High Aspect Ratio EHD Printing with High Viscosity Ink Ejection

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ABSTRACT

Electro-Hydrodynamics printing technology, one of the printing technologies based on Electro-Hydrodynamics discharging theory, can be patterning of high resolution and high aspect ratio compared to conventional inkjet printing systems. We have been investigating to define the optimal regions of Electro-Hydrodynamics printing, including ink conductivity and viscosity, to generate a high aspect ratio of line patterns for printed electronics. First, various industrial conductive inks are ejected to find the most suitable ejection mode for feature of patterning using a gate electrode Electro-Hydrodynamics printing system. Most inks have poor ejection performance with spraying, but some inks exhibit a good pulsed jet mode for the neat patterning. In particular, it requires at most 10^{-5} S/m of electrical conductivity of inks to be used for a stable pulsed jet mode of ejection; otherwise the ejection tends to appear with spraying. Higher viscosity ink has been patterned with better characteristics than lower viscosity ink on a non-conductive substrate without surface treatment because higher viscosity has retained the formation of pattern without spreadable phenomenon on a substrate using a direct Electro-Hydrodynamics printing system. Also, higher viscosity ink is better to form a higher aspect ratio of patterning than a lower viscosity ink.

Keywords: inkjet, printing, ink, aspect ratio, Electro-Hydrodynamics (EHD)

1 INTRODUCTION

The industrial applications of printing technology have recently attracted considerable attention due to the direct, low cost, yet flexible patterning means that the printing technology can offer for the fabrication of micro systems [1]. Thus, printing technology is very representative fabrication process for replacing existing and conventional fabrication process in the industrial world. In particular, inkjet printing for industrial printing, one of printing technology, have been studied for achieving the purpose of printing technology [2].

Currently, the industrial printing highly demands the high resolution patterning and high aspect ratio patterning for manufacturing electronic/bio devices and increasing the efficiency of device.

In order to manufacture the patterns of high resolution and high aspect ratio, we have been investigated the Electro-Hydrodynamics (EHD) printing technology which is alternative inkjet printing technology because it can be ejected very tiny droplets and made the patterns of good physical and chemical characteristics [3].

Electro-Hydrodynamics printing technology based on EHD discharging of tiny droplets is known to be able to generate not only a higher resolution of but also a higher aspect ratio of patterns than the conventional inkjet printing technologies based on the thermal bubble and piezoelectric actuator.

Electro-Hydrodynamics printing technology typically have approximately 10 ejection modes [4], but micro-dripping mode, pulsed cone-jet mode and continuous cone-jet mode are used for the ejection and patterning of industrial ink. Furthermore, micro-dripping mode, pulsed cone-jet mode and continuous cone-jet mode can make the high resolution patterns, because they form the droplet or jet from only endmost of meniscus formed at the nozzle [5].

Based on aforementioned explanation, we have the result of high resolution patterning using Electro-Hydrodynamics printing technology, and the result is published by our team member in the proceeding of Nanotech Conference 2012. The paper title is 'Fine Metal Line Patterning on Hydrophilic Non-Conductive Substrates Based on EHD printing with Laser Sintering'.

Also, Electro-Hydrodynamics printing technology forms droplet or jet by strong electric force using the high voltage supplier, so the higher viscosity ink can be easily ejected. It is known that the ejected droplet or jet using the higher viscosity ink can make thick patterns on the substrate, thus the ejection of higher viscous ink can make the patterns with the high aspect ratio.

Therefore, this paper demonstrates that higher viscosity ink can be ejected by Electro-Hydrodynamics printing technology. Furthermore, we have been investigating to define the optimal regions in the parameter space, including ink conductivity and viscosity, to generate a high aspect ratio of line patterns under the minimum repetition in Electro-Hydrodynamics printing technology for the applications to printed electronics.

2 EXPERIMENT SYSTEM

Figure 1 shows the schematic of EHD printing system set up for experimentation. Figure 1 (a) shows the gate electrode EHD printing system. A gate electrode is metal plate with hole, and located between nozzle and substrate. Thus, the gate electrode EHD printing system forms the droplet or jet by difference of electric potential between nozzle and substrate. The gate electrode EHD printing system is used for testing various ejection modes using various properties of inks in this paper.

The direct EHD printing system is shown in Figure 1 (b). The direct EHD printing system can make the droplet or jet by difference of electric potential between nozzle and substrate unlike the gate electrode EHD printing system. In this result, the direct EHD printing system for use in actual patterning on a substrate, where the outer diameters of the nozzles used is 200 μm for both.

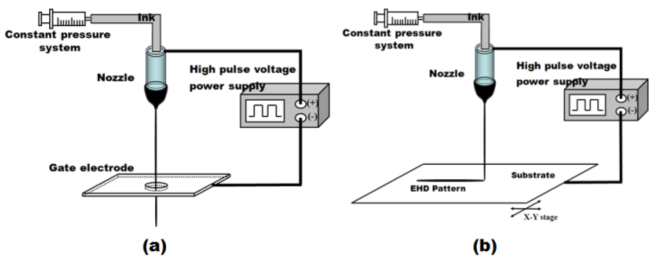

Figure 1. The schematics of EHD printing system and experiment set-up;
(a) The gate electrode EHD printing system,
(b) The direct EHD printing system

3 THE EJECTION TEST OF INKS

The gate electrode EHD printing system can eject the droplet or jet without electric influence between substrate and gate electrode. Therefore, various industrial conductive inks are tested for ejection in order to find the ejection mode most suitable for patterning, using the gate electrode EHD printing system.

