Fine Metal Line Patterning on Hydrophilic Non-Conductive Substrates Based on EHD Printing with Laser Sintering

Sanguk Son*, Sukhan Lee*, Yong-Jae Kim*, Kichul An*, Jaeyong Choi*
*School of Information and Communication Engineering, Sungkyunkwan University, 300 ChunChun-Dong, JangAn-Gu, Suwon, KyungGi-Do, 440-746, Korea
ssu2003@skku.edu

ABSTRACT

In this paper, we report the successful EHD printing and laser sintering of a 5 um width of metal line patterns, with the line thickness of over 340 nm, on a hydrophilic non-conductive glass substrate without any prior surface treatment for the repair of FPDS. There are two critical issues to overcome: 1) Printing on a non-conductive substrate such as glass is subject to sprays scattered around the patterned line due to the disturbance of the original electrostatic field by the charges accumulated on the printed lines. 2) Printing on a hydrophilic surface such as glass without prior surface treatment is subject to ink spreading such that the width of printed line patterns becomes as much as 5 times larger than the actual diameter of jetting. To find the optimal setting of parameters, an array of extensive experimentations were conducted under various parameter settings. The application of laser sintering to the above, EHD printed, metal line was successful for meeting the required electrical resistivity of less than 60 μΩ·cm, while avoiding thermal damages.

Keywords: EHD, line patterning, laser sinstering

1 INTRODUCTION

Printing based on the principle of EHD (Electro-Hydro-Dynamic) discharging has recently attracted much attention due to its capability of a high resolution and/or a high aspect ratio of pattern formation. The conventional inkjet print heads have been based on forcing out the liquid in a chamber through a nozzle by an actuator such as a thermal bubble or piezoelectric actuator. For this reason, conventional inkjet heads are difficult to manage the droplet size smaller than the nozzle diameter. As a results, conventional inkjet printing methods have serious limitations on patterning of fine metal line (less than 50 μm in width), and thick patterns for high electrical resistivity. On the other hand, EHD printing provides very fine, even a submicron scale of, jetting, while allowing the adoption of a variety of ink materials such as metal, organic and bio materials with a wider range of ink viscosity reaching thousands CPs. The above advantages of EHD printing, supported further by its flexibility and cost-effectiveness in manufacturing, prompt various applications to be sought after, such as forming and/or repairing fine patterns for flat panel displays (FPDS), printed circuit boards (PCB), flexible electronics, as well as micro bio and sensor chips [1-5]. Specially, many researchers have studied a fine metal line patterning based on EHD. Kazuhiro Murata [6] achieved the direct print of ultra-fine metallic wire of only a few micrometers on substrate. Lee et al. [7] demonstrated silver lines with a few hundred nanometers in thickness and with a few hundred micrometers. Youn et al. [8] presented the fine metal line (5.8 μm in width) and conductive($7\times10{-}7$ Ω•cm) patterns. However, in order for EHD to become a competitive technology for industrial applications, conductive substrate, as well as in non-conductive substrate, reliably printing technology is essential. Also, a thermal damage by annealing process on the layer formed by the previous fabrication process should be avoided. Lee et al. have been developing noverl electrostatic drop-on-demand print heads and studying various EHD printing technology [9-12]. This paper introduces a high resolution EHD printing system and report the successful EHD printing and laser sintering of a fine metal line patterns on a hydrophilic non-conductive glass substrate without any prior surface treatment.

