Array-Nozzle EHD Print Head and Its Drop-on-Demand Experimentation

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ABSTRACT

EHD (ElectroHydroDynamic) printing has critical merits in printing micro/nano size patterns compared to other inkjet printing technologies; however, the development of multi-nozzle EHD print heads is essential for high throughput printing and commercialization of this inkjet head technology. This paper introduces a novel nozzle array EHD print head that features control electrodes designed for electrostatic ejection and screening to reduce electric field interference. The printer head consists of a nozzle plate, an insulator, and control electrodes, and it is assembled by stacking the components. Experimental prototypes were fabricated by using micro-CNC, EDM, and ceramic processing. Two experiments were conducted to verify functions of the head, i.e. (i) drop-on-demand printing without the control electrodes and (ii) printing with the control electrodes. Preliminary experimental results show a successful drop-on-demand printing with an array of nozzles. The control electrodes were used to reduce the operating voltage and electric field interference among the nozzle array.

Keywords: EHD, drop-on-demand, inkjet, printing

1 INTRODUCTION

EHD (ElectroHydroDynamic) printing has critical merits in printing micro/nano size patterns compared to other inkjet printing technologies, i.e. piezoelectric driven and bubble jet driven, because it can eject droplets that are much smaller than the diameter of a nozzle. This technology is becoming more useful with the availability of a broad range of inks for industrial applications. Such inks include metals, organics, and bio materials, and the capability of EHD for printing inks with a wide range of electric conductivities and fluidic viscosities further widens the application space [1-2]. In order for EHD to become a competitive technology for industrial applications, high throughput capability is essential. Thus, printing multiple dots with an array of nozzles in parallel has been preferred over sequential printing of single dots using one nozzle. This demands the development of multi-nozzle EHD print heads for commercializing this technology. However, applying multiple nozzles in EHD printing is complicated due to its basic operating principle. In EHD printing a droplet is formed from an apex of meniscus at the end of the nozzle using a high intensity electric field. If a nozzle array is used, the electric field distribution at a nozzle can be affected by adjacent nozzles. Therefore, reducing the interference of the electric field among the adjacent nozzles is vital in designing a multiple nozzle EHD print head, and especially crucial when nozzles are in the micron scale and need to be arrayed with a small pitch. The interference problem has been discussed in several references. The droplet ejection characteristics around stainless nozzles were studied by Reagle [3], and the electric field distribution for multiple nozzles was analyzed experimentally by Quang [4]. Although many researchers have studied the electric field interference effect for EHD printing head, none of the designs were able to remove the interference effectively [5-7]. As an effort to solve this problem, Lee et al. have been developing electrostatic drop-on-demand print heads and nozzle array EHD print heads [8-11]. This paper introduces a novel nozzle array EHD print head that features control electrodes designed for electrostatic ejection and screening to reduce electric field interference. The preliminary experimental results clearly demonstrate the validity of the design concept by showing drop-on-demand ejection through four nozzles at one time.

2 DESIGN

Figure 1 represents the structure of the novel array nozzle EHD print head. This head houses an ink chamber (not shown), a nozzle plate, an insulator, and control electrodes. The nozzle plate was designed to have a 4x4 array of nozzles. Each nozzle is 450μm long with an inner diameter of 40μm. The nozzle is made of a stainless steel plate using both micro-CNC and micro-EDM (electrical discharge machining) processes. The insulator and control electrodes were fabricated from ceramic material with a high dielectric strength. The control electrodes include patterned gold film on the ceramic material. The printer head is assembled by stacking the components and fixing them with four plastic screws. As shown in Figure 1(a) and (b), the printer head can be used in two configurations, i.e. (i) without the control electrodes and (ii) with the control electrodes. Printing without the control electrodes can generate multiple jetting simultaneously while printing with