As shown in figure 2, the first three inks exhibit a good pulsed jet mode of ejection for neat patterning while the last two inks show a poor ejection performance with the occurrence of spraying at the tip during the ejection (refer to the dotted circles). As illustrated in Table 1 where the properties of the inks used are characterized in terms of their electrical conductivities and viscosities, the performance of ejection is mostly influenced by their electrical conductivities: in particular, we found that, for a stable pulsed jet mode of ejection, it requires at most 10-5 S/m of electrical conductivity of inks to be used, otherwise the ejection tends to appear with spraying. Based on the result of the above investigation using the gate electrode type, we select Ink 1 and Ink 2 of Figure 2 for the further investigation of the performance of pulsed jet mode of pattering due to the difference in ink viscosity, using the direct type EHD printing system. Note that Ink 1 was made by Harima Chemicals, Inc. whereas Ink 2 was by InkTec® .

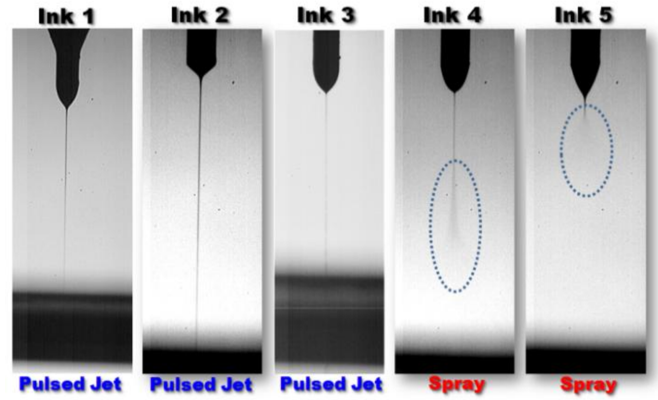

Figure 2. The ejection image of various inks

	Ink 1	Ink 2	Ink 3	Ink 4	Ink 5
Electrical Conductivity (S/m)	3×10^{-6}	1×10^{-5}	9×10^{-6}	1.6×10^{-3}	8.8×10^{-1}
Viscosity (cPs)	9.3	419	2.8	35	220

Table 1. The electrical conductivity and viscosity of various inks

4 RESULT

What we found is that, as shown in Figure 3, 1) Ink 1 and Ink 2 exhibit the same pulsed ejection mode for patterning with the direct EHD printing system. 2) But, Ink 2 with much higher ink viscosity than Ink 1 is shown better in ejection performance, since it is less affected by the spurious electrostatic charges accumulated on the patterns already printed on a non-conductive substrate without prior surface treatment (here, we used a pure glass wafer).

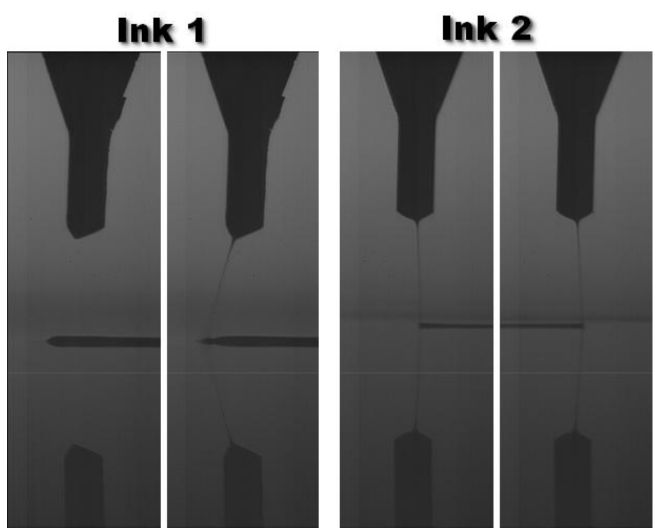

Figure 3. The patterning on a non-conductive substrate without surface treatment of Ink 1 and Ink 2

In other words, the higher viscosity of ink, Ink 2, is better to use for pattering under electrostatic disturbances,

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such as EHD printing on a non-conductive substrate without prior surface treatment, due to the fact that the higher viscosity of ink help retain the jetting formation without spraying.

Figure 4 shows the height profile of the line patterns using Ink 1 and Ink 2, respectively, after sintering. The line pattern using Ink 1 has 260 μm of width and 820 nm of thickness, whereas the line pattern using Ink 2 has 70 μm of width and 390 nm of thickness, illustrating that the line pattern using Ink 2 is much desired with higher aspect ratio than that using Ink 1. Besides, we found that Ink 1 is more vulnerable to have a crown shape on its height profile than Ink 2 (refer to the red circle in Figure 4). As such, generating a pattern without a crown shape for Ink 1 requires a careful control of the supplying pressure in a specific range, as shown Figure 4 (a) and (b).