2 EXPERIMENTAL SETUP

Fig. 1 shows the schematic of experimental set-up for high resolution EHD printing. We had to use a tapered glass nozzle. The outer diamteter of the nozzle is 5um. The ink used in this study was a commercially available silver ink (Harima Co., NPS-J) with its viscosity and conductivity to be, respectively, 8~10cps and $3\times10{-}6$ S/m. The selected ink has been known to be stable for generating a cone-jet mode of jetting. The ink was supplied through the chamber to the nozzle with a constant pressure by a pressure controller. The gap between a glass substrate and the nozzle orifice is 40um. This glass substrate is located on a metal plate that provides an electrically grounded conducting support. The plate is equipped with a vacuum chuck and connects to a computer-controlled x, y and z axes moving stage. The electric voltage signal applied to a ink in the tapered glass nozzle by metal wire against ground electrode plate. A voltage signal from a function generator was amplified through a high voltage amplifier with a relay switch to control the electrostatic field. In order to observe the printing, a high speed camera with a micro-zoom lens and a LED light source were used. Printing images were analyzed through a microscope.

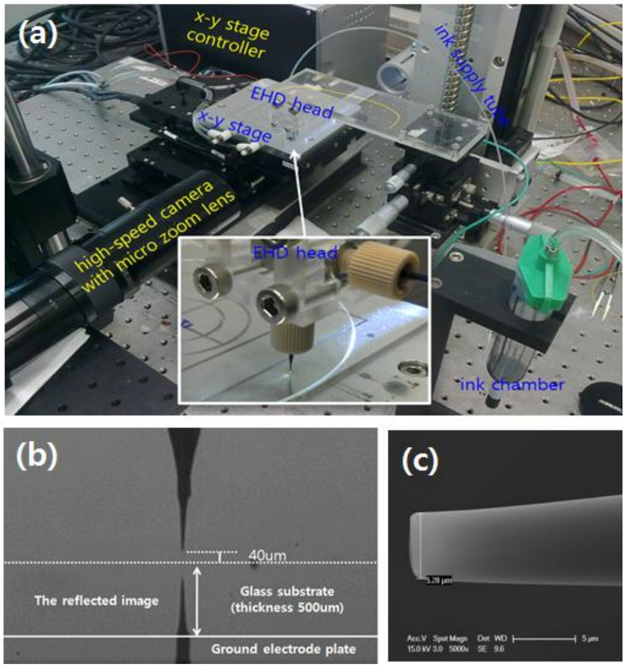

Figure 1: (a) The photograph of high resolution EHD printing system. (b), Nozzle and substrate configuration for printing. (c), SEM images of a tapered glass nozzle (5 µm outer diameter).

3 RESULTS AND DISCUSSION

We performed the direct printing of a fine metal line on a hydrophilic non-conductive glass substrate without any prior surface treatment using high resolution EHD printing system. First, we examined the the difference between printing formation by the electrical characteristics of the substrate and the speed of the moving stage. As shown in figure 2, there are two critical issues to overcome: 1) Printing on a non-conductive substrate such as glass is subject to sprays scattered around the patterned line due to the disturbance of the original electrostatic field by the charges accumulated on the printed lines. 2) Printing on a hydrophilic surface such as glass without prior surface treatment is subject to ink spreading such that the width of printed line patterns becomes as much as 5 times larger than the actual diameter of jetting, requiring about 1 um of jetting diameter for printing 5 um of line width. What we found is that, by optimizing the parameters involved in EHD printing, such as the distance between the substrate and the nozzle, the speed of the moving stage, as well as the applied voltage and pressure, we can be successful in EHD printing of desired line width and thickness, while overcoming the two issues described above. To find the optimal setting of parameters, an array of extensive experimentations were conducted under various parameter settings. Fig. 3 illustrates the establishment of the conditions optimal for the formation of high resolution silver lines without a spraying phenomenon.

