Repeated Duplication in EHD Line Patterning on a Non-Conductive Substrate Based on Controlling the Polarity of Applied Voltages

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ABSTRACT

This paper presents an effective method of repeated duplications in EHD printing for forming a high aspect ratio of metal lines on a non-conductive substrate. As the number of repeated duplication increase, aspect ratio of metal lines increases. At the same time, but also increases the scattering of droplets around the patterned lines grows. To solve this problem, we proposed method is based on controlling of the polarity of the applied pulse voltages in such a way as to hinder the accumulation of charges, thus, reducing the scattering of droplets around the patterned line.

It is verified experimentally that we can be reduce the scattering of droplets around the patterned line through the controlling of the polarity of the applied pulse voltages.

Keywords: EHD, line patterning, duplication printing

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. 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 viscosities. 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 [1-3]. In recent years, fine patterning based on EHD printing, including patterning fine metal lines, has been investigated by a number of researchers [4-6]. However, in order to apply to the industry, it is necessary to solve the problem of high resistance due to a low aspect ratio of metal lines. This paper addresses the EHD printing of a high aspect ratio of metal lines as a means of forming a high conductivity of metal lines. As stated earlier, EHD printing is advantageous over conventional inkjet printing as it allows a high viscosity of ink to be used for increasing the thickness of printed lines [7]. However, in practice, forming a high thickness of metal lines by EHD printing may not solely be from a higher viscosity of ink, but, probably be from a combination of the higher viscosity of ink and the duplication in printing. Despite the necessity of duplicated printing, there has been little study on how to make effective duplication for EHD printing [8]. Although we demonstrated how to increase the thickness of EHD printed metal lines by duplication [8], we found that the repeated duplication of EHD printing of metal lines on a non-conductive substrate causes the scattering of droplets around the patterned lines due to the effect of accumulated charges. This paper presents an effective method of repeated duplications in EHD printing for forming a high aspect ratio of metal lines on a non-conductive substrate. The proposed method is based on controlling of the polarity of the applied pulse voltages in such a way as to hinder the accumulation of charges, thus, reducing the scattering of droplets around the patterned line.

2 EXPERIMENTAL SETUP

Fig. 1 shows the schematic of experimental set-up for EHD line printing. We had to use a tapered glass nozzle. The outer diameter of the nozzle is less than 5µm. 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 3×10-6 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 the glass substrate and the nozzle is about 50 µm while the thickness of the glass substrate is 500 µm. 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 and y 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.

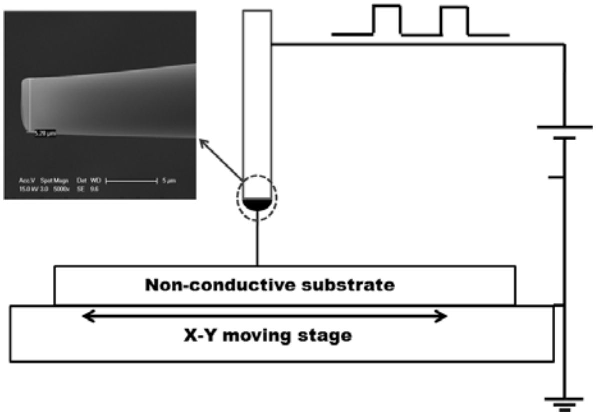

Figure 1: Illustrations of high resolution EHD printing system.

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. The applied voltage is 1000 V and the pressure is 5 kPa. The speed of the moving stage is 100 mm per second. Fig. 2 illustrates the line patterning results due to the number of duplicated printing for implementing the desired line thickness.

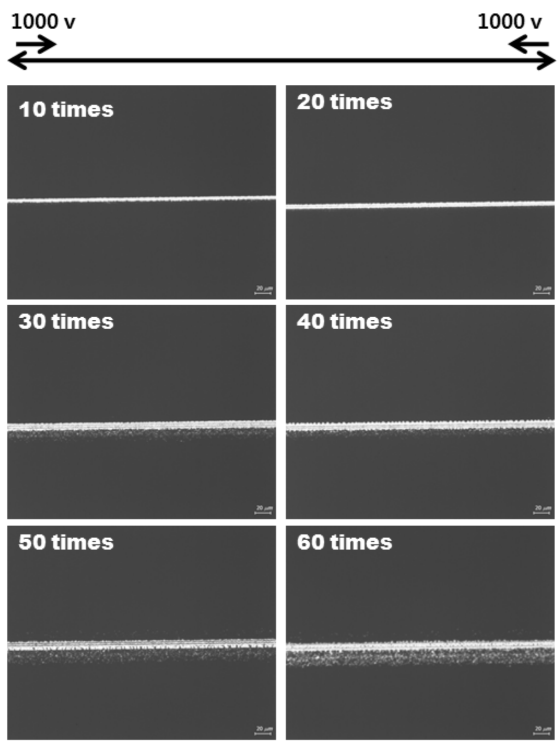

Figure 2: Line patterning results due to the number of duplicated printing using EHD printing system.

