Effect of Charge Accumulation and Dielectric Polarization on EHD Patterning on Non-Conductive Substrates

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ABSTRACT

This paper investigates how the charges accumulated on and the dielectric polarizations induced in a non-conductive substrate affect the quality of EHD patterning by distorting electric field vectors and, thus, scattering the satellites/sprays generated at the meniscus tip. First, we show in simulation that the charges accumulated in time on a non-conductive substrate distort the distribution of electric field vectors, causing them either to diverge away or, even, to reverse their directions from the set printing path. Second, we found that the dielectric constant of a substrate influences the charge induced disturbances in printing: a substrate of lower/higher dielectric constant increases/decreases the scattering in patterning due to charge accumulation. By experimentation the above studies are also verified by generating a cone-jet mode of ink ejection.

Keywords: EHD Patterning, Charge Accumulation, Dielectric Polarization

1 INTRODUCTION

Despite its merits in printing fine patterns, finer than the nozzle diameter used, and in employing high viscosity of ink [1], Electro-Hydro-Dynamic (EHD) printing is yet to be widely adopted due mainly to the charge induced disturbances in patterning, especially, on non-conductive substrates. In present industry, many kinds of substrate are using for large device fabrication. Substrate plays key role on device performance. For this region, it is required to study deeply about impact of different substrates in EHD pattern quality. However, the distribution of the electric field along the path from the nozzle to the substrate plays a critical role in determining the shape of the pattern. This field ordering is changed continuously by the electrostatic interaction of charged droplets or jets [2]. In addition, during EHD discharge, part of droplets or jets loaded can be decomposed into small satellite / spray [3-4]. During EHD printing, the electric field is distorted strongly with the non-conductive substrates. This distortion of field vectors due to the accumulated charges in turn dictates the way how the subsequent accumulation of charges takes place on a substrate. This self-fed coupling between the charge accumulation and the field distortion results in forming a concentric pattern of satellite/spray scattering is regarded as a major source behind the charge induced disturbances in patterning[5]. Due to polarizability characteristic of dielectric, dielectric materials can obtain a dipole moment and charges are displaced along the field [6]. Polarization charges will collect at the surface of substrate in a short gap of nozzle to substrate. Especially, this paper investigates how the charges accumulated on and the dielectric polarizations induced in a non-conductive substrate affect the quality of EHD patterning by distorting electric field vectors and, thus, scattering the satellites/sprays generated at the meniscus tip.

2 EXPERIMENTAL SETUP & SIMULATION CONFIGURATION

Figure 1 (a): shows the schematic of experimental set-up for EHD discharging. The ink used in the experimentation was a, commercially available, Nano-past silver (Ag) ink (InkTec Co., Ltd., K 300). 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. In this study, we had to use a tapered glass nozzle of 5um size. The 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. 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. For experimentation, we generate a cone-jet mode of ink ejection, where a small amount of satellites/sprays are to be generated at the tip of its meniscus. Experimentation is conducted to verify the aforementioned effect of dielectric polarization on EHD printing, using Quartz (dielectric constant of 4.2) and PET (dielectric constant of 2.09) as substrates for various nozzle-substrate distances. As shown Figure 1 (b) design parameters are such as gap from nozzle to substrate and applying dc voltage and charge pattern along on a dielectric substrate. Note that, the charge pattern placed on top of the dielectric substrate in order to emphasize the effect of charge accumulation on the substrate. The observation is also carried out by examining how the different settings of the chosen parameters are to influence the convergence of the electric field along the jetting path unto the target on the substrate in terms of different dielectric substrate.

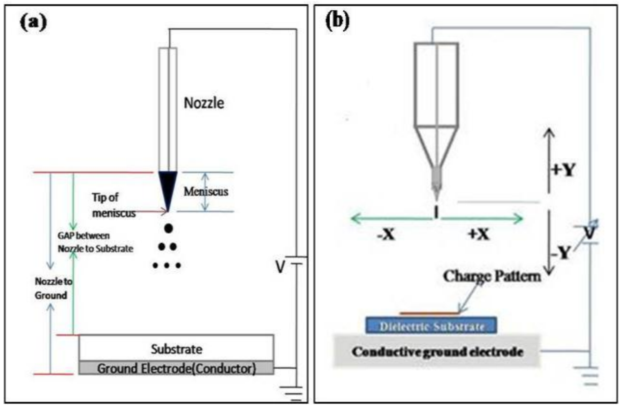

Figure 1: (a) A schematic diagram of experiment of EHD printing with design parameters and (b) The configuration of modeling in EHD printing.

