Electrostatic Induced Inkjet Printing System for Micro Patterning and Drop-On-Demand Jetting Characteristics

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ABSTRACT

Printing technology is a very useful method in the several process of industrial fabrication due to non-contact and fast pattern generation [1]. To make micro pattern, we investigate the electrostatic induced inkjet printing system for micro droplet generation and drop-on-demand jetting. In order to achieve the drop-on-demand micro droplet ejection by the electrostatic induced inkjet printing system, the pulsed DC voltage is supplied from 1.4 to 2.1 kV. In order to find optimal pulse conditions, we tested jetting performance for various bias and pulse voltages for drop-on-demand ejection. For investigated drop-on-demand micro pattern characteristic, conductive inkjet silver ink used. In this result, we have successful drop-on-demand operation and micro patterning. Therefore, our novel electrostatic induced inkjet head printing system will be applied industrial area comparing conventional printing technology.

Keywords: electrostatic induced inkjet printing system, drop-on-demand, pattern, micro droplet, micro dripping mode

1 INTRODUCTION

Printing technology is considered to be a key technology even in the field of electronics, materials processing, and bio applications [2]. Inkjet printing is an interesting patterning technique for electronic devices because it requires no physical mask, less environmental issue, and low fabrication cost, and provides good layer-to-layer registration. It also has the potential to reduce display manufacturing costs and enable roll-to-roll processing for flexible electronics [3]. The conventional inkjet printing systems are based on mechanically or thermally pushing out the liquid in a chamber through a nozzle by actuators, such as thermal bubble and piezoelectric actuators [4]. However, thermal bubble actuator has the heat issues when the array of nozzle make in a large area and piezoelectric actuator is difficult to make droplet smaller than nozzle size [5].

Alternatively, we focused on the EHD theory which may be the type of electrostatic induced actuator based on the direct manipulation of liquid by an electric field that appears to be more promising [6]. It has 10 jetting modes [7] that one of these, micro dipping mode, has a good characteristic to make inkjet printing system. Recently the interference effect is investigated for multi-nozzles [8] and the super-hydrophobic nozzle is fabricated and applied to electro-spray [9].

This paper presents the drop-on-demand operation by the novel electrostatic induced inkjet printing system and patterning lines by conductive nano silver ink, as an alternative to the thermal and piezoelectric print heads described above.

2 EXPERIMENT SYSTEM

Fig. 1 shows the schematic of the electrostatic induced drop-on-demand inkjet printing. That consists of glass capillary tube nozzle which size is 170 μm, electrode, and high pulse voltage power.

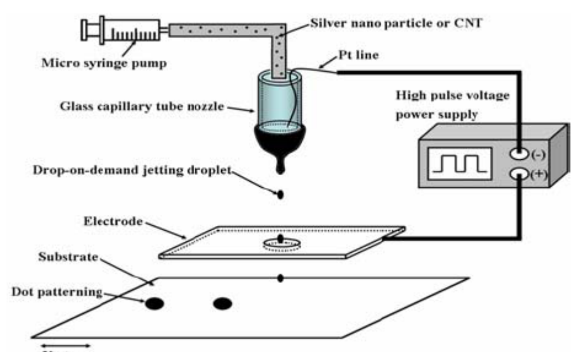

Fig. 1: The Schematic of the electrostatic induced drop-on-demand inkjet printing

The electric voltage signal applied to a ring-shaped upper electrode plate, located against the pole inside the nozzle as the ground, allows a micro-dripping mode droplet ejection to take place. The intense electric field between the electrode and the ground induces the liquid meniscus at the interface to form a micro droplet due to electrostatic force. When the force is stronger than the surface tension on the liquid meniscus, the liquid breaks up into micro droplets which are ejected. A high pulse voltage power supply (maximum voltage of 3.0kV) was used with a relay switch to control electrostatic field. Liquid was supplied by a micro-syringe pump, and an electrode was placed under the nozzle. A linear motor was used to move glass and PET substrate for forming dot and line droplet pattern.

Fig. 2(a) depicts photographs of experiment set-up and the assembly capillary inkjet head that is made of Pt-wire electrode and glass capillary tube packaged on acrylic board. Fig. 2 (b) shows the front and top view of assembly capillary inkjet head. The measurement equipments consist of a high speed camera (IDT XS-4) with a micro-zoom lens and a LED lamp was used to visualize droplet ejection. The high speed camera can image 8000 frames in a second at a 160 x 1280 resolution. Fig. 2(c) shows the fabrication procedure of electrode which extracts the liquid meniscus. The hole is made by sand blaster after deposition of Al layer on the glass wafer.