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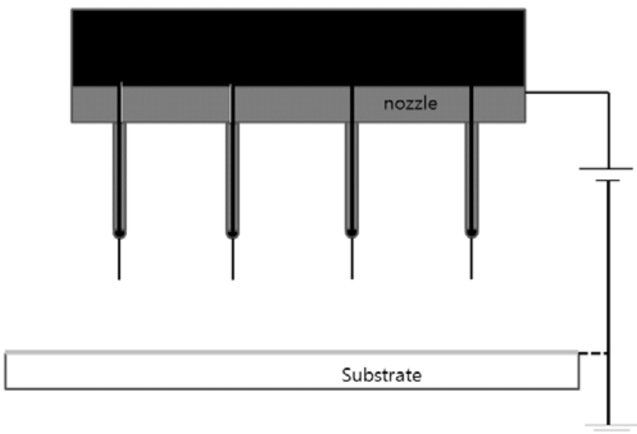
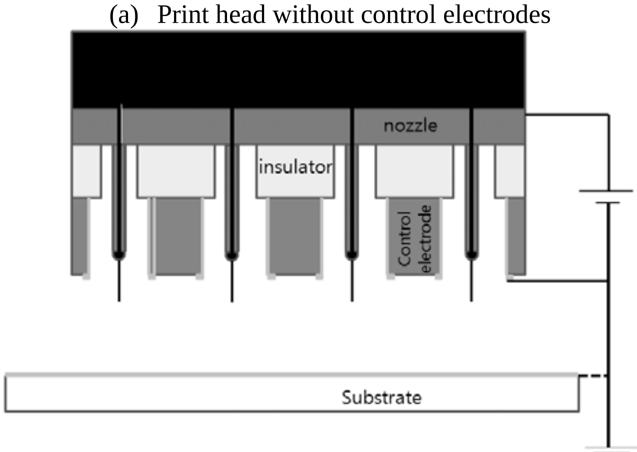
the electrodes can provide better controllability by reducing electrical interference among the nozzles. The control electrodes were designed not only to control the ejection of droplets as a metal shield, but also to reduce the interference effect of the electric field among adjacent nozzles. In our previous studies, we confirmed that a conductive film structure around the nozzles performs better than a nonconductive structure in reducing interference of the electric field. The geometry of the electrode affects the performance of the shielding effect. The electrodes need to be taller than the nozzle tip to be effective as a shield and to maintain a proper gap away from the nozzle to prevent electrical breakdown. The detailed dimensions were designed by FEM analysis of electrical field around nozzles.



(a) Print head without control electrodes



(b) Print head with control electrodes assembled.

Figure 1: Illustrations of array nozzle EHD print head.

3 DESIGN

Two experiments were conducted to test the feasibility of (i) drop-on-demand printing with multiple nozzles and (ii) printing with the designed control electrodes. Figure 2 shows the photographs of the experimental set-up for drop-on-demand printing using the prototype array nozzle EHD print head. Ink used in this study was ethylene glycol, which can be printed in a stable cone-jet mode [10]. The known surface tension coefficient and the conductivity of ethylene glycol are 4.80×10-2 dynes/cm and 7.60×10-5 S/m respectively. The ink was supplied through the chamber to the nozzle with a constant pressure of 2kPa by a pressure controller. 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 capture ejection motion, a high speed camera with a micro-zoom lens and a LED light source were used.

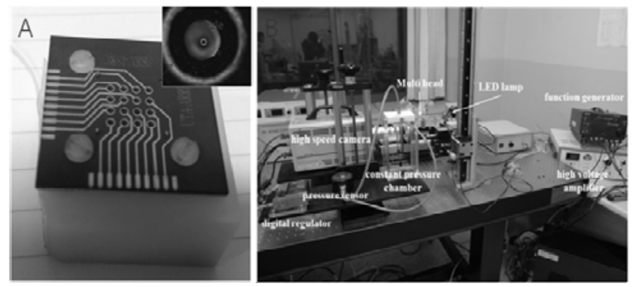


Figure 2: The photographs of (a) array nozzle EHD print head and (b) experimental set-up.

4 RESULTS AND DISCUSSION

A stable drop-on-demand ejection requires suitable conditions such as a bias voltage for maintaining a stable meniscus shape at the nozzle tip and an onset voltage for optimal ejection [10]. In order to determine the onset voltage, we examined the ejection mode with an applied DC voltage on the array nozzle as a preliminary test before drop-on-demand printing. The results are shown in Figure 3. The working distance between the substrate and the nozzle tip was 1.7mm. From Figure 3, it was determined that the suitable onset voltage was about 2.9kV for drop-on-demand ejection.

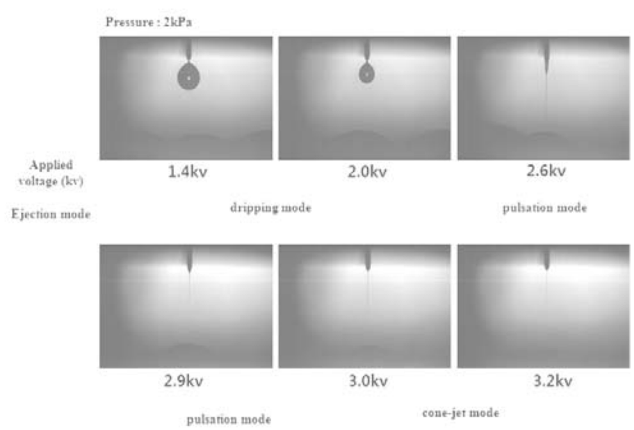


Figure 3: Photographs of meniscus formation and ejection with various applied DC voltage conditions.

