Hybrid Digital Fabrication Method Coupled with Inkjet Printing and Photolithography

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Abstract

We propose for the first time that a hybrid digital fabrication method can be applied to generate micro patterns with highly accuracy of thickness and width. It is simply coupled with inkjet printing and photolithography and mainly aimed to solve several issues of uneven films that are usually found in inkjet printing. First, the draft pattern of film can be fabricated onto a substrate by micro-fluidic deposition method. In other words, inkjet printing basically forms the pre-determined pattern by fluidic droplet deposition. The droplet fluids must belong to material of photo resist. Secondly, pre-baking is applied to dry the solvent of fluidic pattern. In the third step, the draft pattern is further modified with accurate one in desire by the photo mask of lithography. Finally, after stripping process, the micro pattern is successfully generated as desire with high accuracy of morphology. If the photo resist is colored with green/red/blue, we demonstrate the method can be applied to the manufacturing of LCD color filter; moreover, many applications of printed devices in the future can be found in this promising hybrid method.

Introduction

The well-known inkjet printing technology has actually succeeded in office document/photo printing for more than a decade. Not limited to the use of document printer, so many recent study works have focused on employing the technology to many variety of important industrial applications, such as organic polymer,[1] LCD (liquid crystal display) color filter,[2] electric transistor,[3] organic IC (integrated circuit)[4] and so on. It is expected to replace the spin coating and mask patterning technologies of photolithography because less processing time and more material saving may be applied. However, unlike the spin coating, the inkjet deposition film always suffers from the many troubles of inaccurate pattern, including uneven film thickness, wavy rim of film, and so on.[5] The resulting quality of film may be unaccepted for the real use of many applications in the future.

Therefore, in the paper, we proposed a new hybrid micro fabricating method for micro pattern fabrication, which the method was combined with photolithography technology and the micro-fluidic technology. This method expectedly can much improve uneven issue of traditional inkjet deposition and save material consumption.

Conceptual Design

We presented the fundamental modeling for one droplet as shown in Figure 1. Original pattern of deposition film on the surface had diameter D_0 ($=W_0$) and desired shorter width W_b ($< W_0$) caused by the natural coffee-ring effects[6] (see Figure 1a). It may be necessary to be modified as a desired pattern by trimming the width W_0 into W_b (see Figure 1b). In fact, the original pattern can be simply obtained by inkjet printing technology and the latter pattern may be achieved by photolithography technology nowadays. The idea in the study is exactly laid on such a hybrid process coupling with both of them.

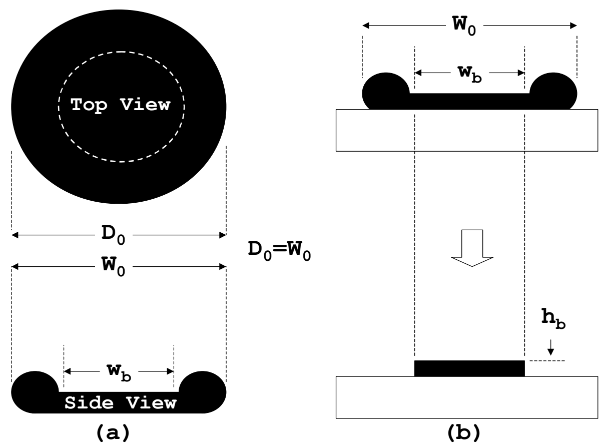


Figure 1. (a) Original pattern of deposition film on the surface (b) modified as a desired pattern by trimming the width W_0 into W_b.

Procedure and Fabrication

Fabrication Process

In this study, the complete process of experimental fabrication was shown in Figure 2. First, a glass substrate was prepared with cleaned flat surface. Second, standard lithography technology was used to define alignment mark. Alignment mark provided the basic function of precise alignment for micro fluidic deposition as well as photolithography technology. Fluid droplets were next to be deposited on the glass substrate aligned by the mark. The undesirable regions (e.g. uneven rims of patterns) can be then modified by photolithography technology. Finally, profiles of micro pattern were finished, which the thickness of film would be measured by using -step; photographs were taken by the image capturing system under an optical microscope or scanning electron microscope (SEM).

Photolithography Design of Mask

The fabrication process of alignment mark was shown in Figure 3. In step (A), we first had a polished soda lime glass substrate cleaned. In step (B), secondly the glass was spin coated with a layer of photoresist AZ4620 (Clariant Inc). In step (C), after soft baking at 120°C for 3 minutes, it was then exposed. In step (D), the glass had been completely developed and finished with a photoresist layer . In the Step (E), Cr(Chromium) metal layer deposition was performed by using E-beam to fabricate the alignment mask. Finally, in the step (F), the photoresist was removed from glass and left with the mask pattern made of Cr only shown in (G).

