A Novel Method for Forming Micron Scale Line Using Inkjet Technology

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Abstract

Producing of the interconnections or electronic devices by inkjet printing is processed with the advantage of direct writing, enhancement of expendable's utility rate and reducing the waste of substrate using. For the development of plastic electronic devices, shrinking of printed line width is an inevitable tendency. However, it is still tough to develop a specific print head in the application of jetting liquid droplet with diameter in nanometer scale nowadays. In order to solve the problems described above, the aim of this paper is to get a thinner line width by using "coffee ring" effect and the convective flow splitting effect, which occurred during solvent evaporating, and following by the etching step to make a thin printed line. With scale down of the inkjet head, change of the ink recipe and process recipe, it is able to gain the narrower line width. In this paper, a fine line with 8 μm in width had been demonstrated and printed by using the ordinary print head with orifice diameter of 65 μm.

Introduction

Nowadays, the interconnections or electronic devices are used to being fabricated by semiconductor processes. And the patterning by photolithography process, mainly. But there are still some drawbacks about the cost and application in the process. Hence there are various researches be put into take the place of photolithography.[1] Among these, the technology, which is about using ink jet printing process to write interconnections or electronic devices on substrates directly, have gained more attention because of the advantages what follows:

1. Direct Writing: Direct writing would save the cost of mask manufacture, and suit with the sample production.
2. Raising the utility rate of expendables: To Raise the utility rate of expendables from 5% to 95% by substituting for spin coating process.
3. Low substrate limitation: Inkjet printing has the potential for fabricating circuit and electric elements on non-plane surface or flexible substrates.[2-4]

Presently, in industrial application, the smallest droplet volume of inkjet printing is 20pl, and line width is around 30 μm. Thus, the specification is suitable for PCB manufacture. However, it is not qualified to fabricate LCD TFT (Thin Film Transistor) driver. To fitting with the line width of 3 μm that is needed by TFT driver fabrication, one way is to develop the ink jet print head that could ejection the volume of droplet in femto-liter (10^{-15}) scale. Thus the diameter of the nozzle has been scaled down to sub-micron, and it will cause some problem as below:

1. High cost and low yield rate for print head manufacture: To fabricate extremely narrow nozzle must used by FIB (Focus Ion Beam), etc. Nevertheless, the process are high cost and unstable.
2. High solution restriction: To improve printing quality and preventing the nozzle from clogging, it must use nano-particle and dispersant.
3. Shorten the life of print head: In the ejection process, the inlet of the nozzle must suffer pressure exceed 1000atm. Therefore; the life of print head may decay soon.

For avoiding difficulties resulted from fabricating inkjet head in nanometer scale, we can make use of coffee ring effect and etching process to form micro scale line. Here the coffee ring effect is a ring-like appearance that occurred when the solvent evaporate from the solution and remain solute to concentrate along the perimeter.[5,6] In this study, we can get lines which are thinner than original ribbon by ejection droplets which composed of solute and easy-evaporate solvent, and then we can narrow and isolate each line further. Figure 1 and Figure 2 are results of our pre-study.

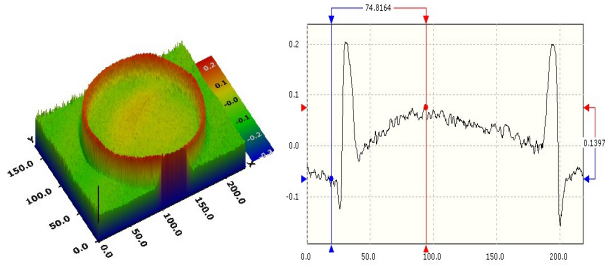

Figure 1. The 85pl droplet was jetted on the glass substrate and formed a circle which is 150μm in diameter and the rim is around 20μm in width.

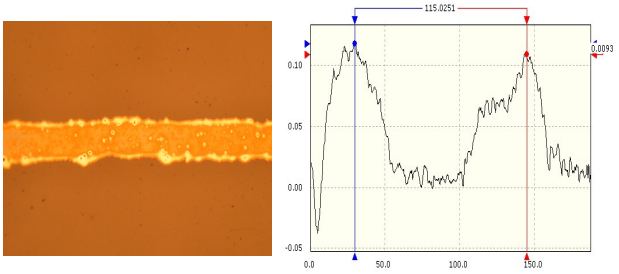

Figure 2. The 85pl droplets were jetted on the glass substrate and formed a line which is160μm in width and the edge is around 40μm in width, 0.1μm in height.

Experiment

1. Process

This process is used to evaluate and develop the use of coffee ring effect to form thinner line width. Figure 3 is the sketch of the process.

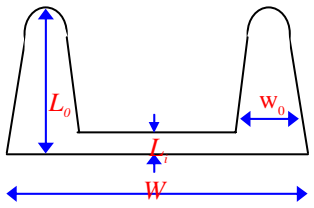

Figure 3. The sketch of the coffee ring structure.

