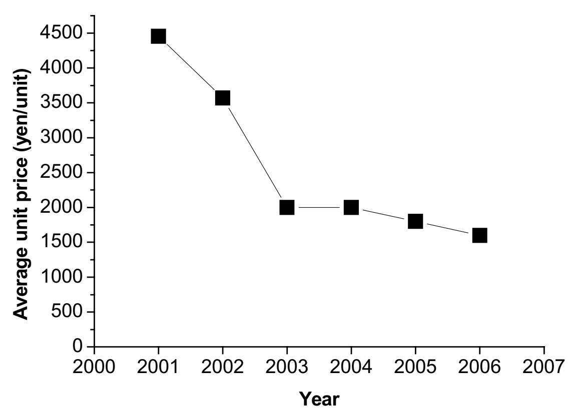

Figure 1. Annual trend of 14" LCD color filter unit price. (2001-2005 actual, 2006 forecast)

2. Experiment and Result

The physical requirements of inkjet inks are quite different from those of color photoresist materials. For photoresist materials, volatility should be quite large in order to make uniform coating; for inkjet inks, volatility should be low in order to prevent inkjet nozzle clogging. Thus, inkjet process uses lower vapor pressure solvents than those used for spin coating process. Drying condition after patterning is also very important as well as solvent composition in order to get uniform sub-pixel surface. Deegan and others investigated flow effect on liquid drop uniformity in drying process [4]. Surface tension gradient that induces Marangoni flow should be minimized to get the uniform sub-pixel. In order to minimize Marangoni flow ink surface tension should be designed precisely all the time from jetting to drying. Thus, proper surfactant selection and solvent mixture design are critical.

To make stable jetting, the ink viscosity and surface tension were controlled so that the Ohnesorge number of the ink is in the range from 0.1 to 1 (inkjet operation window). The Ohnesorge number (Z) is a dimensionless number defined as

$$Z = \frac{\mu}{\sqrt{g_c \rho L \sigma}}$$

where g_c is a dimensional constant, L is the characteristic length, μ is the viscosity of ink, ρ is the density of ink and σ is the surface tension of ink, respectively. In the experiment viscosity control is critical to ensure that the ink's Ohnesorge number is in the inkjet operation window. Because, organic ink constituent materials have similar densities and it is impractical to control the density of inks. The ink surface tension is also an important parameter for ink-black matrix interaction and inkjet nozzle wetting thus cannot be freely adjusted for Ohnesorge number control.

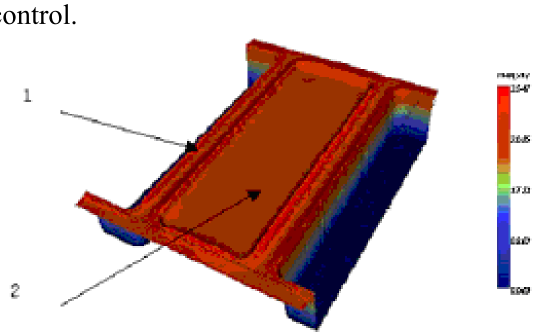

Figure 2. 3D diagram of LCD sub-pixel by inkjet printing. Black matrix (1) and color sub-pixel (2) have almost the same thickness

Black matrix patterns were made by photolithography using our black photoresist specially designed for inkjet process. The surface energy of resin black matrix substrate was precisely controlled by material formulation and/or physical treatments so that inks fill the pixel area evenly without overflow.

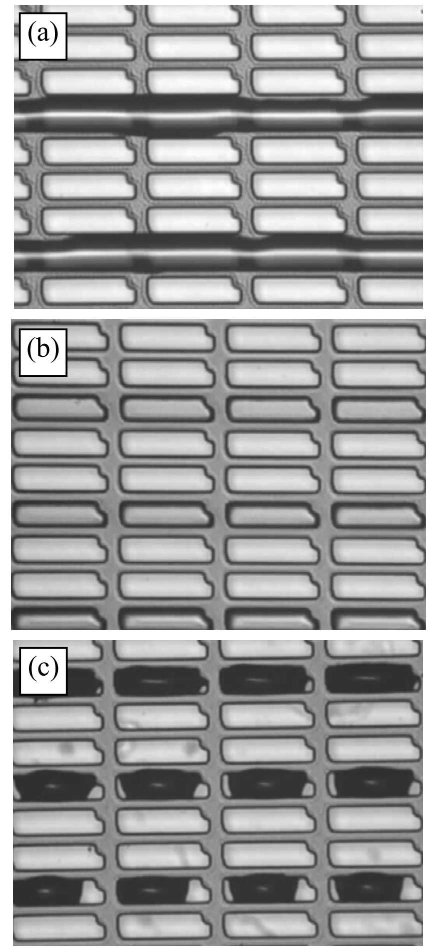

Figure 3. Black matrix substrate wetting control. Overflow (a), uniform (b) and non-wetting (c) patterns obtained depending on the black matrix substrate surface energies.