Figure 4 shows the images of drop-on-demand ejection using the fabricated array nozzles. In this experiment, only

4 nozzles were used to print the ink on a copper coated glass slide. Signals were generated by a function generator and then amplified to a high voltage. Stable drop-on-demand ejection was observed at a bias voltage of 1.6kV with added onset pulse of 1.7kV to the bias voltage. A square wave pulse was used with a frequency of 200Hz and a duty cycle of 500μs. Figure 5 shows the printing results from the array nozzles.

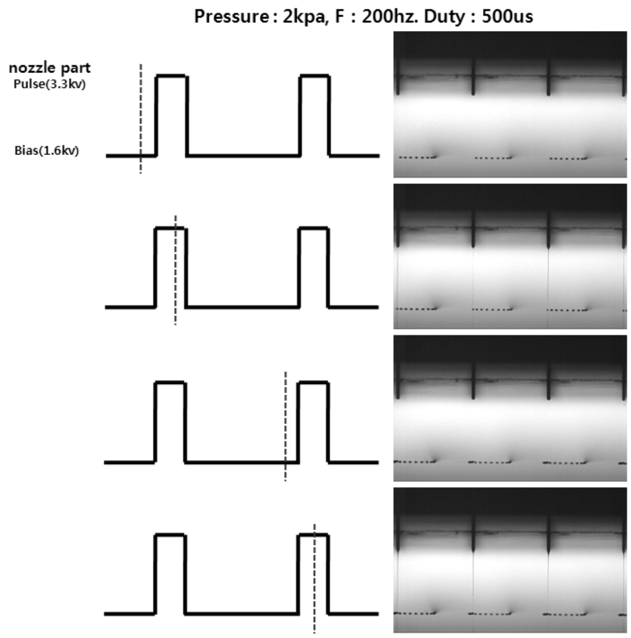


Figure 4: Jetting images of EHD drop-on-demand using the prototyped array nozzles.

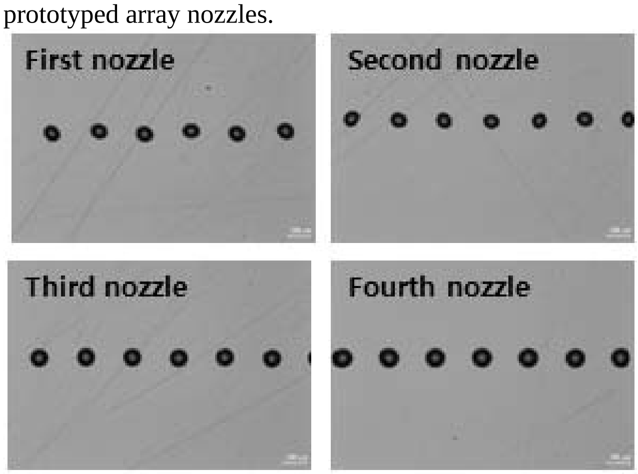


Figure 5: Dot patterns of EHD drop-on-demand printing using the prototyped array nozzles.

Figure 6 shows the images of drop-on-demand ejection using the control electrodes. Since the thickness of the control electrodes is taller than the length of the nozzles, the nozzles are hidden in the ceramic electrode structure and are not seen in these images. Although the electrodes were designed to control all 4x4 nozzles individually, only 2 nozzles were used in this preliminary experiment with the same voltage applied at the same time. Figure 6(A) is the printing result with an operating condition of DC voltage of 1.2kV applied to the two nozzles and a 0kV bias with a 0.9kV pulse voltage applied to the control electrodes. Figure 6(B) is the printing result with an operating condition of DC voltage of 1.5kV applied to the two nozzles and a 0.3kV bias with a 1.2kV pulse voltage applied to the control electrodes. In both cases, the pulse signal used was a square wave with a frequency of 1kHz and a 500μs duty cycle. Also, the field strength between the nozzle and the side electrodes are the same, but the electrostatic field between the side electrode and the substrate is different. Case B is a way to help in the stable ejection between the side electrode and the substrate because the direction of the electric field is identical to the direction of the ejection. The electric field strength is too strong.