3 RESULTS AND DISCUSSION

As seen by, Figure 2(a1) illustrates the field vectors streamlined towards the substrate when no accumulated charge is present on the substrate. However, with the charges accumulated on the substrate, not only the field vectors are scattered farther away but also those in the vicinity of the substrate center are forced to reverse their directions, as shown in Figure 2(a2). Note that this distortion of field vectors due to the accumulated charges in turn dictates the way how the subsequent accumulation of charges takes place on a substrate.

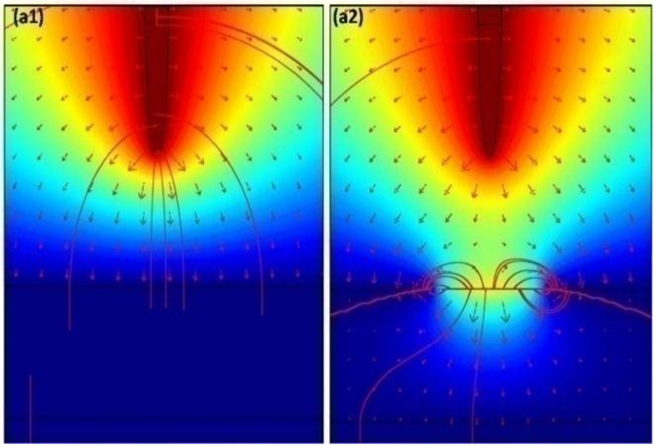

Figure 2: Image of the simulated electric field streamline, potential and vector distribution by COMSOL: (a1) no pattern on a non-conductive substrate and (a2) collected charged pattern on a non-conductive substrate

This self-fed coupling between the charge accumulation and the field distortion results in forming a concentric pattern of satellite/spray scattering, as shown in Figure 3(a) and (b), and is regarded as a major source behind the charge induced disturbances in patterning that the irregular satellites/sprays are formed in a regular pattern. In the case of a non-conductive substrate, the pattern of the spray type is formed around the center, as shown in figure 3 (a). In particular, it can be confirmed that by using the microscope image of figure 3 (b), the pattern of concentric circles are formed around the center[7].

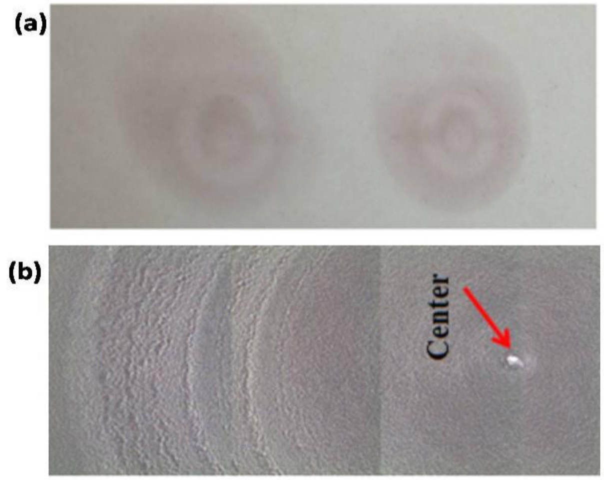

Figure 3: The ink pattern printed on the substrate in stopped state: (a) non-conductive substrate (b) conductive substrate (c) microscope image on a non-conductive substrate

We found that the dielectric constant of a substrate influences the charge induced disturbances in printing: a substrate of lower/higher dielectric constant increases/decreases the scattering in patterning due to charge accumulation. Although this is expected as the dipoles induced by dielectric polarization have an effect of compensating the accumulated charges with their opposite polarities, the induction of dipoles is again governed by the self-fed coupling. Here, we investigate the effect of the dielectric constant of a substrate on the distortion of field vectors by simulation and on the scattering in patterning by experimentation, taking the self-fed coupling among the charge accumulation, the field distortion and the dielectric polarization into consideration.