As Figure 4(A) shows, the droplet that contains solute and solvent was jetted to the substrate. In Figure 4(B), after the droplet dropping on the substrate, it will form the structure, which is thicker at outer circle part and thinner at center part. And, because of the difference from the kind of solutions and concentration, the volatility will be different. In Figure 4(C), we can take use of dry etching process to remove the thinner part of the structure and to get thinner and isolated line.

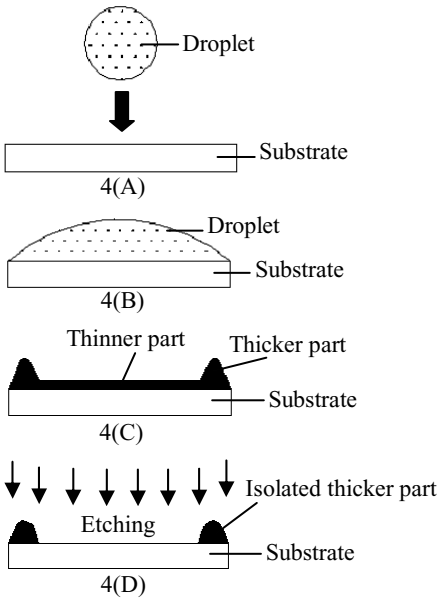

Figure 4. The sketch of the fabricating process to form coffee ring structure.

2. Forming Coffee Ring

Due to the properties of the solution will affect the result of forming coffee ring structure.[7] In this study, we must make sure that the solution is suitable for the process. Therefore, anisole has been selected in this study, because of it is high volatility and it is suitable for our own inkjet head. Besides, we choose PMMA as solute since it can be etched by O_2 plasma. And then, the specification of the inkjet head used in the process is listed in the Table 1.

Table1. The Specification of the Inkjet Head

Diameter of the nozzle plate	65 μm
Thickness of the nozzle plate	50 μm
Thickness of the micro channel	30 μm

Here we select PMMA/Anisole at three different concentrations. There are 3%, 5% and 7% (weight percentage). And then we jetted the solution on the glass substrate by the inkjet head above-mentioned to observe the difference of each coffee ring structure.

3. The Etching Process

The etching process is aimed at isolating and narrowing coffee ring structure. Here O_2 plasma is selected to etch PMMA. After tuning the etching rate of PMMA, the plasma power is determined to be 400 watts, the flow rate of O_2 is 800 sccm and the etching time is one minute.

Results & Discussion

1. The Coffee Ring Structure at Different Concentration

As Figure 3 shows, in order to differentiate each characteristics of each coffee ring structure easily, we must define some parameters such as L_o is the height of the rim, w_0 is the thickness of rim, L_i is the height of central thinner part and W is the original diameter of the droplet on the substrate.

Figure 5~7 are the coffee ring structures of the solution at 3%, 5% and 7%, and part (A) is 3D structure image which was scanned by non-contact-optical scanning instrument, and part (B) is cross-sectional measurement of the coffee ring structure.

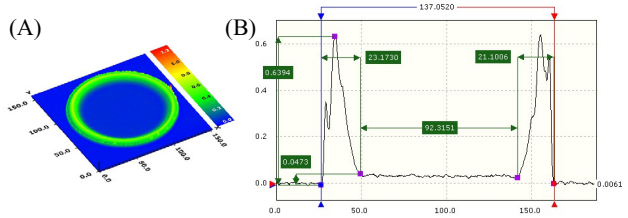

Figure 5. The 3D profile e and surface profile of 3% PMMA/Anisole.

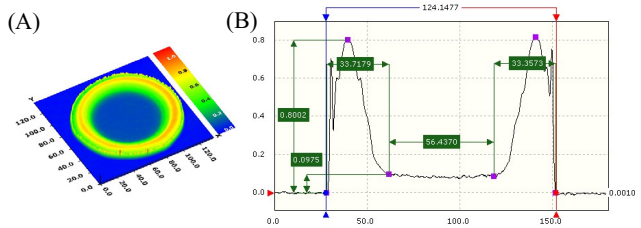

Figure 6. The 3D profile and surface profile of 5% PMMA/Anisole.

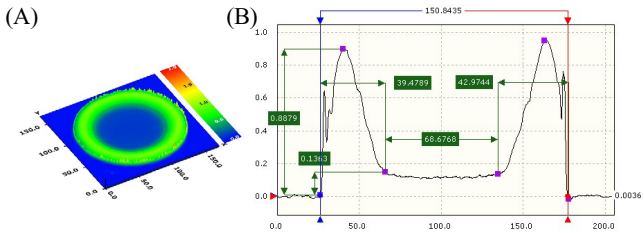

Figure 7. The 3D profile and surface profile of 7% PMMA/Anisole.

The results of the experiment were showed in the Table 2. Thus we can find that the higher concentration of the PMMA the width and the height of the rim will get thicker. Hence we can control the height and the width of the rim by changing the concentration of the solution.