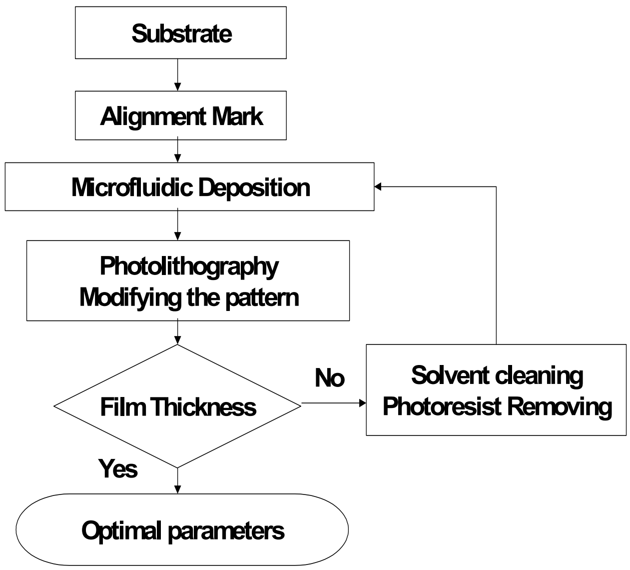


Figure 2.The complete process of experimental fabrication for the digital hybrid method

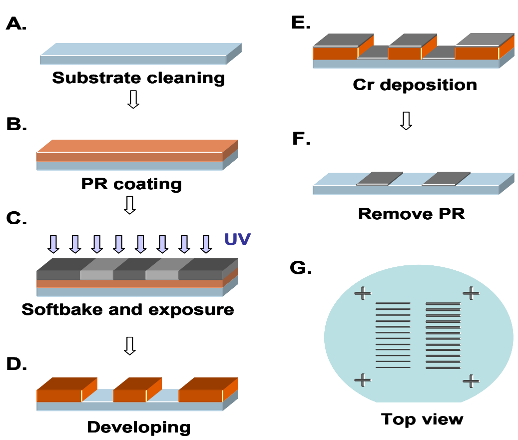


Figure 3. The schematic of alignment mark fabrication process through step (A) to (G).

Micro-Fluidic Deposition

To fabricate micro pattern by micro-fluidic deposition, a line pattern was deposited by using a simple syringe. Each line length was 25 mm, the size of a dose was about 0.5ul (1ul=10^{-6}liter). The uneven issue of thin film and the roughness of a line pattern were often found, as sketched in the Figure 4.

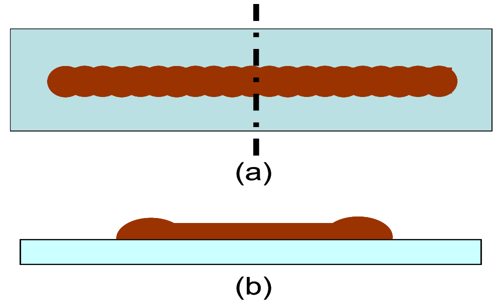


Figure 4. The schematic of micro-fluid deposited a line pattern: (a) Top view. (b) Side view.

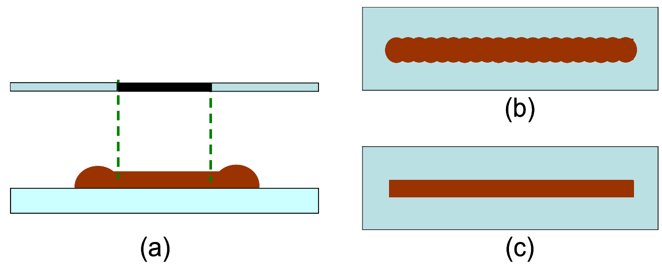


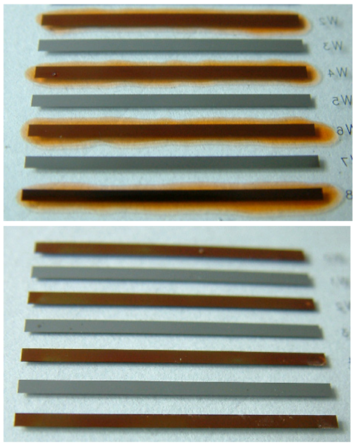
Figure 5. The schematic of photolithography technology modified a line pattern: (a) Side view. (b) Before modifying. (c) After modifying.

Modifying Pattern

Photolithography technology played an important role in this study. We used the photolithography technology to improve above issues by further modifying rough pattern. The procedure for modifying a line pattern as shown in Fig. 5. In this study, the positive photoresist (Shipley S1818) was used. The resist was difficult to dissolve in developer before the exposure; however, it was easy to dissolve in developer after the exposure. The rough area of a line pattern was be able to be easily modified by using this character and designed mask.