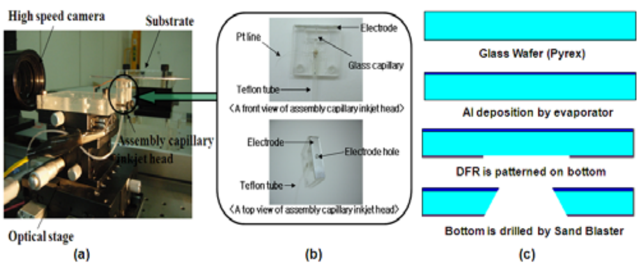

Fig. 2: The photograph of (a) experimental set-up, (b) assembly capillary inkjet head and (c) the electrode of fabrication procedure

3 RESULT

It is important to observe and distinguish dripping mode, which represents jetting drop by drop after swelling on the nozzle tip due to the absence of an electric field and micro dripping mode, where a mono-disperse droplet is formed directly at the meniscus apex, changing the operating voltage. In general, micro dipping mode is appeared under the higher voltage than that for dripping mode.

Fig. 3 shows the images of droplet ejection observed by high-speed camera at various supplied DC voltages of 1.4~2.1 kV. The flow rate of 1 µl/min is supplied, and the gap between the capillary nozzle and the electrode is 2.0 mm. The inner and outer diameters of the glass capillary are 100 µm and 170 µm, respectively.

In the dripping mode at 1.4 kV, the droplet size is bigger than the nozzle size. However when the operating voltage increases above 1.5 kV, the micro dripping mode comes to make tiny droplet.

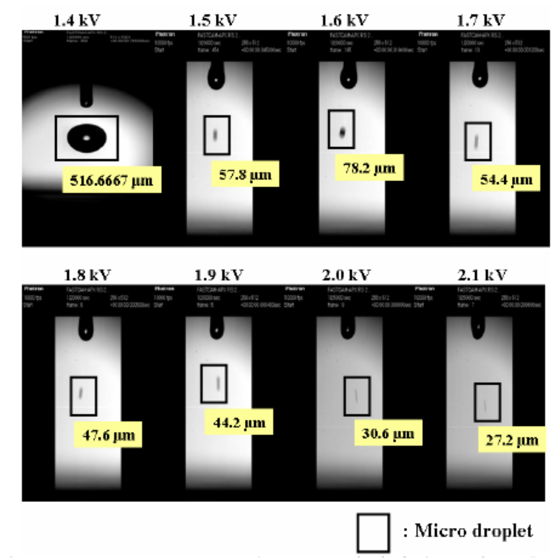

Fig. 3: Snap shot of jetting image using the conductive nano silver ink

We could find that the optimal operating voltage is 2.1kV for the smallest droplet size. Also, droplet ejection is able to take place at frequencies ranged from a few tens Hz to several thousands Hz, giving uniform droplet sizes of about 30 µm. Furthermore to investigate the optimal pulse conditions for the drop-on-demand jetting, we carried out more experiments varying the bias and pulse voltages. By means of the bias voltage of 1.4 kV, forms the shape of semicircular meniscus, and then using the pulse of 0.7 kV, micro droplet is ejected. External pulse is given to the power supply and makes 0.5 kHz and 0.7 kHz square wave high voltages.

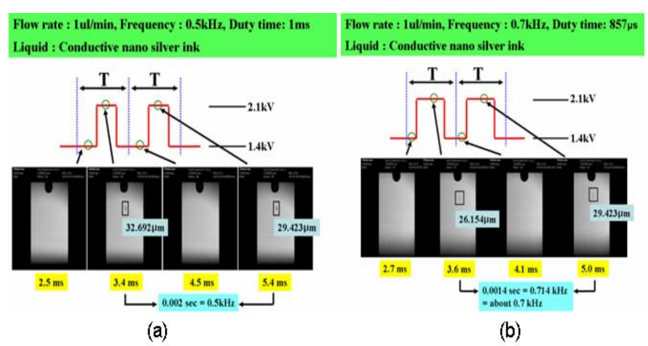

Fig. 4: The jetting images of drop-on-demand result using conductive nano silver ink; (a) 0.5 kHz and (b) 0.7 kHz

Fig. 4 shows the sequential images of drop-on-demand operation using conductive nano silver ink. From these fundamental studies to find the optimal conditions for jetting, we could carry out drop-on-demand operation using conductive nano silver ink and then try to pattern lines on a substrate.

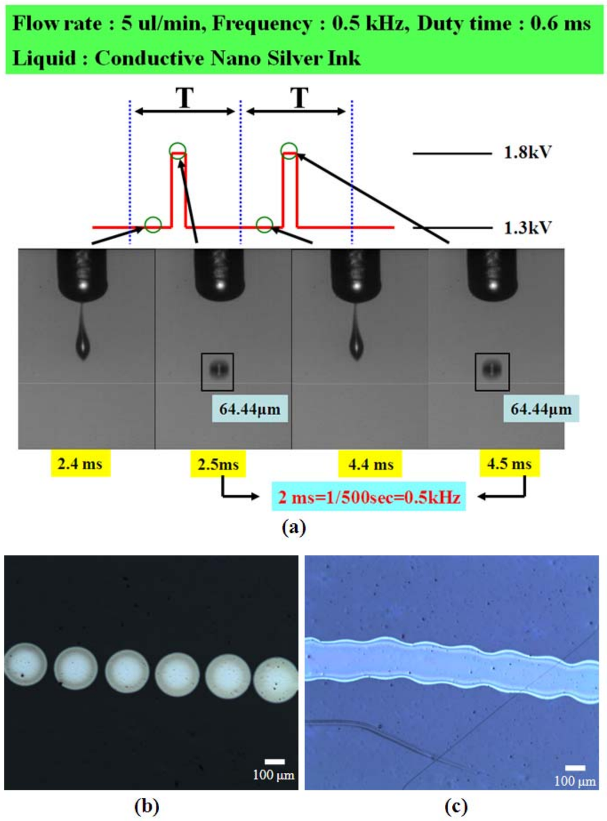

Fig. 5: (a) the jetting images of drop-on-demand (0.5 kHz), (b) the dot pattern of drop-on-demand jetting, (c) the line pattern of drop-on-demand jetting