Table 2. The Results of the Concentration Experiment

concentration	L_0(um)	L_i(um)	W_0(um)	W_i(um)
3%	0.64	0.05	23.2	137
5%	0.80	0.10	33.7	124
7%	0.89	0.14	39.5	150

2. O_2 plasma etching process

After etching by O_2 plasma, we can get isolated rim of the coffee ring structure. As Figure 8(A) & (B) shows, this is the 5% PMMA/Anisole coffee ring structure that was etched by O_2 plasma. We can see the thinner part around center of the coffee ring structure had been removed away from the glass substrate entirely.

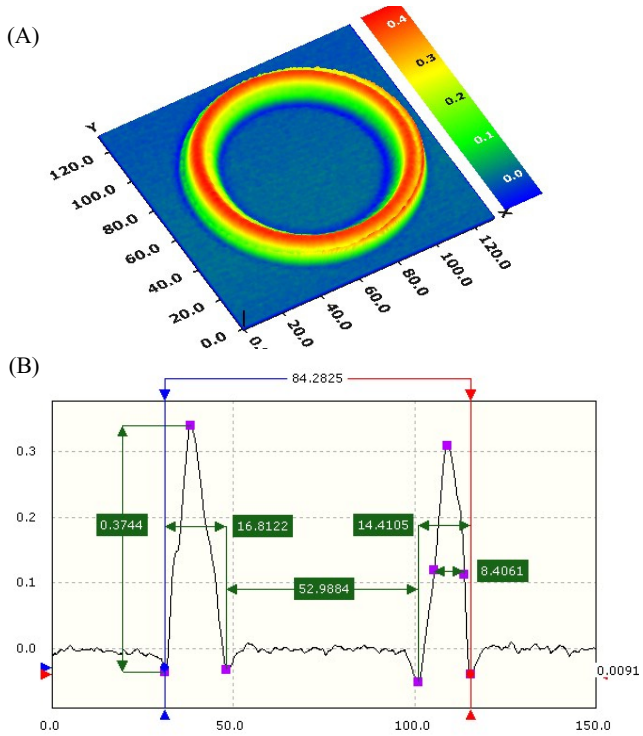

Figure 8. The 3D profile and surface profile of 5% PMMA/ Anisole which was etched by O_2 plasma.

After the coffee ring effect and etching process was demonstrated, we took use of the result to make parallel lines. Using 5% PMMA/Anisole, we can make a parallel, its linewidth is around 50 μm, height is 0.7 μm and initial printed linewidth is 167 μm. (As figure 9(A)&(B)). The result demonstrated that the process in this paper is feasible to fabricate thinner line or ring-like structure.

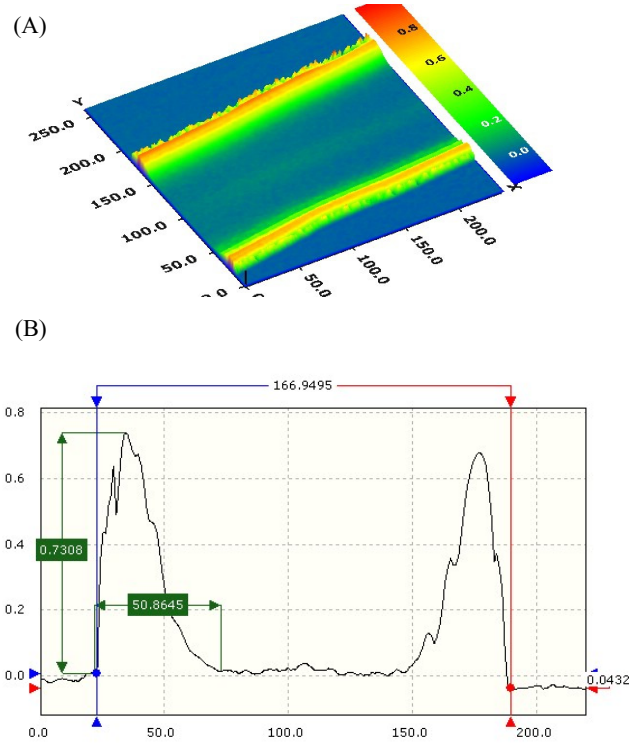

Figure 9. The 3D profile and surface profile of the parallel, which was formed with 5% PMMA/Anisole.

Conclusion

In this paper, we have demonstrated the possibility about using coffee ring effect and etching process to narrow the line width, which is printed by ordinary inkjet head. In brief, we can take use of coffee ring effect and after treatment (as etching process) to form thinner line or pattern, and this may use to not only definition interconnections or electronic devices directly but also could be definition the etching mask in photolithography process. Thus to follow the development of this digitalized printing technology and to scale down the inkjet head, we may put the limitation of linewidth that printed by inkjet head from micrometer scale to nanometer scale. Thereof it will also raise the practicability of printing process for industrial application.

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Biographies

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