Experiment Results

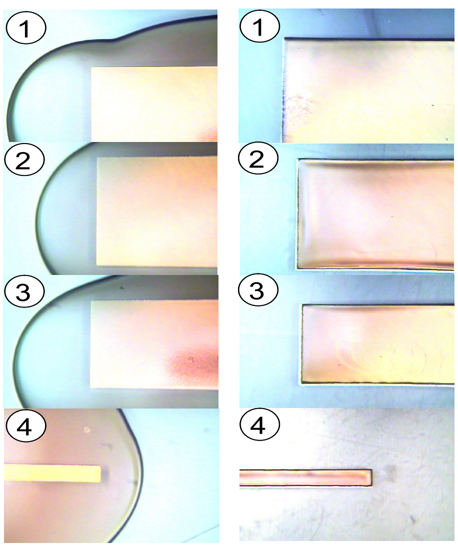
Positive photoresist Shipley S1818 with viscosity of 38 cps was used in the experiments of the study. It was deposited by using the simple syringes. The results were clearly shown in the following Figure 6(a) and Figure 7(a). We noted that the photo mask pattern used for the line patterns modification had maximum and minimum width of 1.5mm and 50um (1um=10^{-6}m). In this study, the rough areas of a line pattern were modified by using photolithography technology as shown in Figure 6(b) and Figure 7(b). In Figure 7, the modified width of mask was 1.4 mm, 1.1 mm, 0.8 mm and 170 um, respectively. The profile of micro fluid deposition and modified micro pattern were measured by using α-step as shown in Figure 8.



(a)

(b)

Figure 6. Images of micro fluid deposition and modification: (a) before modifying. (b) After modifying.

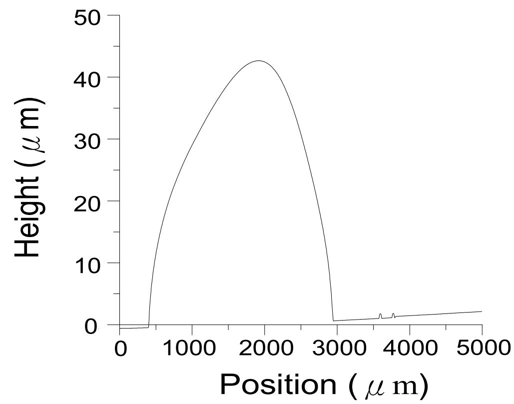


(a) (b)

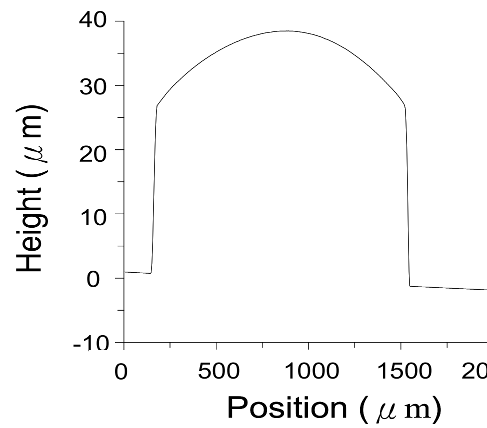
Figure. 7. Microscope images of micro fluid deposition and modification: (a) before modifying. (b) after modifying, the modified width of mask was 1.4 mm, 1.1 mm, 0.8 mm and 170 um, respectively.

Discussion and Conclusion

We presented in the paper that a hybrid digital fabrication method could be applied to generate micro patterns with highly accuracy of thickness and width. The new method is actually coupled with inkjet printing and photolithography to solve several issues of uneven films, which are usually found in inkjet printing. First, inkjet printing (micro-fluidic deposition) basically forms the pre-determined pattern (draft) by fluidic droplet deposition. The droplet fluids should be a kind of photoresist. Secondly, after the pre-baking to dry the solvent of fluidic pattern, the pattern is further modified with accurate one in desire by the photo mask of lithography. Finally, after stripping process, the micro pattern is successfully generated as desire with high accuracy of morphology as shown in Figure 9.



(a)



(b)

Figure 8. The profile of surface for the micro line pattern: (a) the draft of micro fluid deposition. (b) The modified pattern after photolithography.

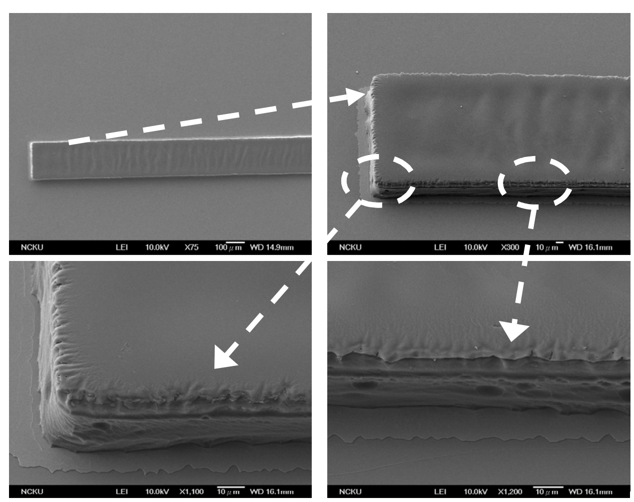


Figure 9. SEM picture for the morphology of the micro line pattern by present hybrid method.

It was demonstrated for the complete process that the positive photoresist Shipley S1818 was employed in the experiment. Line widths for the micro pattern were 1.4mm, 1.1mm, 0.8mm and 170um, respectively. The results showed that the rough boundaries of the draft lines were sharply trimmed with success as desired. Hence, the hybrid method would be a promising fabrication technology for many applications of printed devices in the future.

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