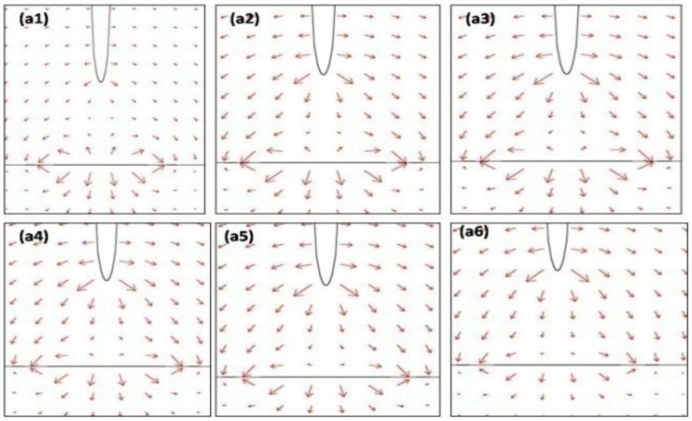

Figure 4: Electric field distribution for several Dielectric substrates: a1 (silica glass, Dielectric constant: 2.09), a2 (Glass, 4.2), a3 (Borosilicate, 4.8), a4 (Al2O3, 5.7), a5 (ZnO, 8.3) and a6 (SiC, 9.7)

Figure 4 (a1–a6) show in simulation that the higher the dielectric constant of a substrate, the less the distortion or the inversion of the field vectors around the center surface is, indicating the charge effect is compensated more with the increase in the dielectric constant.

Substrate	Dielectric Constant	Electric field at tip of meniscus (c/m^2)	Electric field at midpoint of meniscus to substrate (c/m^2)	Electric field at top of the center substrate (c/m^2)
Silica glass	2.09	-8.9743*10^6	-1.3708*10^5	-4.1207*10^6
Glass (Quartz)	4.2	-1.0939*10^7	-7.0632*10^5	-2.4382*10^6
Borosilicate	4.8	-1.1235*10^7	-7.9213*10^5	-2.1846*10^6
Al_2O_3	5.7	-1.1579*10^7	-8.9189*10^5	-1.8897*10^6
Mica	6.0	-1.1674*10^7	-9.1942*10^5	-1.8084*10^6
ZnO	8.3	-1.2198*10^7	-1.0712*10^6	-1.3596*10^6
SiC (6H)	9.7	-1.2406*10^7	-1.1316*10^6	-1.1811*10^6

Table 1: The electric field intensity is at major three points of EHD printing for several dielectric substrates.

Table 1 shows quantitatively how much the charge effect is compensated by the dielectric constant: as the dielectric constant is increased from 2.09 for silica glass to 9.7 for SiC (6H), the strength of the reversed field vector at the center surface is increased respectively from $-4.1207*10^6$ to $-1.1811*10^6$. As such, the amount of satellite/spray scattering in printing is decreased/increased respectively as the dielectric constant of a non-conductive substrate increased/decreased.