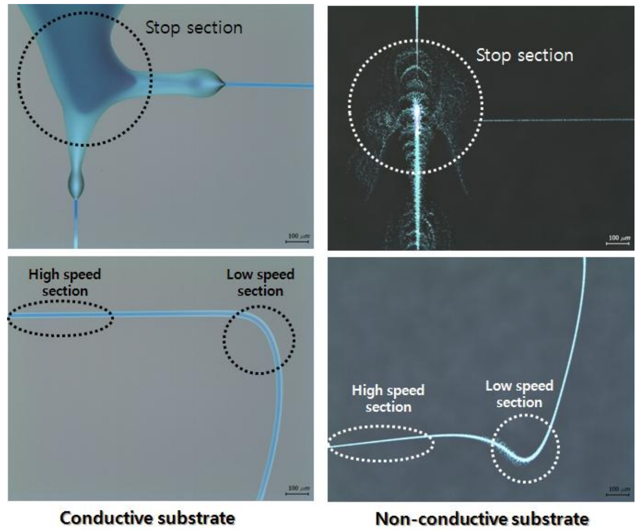

Figure 2: The difference between printing formation by the electrical characteristics of the substrate and the speed of the moving stage.

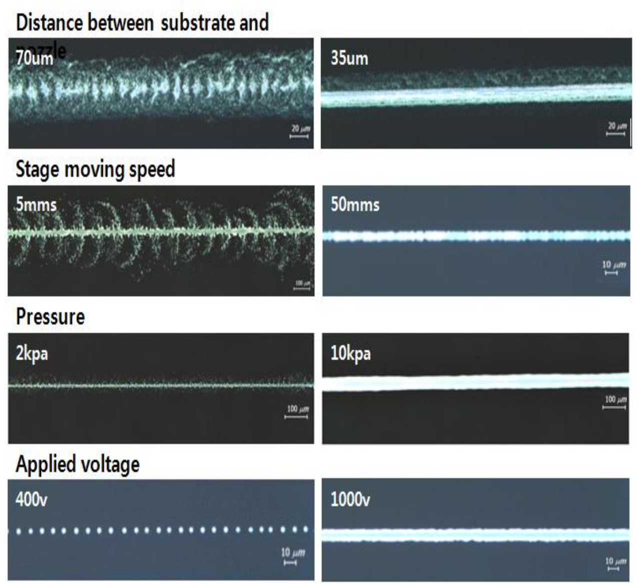

Figure 3: Printing images of in a variety of conditions using non-conductive substrate (glass substrate).

The problem of metal line pattern by conventional inkjet printing methods is very small aspect ratio (thickness compared to width ratio). As a results, lowered resistance have problems . In order to solve these problems, how to increase the thickness of the patterned line using high viscosity ink or duplicated printing should be used. Fig. 4 illustrates the working of duplicated printing for implementing the desired line thickness. The optimal parameter settings obtained by the experimentation were

NSTI-Nanotech 2012, www.nsti.org, ISBN 978-1-4665-6275-2 Vol. 2, 2012

used to fabricate and/or repair actual TFT metal lines based on the EHD printing of silver lines (refer to Fig. 7).

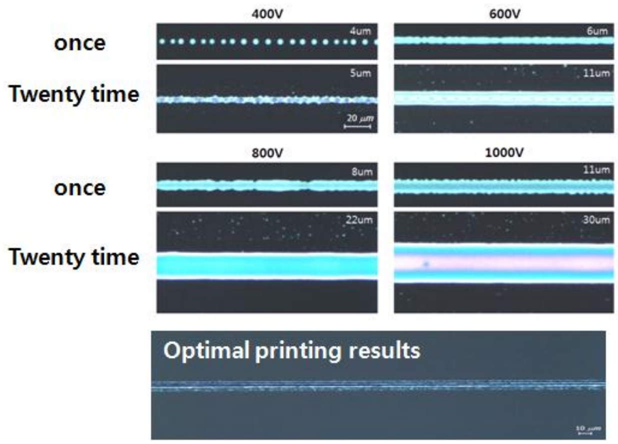

Figure 4: Printing results due to the number of repeat printingusing EHD printing system and optimal printing results.

Then, a sintering process was carried out to obtain the appropriate electrical property such as conductivity of the printed metal line. It turns out that the conventional oven or hotplate based global sintering process inflicts a thermal damage on the layer formed by the previous fabrication process. As a means of preventing this from happening, we adopted laser sintering to sinter only the required local area or the printed metal lines, as shown in Fig. 5. We used DPSS (diode pumped solid state) laser and its power and spot size to be, respectively, 100mW@532nm and 20um@1.1mm. from, lens.