When the surface energy of the black matrix is too high, ink materials tend to flow even on the black matrix barrier, which results ink overflow as shown in Figure 3 (a) or an edge-thick convex ink filling. On the contrary, when the surface energy of the pixel area is too low, inks cannot wet the pixel fully, which results void area in the pixel as shown in Figure 3 (c). When the surface energy of the black matrix is low and that of the pixel is high, ink fills the whole pixel without overflow as shown in Figure 3 (b). The "highs" and "lows" of surface energy of the substrates are not absolute but relative values depend on the surface tension of the ink.

Figure 2 shows the 3D measurement of a sub-pixel after curing. We controlled the inkjet drop volume by inkjet head operation parameters such as voltage and pulse duration time, and ink materials' solvent content so that the thickness difference between the resin black matrix and the color pixel can be minimized. After curing the thickness difference between the black matrix barrier and the pixels is less than 0.1 micron. Pixel uniformity and thickness control is important to make precise color value of the pixel. Ink drop distribution in a pixel, i.e., drop placement patterning and inter-drop distance control was also critical to make a uniform pixel.

Inks are normally mixture of pigments, binders, solvent and other additives. Pigments affect mainly the color properties of inks such as chromaticity, brightness and contrast ratio. Recently smaller particle size (<100 nm) pigments are used to increase contrast ratio and brightness.

Chemical, mechanical and adhesion stability of the color filter were mainly determined by polymer binders. Chemical structure and molecular weight of the binder should be carefully designed to have proper interaction between pigment, glass, black matrix materials and binder polymer. Solubility parameter or solvent-polymer interaction control is also important for binder design to enhance chemical resistance of color filter. Our binder polymer is composed of several kinds of monomers to control the physicochemical properties [5]. Moreover, it is very important for binders to have adequate viscoelastic properties so that ink jetting makes good drops without long ligament or satellite droplets.

Our precision printer system deposit red, green and blue color inks in the resin black matrix pattern. A Piezo inkjet head was used for each color. On-the-fly drop placement compensation algorithm was used to minimize the inkjet drop position error during the substrate stage movement, which enables micron-order drop position accuracy even at high-speed printing operation.

After ink jetting, a curing process was followed. Depends on ink materials, UV or thermal curing method was used. We made both UV and thermal curing inks. From material point of view, both systems make very similar quality color filter. Thus color filter production cost will be the key point for the ink system selection. For UV-curing inks, a simple in-line UV machine was used for UV-exposure without any photomask. For thermal curing inks a hot plate and a convection oven was used for soft (80~160 °C) and hard baking (>200 °C) processes, respectively.

14.1" XGA LCD color filters were printed using our inks and black matrix materials as shown in Figure 4. Our inkjet materials machine and process can make uniform pixels without defect as shown in Figure 5.

Figure 4. 14.1" LCD color filter by inkjet printing technology in 2005.

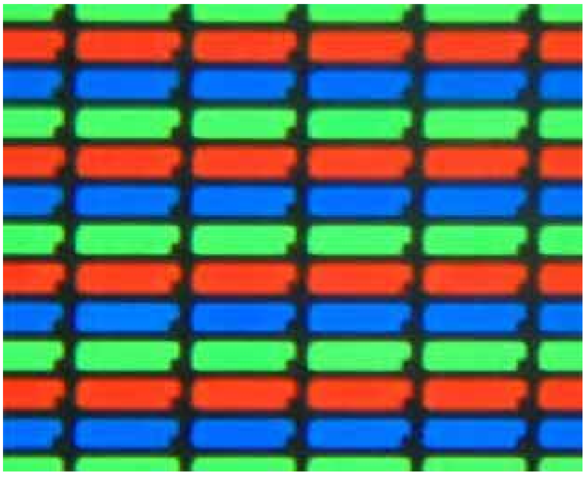

Figure 5. Pixels of 14.1" LCD color filter by inkjet printing technology.

3. Impact

Inkjet is already used for large area signage printing and makes significant change in industrial printing market. Now, inkjet technology is expected to replace the expensive photolithography in display industry, and the LCD color filter manufacturing cost can be reduced more than 50 %.

For precise LCD color filter pattering, ink materials and barrier material should be adequately designed for the inkjet printing process. Here we explain several important points of inkjet material design and demonstrate our inkjet materials and LCD color filter made of our materials.

4. References

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