To obtain the resistance of the lines, we have carried out a sintering process using the oven. The heat treatment was allowed to proceed for one hour at 200 ℃. After heat treatment, the line width and thickness is reduced. In order to calculate the electrical resistivity, after the process of sintering was over, the printed and sintered metal lines' width (w) and thickness (t) were analyzed based on microscope and AFM. Fig. 3 shows the variation of line width and thickness by the number of duplicated printing. As the number of repeated duplication increase, the line thickness is increased, the line width is almost unchanged. Because of the high rate of increase in thickness compared to the rate of increase of the line width, the aspect ratio is increased as a result. On the other hand, as the number of repeated duplication increase, the scattering of droplets around the patterned lines grows. In addition, because of this, line shape is increasingly pointed and the surface of the line is uneven, as shown in fig 3.

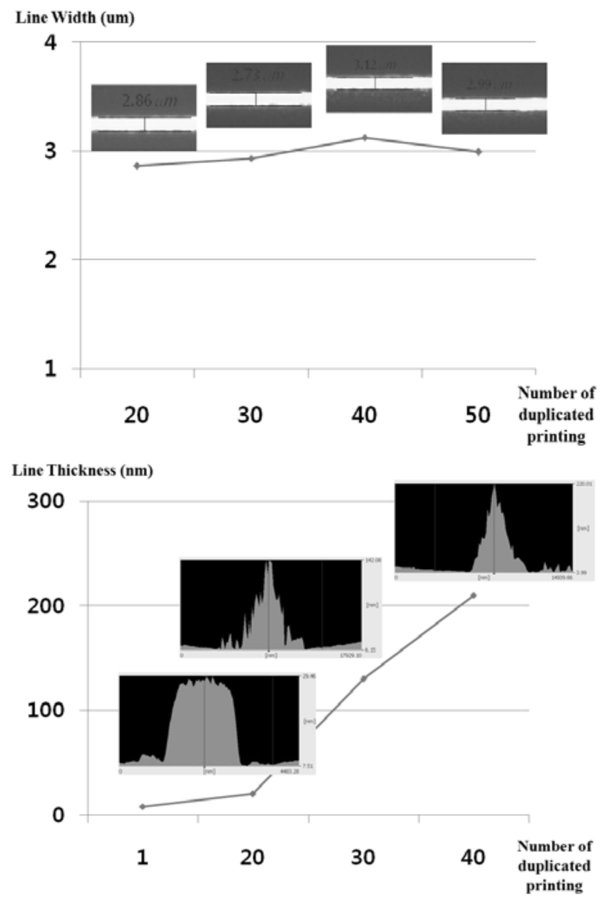

Figure 3: Variation of line width and thickness by the number of duplicated printing.

To measure the resistivity of the printed metal lines, we attached a few patches of silver paste on the lines for use as electrodes. The specific electrical resistivity of the line was calculated using the 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 area of the line. The resistance was calculated using an I-V curve measured with an I-V meter. Fig. 4 shows a high aspect ratio metal line patterned by the 40times repeated printing and heat treatment. The length of the line is about 630μm and line width and thickness is 3.12 μm, 210nm, respectively. The resistance of this line was measured at 111Ω, which value is convertible to an electrical resistivity of 13.1μΩ·cm. In fact, since the shape of the line is sharp, A is smaller. So, the actual electrical resistivity is lower than expected.

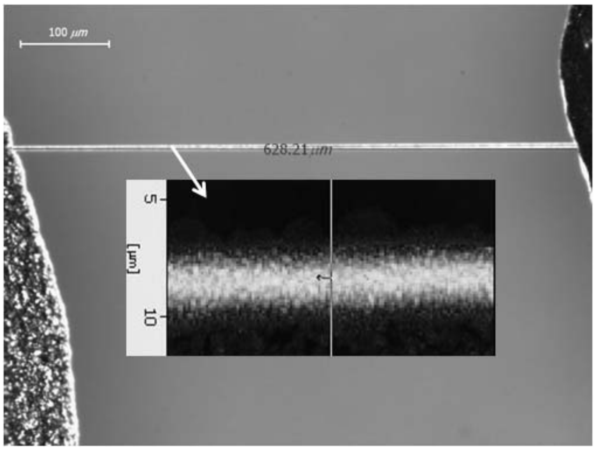

Figure 4: High aspect ratio metal line patterned by the 40times repeated printing and heat treatment.