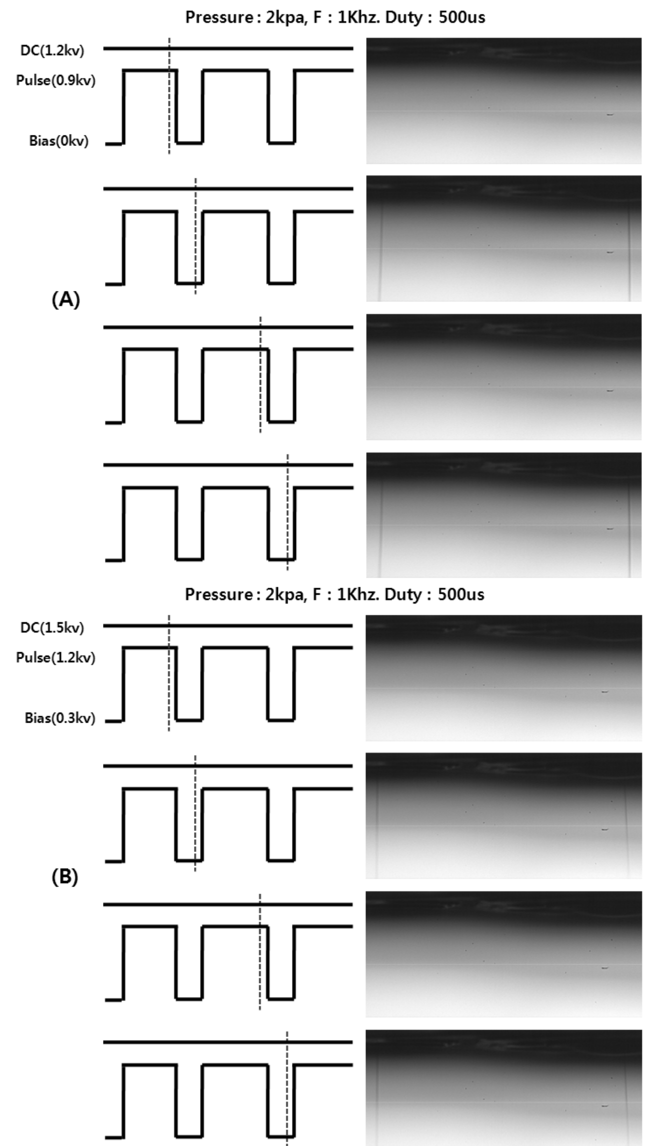


Figure 6: Jetting images of EHD drop-on-demand using the control electrodes. Two different voltages conditions were tested on two nozzles.

5 CONCLUSIONS

In this paper, we introduced a novel array nozzle EHD print head and demonstrated droplet ejection based on EHD drop-on-demand. The prototyped print head has an assembly structure with all components stacked, aligned and screw tightened. This feature allowed us to experiment with the feasibility of printing conditions both with and without the control electrodes. From this experimental study, we have demonstrated drop-on-demand printing using a nozzle array EHD print head. The control electrodes contributed in the reduction of the electric field interference and also allowed ejection at a lower voltage condition. Further studies are expected to characterize the performance of individual control of each nozzle for patterning applications.

6 ACKNOWLEDGMENT

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REFERENCES

[1] A. Jaworek, A. Krupa, “Classification of the modes of EHD spraying,” J. Aerosol Sci. 30, pp. 873-893, 1999.

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

[3] J.D. Regele, M.J. Papac, M.J.A. Rickard, D. Dunn-Rankin, “Effects of capillary spacing on EHD spraying from an array of cone jets,” J. Aerosol Sci., 33, pp. 1471-1479, 2002.

[4] B. Quang T. Si, D. Byun, S. Lee, “Experimental and theoretical study of a cone-jet for an electrospray microthruster considering the interference effect in an array of nozzles,” J. Aerosol Sci., 38, pp. 924-934, 2007.

[5] K. Tang, Y. Lin, D.W. Matson, T. Kim, R. D. Smith, “Generation of Multiple Electrosprays Using Microfabricated Emitter Arrays for Improved Mass Spectrometric Sensitivity,” Anal. Chem., 73, pp. 1658-1663, 2001.

[6] W. Deng, A. Gomez, “Influence of space charge on the scale-up of multiplexed electrosprays,” Aerosol Science 38, pp. 1062–1078, 2007.

[7] R. Krpoun, H.R. Shea, “A method to determine the onset voltage of single and arrays of electrospray emitters,” J. of Appl. Phys., 104, 064511, 2008.

[8] 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.

[9] 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.

[10] 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.

[11] Ink-jet print head, U.S. Patent No. 7,708,385.