Fig. 5 (a) shows one example of patterning of nano silver ink by means of drop-on-demand ejection at the jetting frequency of 0.5 kHz. To investigate the effect of flow rate, in figures 5 and 6, we supplied 5 µl/min and 15 µl/min, respectively. As flow rate increases, liquid is supplied fast so we can increase jetting frequency. However the optimal voltage for drop-on-demand operation is 1.8 kV with the bias voltage of 1.3 kV. Fig. 5 (b) and (c) show dots and a line patterned on the PET substrate. The patterning was carried out with drop-on-demand operation at jetting frequency of 0.5 kHz and linear motor speed of 100 mm/sec. The width of the patterned line is 205 µm with 5 µm standard deviations. Even if the diameter of the droplet is around 65 µm, the width of the line is printed as around 3 times larger. It is a good reason that the glass and PET substrate are hydrophilic surface, the droplet is able to be in spread so that size of dot or the width of the line become much larger than size of droplet. Therefore, further research for tuning the condition for tiny droplet and treating the surface of the substrate is needed in order to pattern the tiny lines using our novel electrostatic induced inkjet printing system.

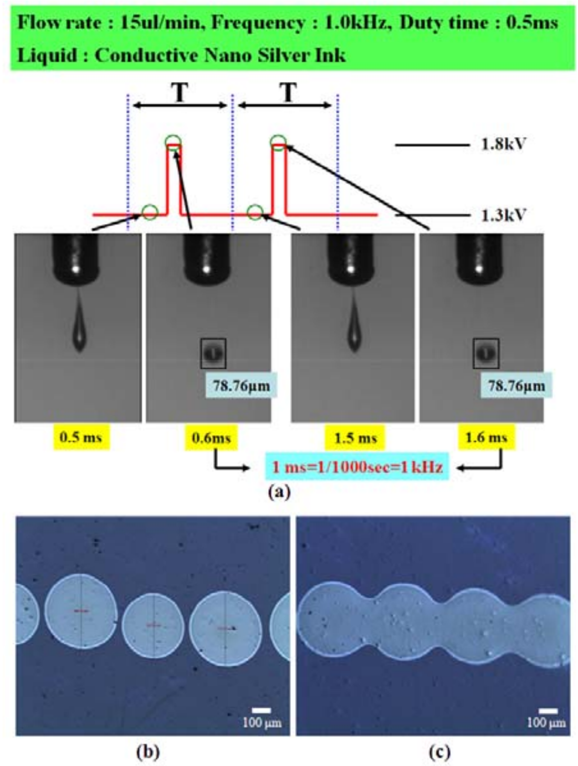

Fig. 6: (a) the jetting images of drop-on-demand (1 kHz), (b) the dot pattern of drop-on-demand jetting, (c) the line pattern of drop-on-demand jetting

As shown in Fig. 6 (a), the condition of drop-on-demand ejection is also 1.8 kV even for 15 µl/min allowing jetting frequency of 1 kHz. Fig. 6 (b) and (c) show dots and a line patterned on the PET substrate. The width of the line is around 350 µm with standard deviations of 22.54 µm. The uniformity looks good in Fig. 5 (b), while the uniformity is not good in Fig 6 (b). It may depend on the flow rate and the following instability. We need further studies associated with the reliability issues and precise control of operating conditions to enhance the uniformity.

4 CONCLUSION

We present the drop-on-demand droplet ejection and micro size pattern using our novel electrostatic induced inkjet printing system. The assembly capillary inkjet head system is composed of capillary tube and electrode, and is packaged by acrylic board. We investigated the optimal conditions of voltage, pulse, and flow rate for drop-on-demand electrostatic droplet ejection of conductive ink. To make micro-dripping mode for tiny droplet ejection, it is needed to apply 1.8 kV to 2.1 kV. Using these conditions, the dots and lines are fabricated by the inkjet system. Our novel electrostatic induced inkjet printing system may possibly be considered as one of alternatives which is able to be applied in industrial printing and to overcome the limitation of conventional print heads such as thermal bubble or piezoelectric inkjet heads which droplet size is similar nozzle size.

5 ACKNOWLEDGMENT

This work was supported by a grant from the National Research Laboratory program, Korea Science and Engineering Foundation Grant (R0A-2007-000-20012-0) and Seoul R&BD program. VDN acknowledges partial support from the Korea Research Foundation (KRF-2007-211-D00019).

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