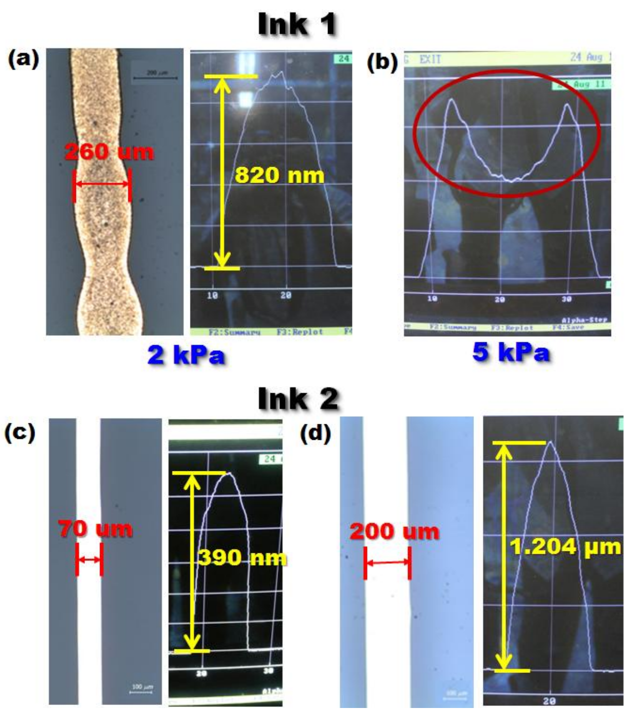

Figure 4. The patterning results on a substrate; (a) and (b) are the results of Ink 1 as supplying pressure, (c) is the result of only once patterning and (d) is twice patterning called the repetitive printing and patterning

Since the aspect ratio is one of the demanding requirements with great significance in printing technology, and, as Figure 5 demonstrates, a higher viscosity of inks, such as Ink 2, is better to form a higher aspect ratio of patterning than a lower one, such as Ink 1, EHD printing known to be capable of ejecting higher viscosity of inks may be favored for the applications required for a high aspect ratio of printing. Note also in Fig. 4 (d) that we can have only a minor improvement in the aspect ratio, say by about 0.006, with repetitive printing, implying that using a high viscosity of ink is important for a high aspect ratio of printing under the minimum repetition.

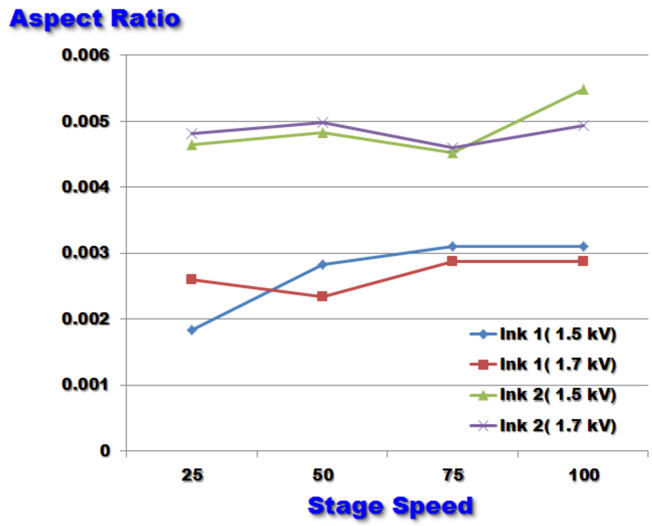

Figure 5. The graph of aspect ratio to the stage speed by Ink 1 and Ink 2

5 CONCLUSION

The pattering of high aspect ratio by Electro-Hydrodynamic printing technology has the most important meanings in industrial printing. Thus, in this paper, various industrial conductive inks are tested for ejection in order to find the ejection mode most suitable for patterning.

The ejection mode has been largely affected by electrical conductivity. A pulsed jet mode has completely ejected within 10^{-5} S/m, otherwise ejection would appear with spray mode. Hence, Ink 1 and Ink 2 with pulsed jet mode have been selected for investigation of patterning characteristics in the direct printing system depending on ink viscosity.

Ink 1 and Ink 2 have entirely same ejection mode for patterning in the direct printing system, but they have different the feature of pattern on a non-conductive substrate without surface treatment (a pure glass wafer). Ink 2 has been patterned with very good feature on a substrate because higher viscosity has retained the formation of pattern without spreadable phenomenon.

The pattern of Ink 1 which is the width of 260 μm and thickness of 820 nm has a rough characteristic, whereas the pattern of Ink 2 has a neat characteristic with the width of 70 μm and thickness of 390 nm. Also, higher viscosity Ink 2 has better aspect ratio of pattern than lower viscosity Ink 1, which means higher viscosity ink can be patterned in very good aspect ratio with high thickness. Moreover, the patterns of higher viscosity ink have improved aspect ratio with 0.006 by repetition printing and patterning in this result.

Therefore, high viscous ink could be patterned very well and neatly as well as aspect ratio with high thickness.

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