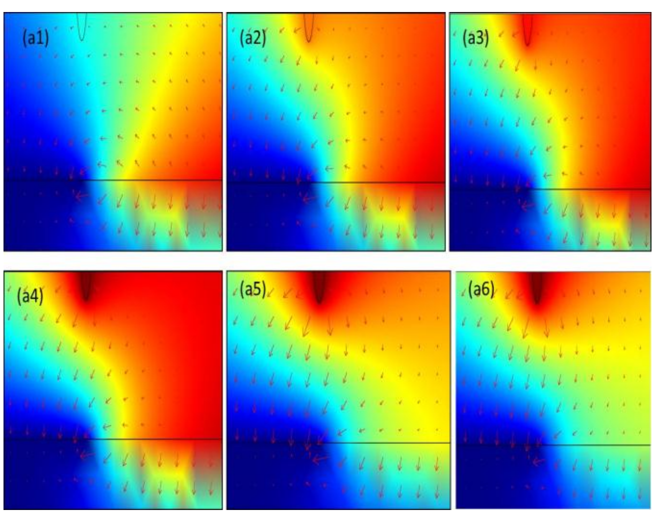

Figure 5: The surface view of electric field distribution in respect to multiple dielectric substrates in a specific condition: a1 (silica glass, Dielectric constant: 2.09), a2 (Glass, 4.2), a3 (Borosilicate, 4.8), a4 (Al2O3 , 5.7), a5 (ZnO, 8.3) and a6 (SiC, 9.7)

It is shown from surface view of electric field distribution in Figure 5 (a1-a6) that the electric field has been become stronger by increasing dielectric constant at tip of meniscus. It causes electric field becoming more week at the center line for non-conductive substrates with less dielectric constant, due to this region displaced huge droplet from the target local point of pattern. As a result, the scattering has to be happened highly on a non-conductive substrate along low dielectric constant.

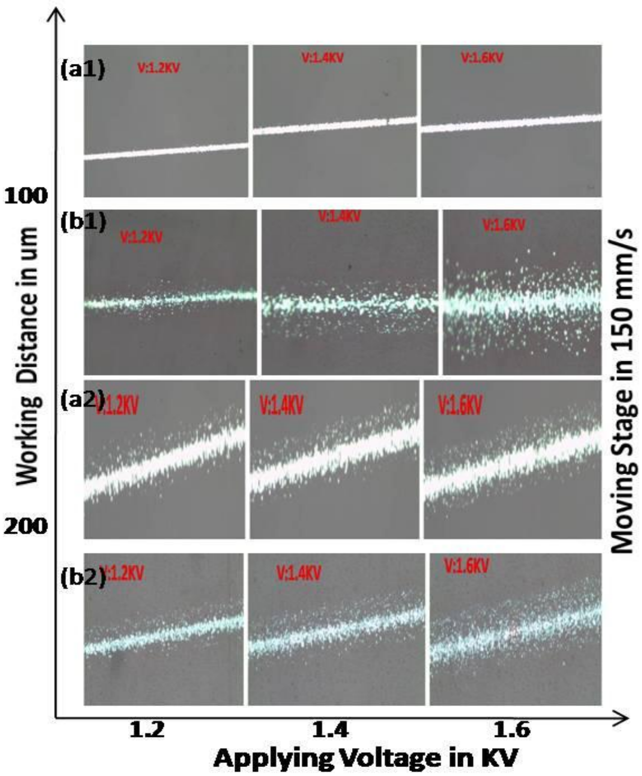

Figure 6: Line patterning result on Glass (Quartz): a1, a2 and PET: b1, b2.

As shown by Figure 6, the result indicates clearly that there occurs less scattering in line printing on the Quartz with its dielectric constant of 4.2, compared to that on the PET with its dielectric constant of 2.09, for various nozzle-substrate distances, verifying the aforementioned effect of dielectric polarization on EHD printing.

4 CONCLUSIONS

In this paper, we reported how the charges accumulated on and the dielectric polarizations induced in a non-conductive substrate affect the quality of EHD patterning. The charges accumulated in time on a non-conductive substrate distort the distribution of electric field vectors, causing them either to diverge away or, even, to reverse their directions from the set printing path. With the charges accumulated on the substrate, not only the field vectors are scattered farther away but also those in the vicinity of the substrate center are forced to reverse their directions. This self-fed coupling between the charge accumulation and the field distortion results in forming a concentric pattern of satellite/spray scattering. We found that the dielectric constant of a substrate influences the charge induced disturbances in printing: a substrate of lower/higher dielectric constant increases/decreases the scattering in patterning due to charge accumulation. It is verified using experimentation that the scattering become high with non-conductive substrate along low dielectric constant due to the aforementioned effect of dielectric polarization.

5 ACKNOWLEDGMENT

This work was supported in part by NRF-2013M1A3A02042335, the Ministry of Science ICT and Future Planning, Korea.

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