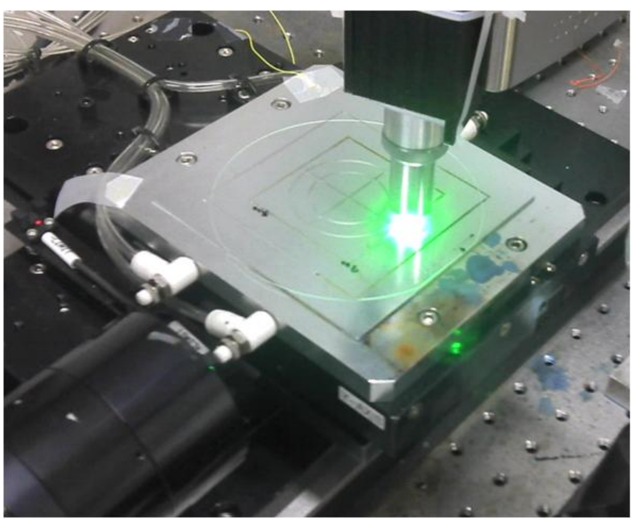

Figure 5: The photograph of laser sintering system.

After the process of laser sintering was over, to calculate the electrical resistivity, the printed and sintered metal lines width (w) and thickness (t) were analyzed based on AFM and SEM, as shown in Fig. 6. Specific electrical resistivity of the line was calculated by a formula, $\rho=RA/l$, where R is the electrical resistance of the line, l is the length of the line, and $A(A = wt)$ is the cross-section of the line.

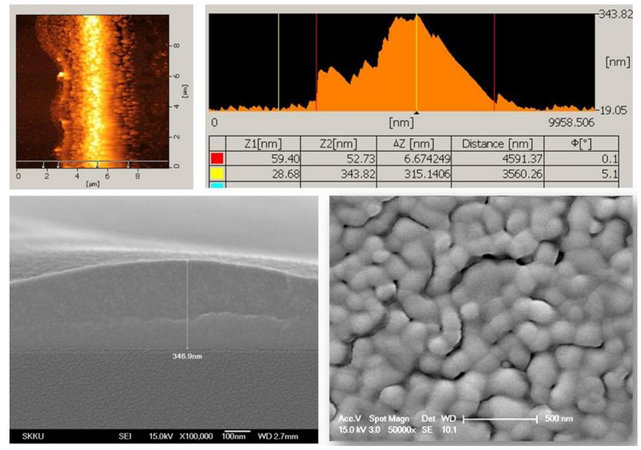

Figure 6: AFM and SEM images of optimal printing results for pattern analysis.

Fig. 7 shows a high resolution of EHD printed and laser sintered metal line patterned for FPDS repairs, where the width and the thickness of the printed metal lines are 5 um and 0.3um, respectively. To measure the resistivity of the printed metal line, we attach a few patches of silver paste on the line for use as electrodes. The resistance was calculated from an I-V curve measured by an I-V meter. The resistance was measured to be175Ω, which can be converted to the electrical resistivity of 51.9μΩ·cm.

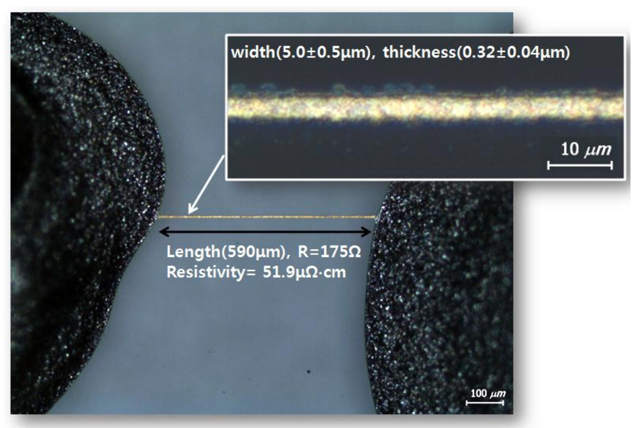

Figure 7: High resolution silver line printing results using EHD printing and laser sintering.