As shown fig.2 and 3, excessive repeated duplication of EHD printing of metal lines on a non-conductive substrate causes the scattering of droplets around the patterned lines due to the effect of accumulated charges. To solve this problem, we proposed method is based on controlling of the polarity of the applied pulse voltages in such a way as to hinder the accumulation of charges, thus, reducing the scattering of droplets around the patterned line. Fig. 5 shows comparisons of line patterning results by positive-positive repeated duplication printing and positive-negative repeated cross-duplication printing. The frequency is 50hz and the speed of moving stage is 5mm/s. Compared to positive-positive duplication, positive-negative duplication reduces the scattering of droplets around the patterned line. Fig. 6 shows repeated duplication line patterning results with EHD drop-on-demand (DOD) ejection based on controlling of the polarity of the applied pulse voltages. Usually, DOD ejection based on EHD use a bias voltage and added pulse voltage with same polarity. However, using the DOD ejection, as compared to the continuous ejection by DC voltage, the scattering of droplets around the patterned lines is further increased, as shown in fig 6(a). This is because the tiny ink drop by pulsed voltage is continuously accumulated. As a result, the effect of accumulated charge increases. The scattering of droplets around the patterned line by DOD ejection can be reduced through the controlling of the polarity of the applied pulse voltages, as shown in fig 6 (b).

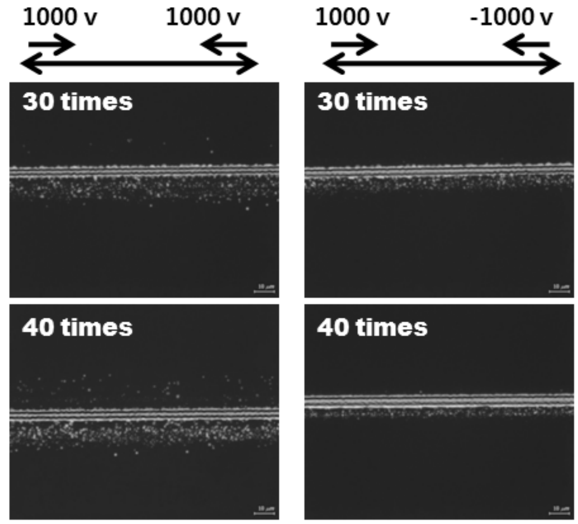

Figure 5: Comparisons of line patterning results according to positive-positive repeated duplication and positive-negative repeated cross-duplication.

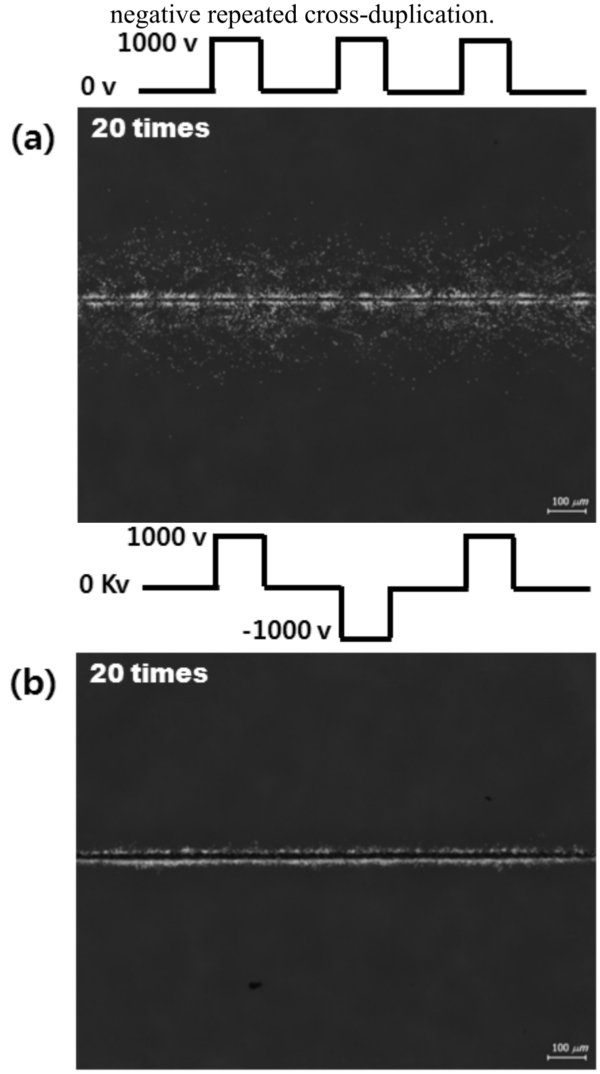

Figure 6: Repeated duplication line patterning results with EHD drop-on-demand ejection based on controlling of the polarity of the applied pulse voltages.

4 CONCLUSIONS

In this paper, we demonstrated how to increase the thickness of EHD printed metal lines by duplication printing. As the number of repeated duplication increase, aspect ratio of metal lines increases. At the same time, but also increases the scattering of droplets around the patterned lines grows. To solve this problem, we controlled the polarity of the applied pulse voltages in such a way as to hinder the accumulation of charges, thus, reducing the scattering of droplets around the patterned line. It is verified experimentally that we can be reduce the scattering of droplets around the patterned line.

5 ACKNOWLEDGMENT

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