4 CONCLUSIONS

In summary, this paper shows that ahigh resolution of metal lines can be patternedby EHD printing and can be laser sintered to have proper electrical properties such as the desired conductivity. We achieved a 5 um width of metal line patterns, with the line thickness of over 340 nm, on a hydrophilic non-conductive glass substrate without any prior surface treatment for the repair of FPDS. The application of laser sintering to the above, EHD printed, metal line was successful for meeting the required electrical resistivity of less than 60 μΩ·cm, while avoiding thermal damages. To our knowledge, this is the first time to show the EHD printing successfully applied to FPDS repair with its performance thoroughly tested and approved by an FPDS manufacturer.

5 ACKNOWLEDGMENT

Your This work was carried out for the Direct Nano Patterning Project supported by the Ministry of Knowledge Economy under the National Strategic Technology Program.

REFERENCES

[1] R.T. Collins, “Electrohydrodynamic tip streaming and emission of charged drops from liquid cones”, Nature Physics, Vol. 4, 2007.

[2] Park, J. U., et. al and Rogers, J. A., "High-resolution electrohydrodynamic jet printing", Nature Materials, Vol. 6, No. 10, pp. 782-789, 2007.

[3] Park, J. U., et. al and Rogers, J. A., "Nanoscale Patterns of Oligonucleotides Formed by Electrohydrodynamic Jet Printing with Applications in Biosensing and Nanomaterials Assembly", Nano Lett., Vol. 8, 4210-4216, 2008.

[4] x. sheng., et. al, “Electro-hydrodynamic fabrication of ZnO-based dye sensitized solar cells”, Appl Phys A, 87, 715–719, 2007.

[5] Park, J. U., et. al and Rogers, J. A, “Nanoscale, Electrified Liquid Jets for High-Resolution Printing of Charge”, Nano Lett., 10, 584-591, 2010.

[6] Kazuhiro Murata, “Super-fine ink-jet printing for nanotechnology”, ICMENS’03, 2003.

[7] Dae-Young Lee., et. al, “Structuring of Conductive Silver Line by Electrohydrodynamic Jet Printing and Its Electrical Characterization”, Journal of Physics: Conference Series 142, 2008.

[8] Doo-Hyeb Youn., et. al, “Electrohydrodynamic micropatterning of silver ink using near-field electrohydrodynamic jet printing with tilted-outlet nozzle”, Appl Phys A, 96: 933–938, 2009.

[9] J. Choi, Y.J. Kim, S. Lee, S.U. Son, H.S. Ko, V.D. Nguyen, D. Byun, “Drop-on-demand printing of conductive ink by electrostatic field induced inkjet head”, Applied Physics Letters, Vol. 93, 193508, 2008.

[10] S. Lee, B. Byun, D. Jung, J. Choi, Y. Kim, J.H. Yang, S.U. Son, S.B.Q. Tran, H.S. Ko, “Pole-type ground electrode in nozzle for electrostatic field induced drop-on-demand inkjet head”, Sensors and Actuators A, Vol. 141, pp. 506-514, 2008.

[11] S. Son, K. An, Y.J. Kim, S. Lee, “Study of the phenomenon of meniscus deformation and ejection by pulse voltage and frequency in drop-on-demand EHD printing”, Nanotech2010, Vol. 2, pp. 500-503, 2010.

[12] Sukhan Lee., et. al, “Array-Nozzle EHD Print Head and Its Drop-on-Demand Experimentation”, Nanotech2011 Vol. 2, pp. 516-519, 2011.