New Micro Fabrication Techniques Utilizing Electrostatic Inkjet Phenomena

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Abstract

Electrostatic inkjet phenomena took place when strong electric field was applied to water pin electrode. In this paper we developed two new micro fabrication techniques utilizing electrostatic ink jet phenomena. First technique is to thin a metal rod. The metal rod was set on a metal plate electrode. The diameter of the rod was controlled by the time of voltage application between the capillary tube and the metal rod. The other is to punch a hole in a metal thin sheet. A shin metal sheet was set on the metal plate electrode. When the formation and locus of droplets that contained commercial etching liquid was controlled, small hole was punctured on the shin sheet. Hole diameter, less than 10 μm to some 100 μm was controlled by the voltage application between the sheet electrode and the capillary tube that was filled with the etching liquid.

Introduction

Electrostatic inkjet phenomena took place when high voltage was applied between an insulative capillary tube filled with ion conductive liquid and a metal plate electrode [1, 2]. Droplet diameter and dropping frequency were controlled by the voltage application. An investigation has been carried out on the control of a micro-droplet in electrostatic inkjet phenomena [3], because the electrostatic inkjet phenomena have merits that the formation and locus of the droplet can be controlled by the application of the electric field and it is possible to treat highly viscous liquid. It was observed that a Taylor cone of the liquid was formed at an end of the tube and the tip of the cone was broken to form a very small droplet at the beginning of the corona discharge. Because the inkjet phenomena have these merits, many scientists have been developing mask-less lithography utilizing conductive paste [4, 5] and new three-dimensional micro rapid-prototyping utilizing glass paste [5].

We are now applying the inkjet phenomena for new micro dissolving methods utilizing etching liquid for the purpose of new micro fabrication techniques. In this paper, we investigated the fundamental characteristics of droplet formation of etching liquid and preliminary experiments of dissolving methods were carried out. One is to thin metal rod. This goal is to fabricate micro tools to manipulate individual cells. The diameter of the metal rod was determined by time of voltage application. The other is to punch a hole in a shin metal sheet. This goal is to fabricate micro filter of cell fusion experiment. The diameter of the hole was controlled by the amplitude of the applied voltage.

Experimental Set-up

An experimental set-up shown in Fig. 1 was constructed to investigate fundamental characteristics of droplet formation of etching liquid. A capillary tube made of silica coated by polyimide (PolymicroTechnologies, Phoenix, AZ) was equipped with a bottom of a syringe. This tube with the liquid was hanged down perpendicular to a metal plate electrode. Voltage was applied by a power supply (Matsusada Precision Inc, Tokyo, HVR-10P). The droplet formation was captured by a high speed camera (Photron Inc, Tokyo, FASTCAM-MAX 120K/120KC) and a light. The air gap was adjusted by a z-stage and the plate electrode was moved in x and y directions with two linear motors.

The experimental set-up was changed as follows to thin metal rod. Initial diameter of the rod was 300 μm. Two metal blocks those were 10 mm thickness were set under the both ends of the metal rod. A narrow wire was set between the center of the metal rod and the plate electrode. Etching liquid was hard to remain on the surface of the metal rod because after drops were landed on the metal rod, the drops moved to the plate electrode through the narrow wire.

The experimental set-up was changed as follows to punch a hole in a shin metal sheet. The shin metal sheet was attached to the plate electrode because a sheet of shin wet paper was sandwiched between the shin metal sheet and the plate electrode. Etching liquid was hard to remain on the metal sheet because after etching liquid dissolved the metal sheet, the liquid was absorbed into the wet paper.

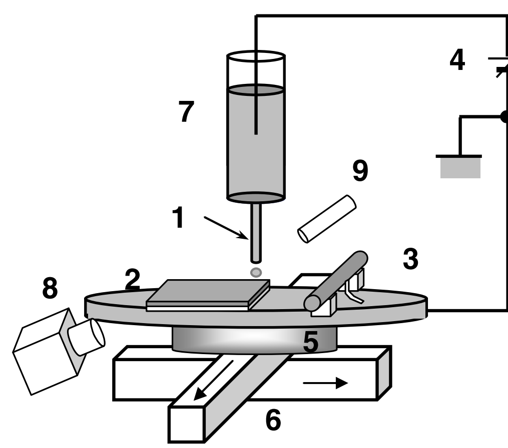
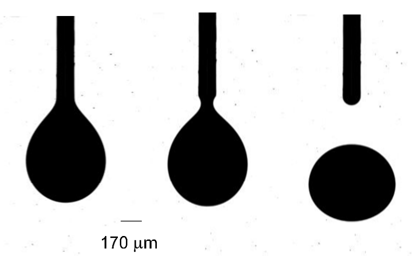


Figure 1: Experimental set-up of electrostatic inkjet. (1: insulative capillary tube filled with liquid, 2: shin metal sheet and shin wet sheet, 3: metal rod, blocks and narrow wire, 4: DC high voltage power supply, 5: mechanical z-stage, 6: x-y linear stages, 7: tank, 8: high speed camera, 9: light).

Droplet Formation of Etching Liquid

Pictures of droplet formation of etching liquid were shown in Fig. 2 and 3. Figure 4 indicated the droplet diameter in case that the applied voltage was changed. Mode of droplet formation was divided into mode 1 (low voltage region) and mode 2 (high voltage region). Figure 2 showed the pictures of droplet formation in the low voltage region. The drop diameter was very large and the frequency of the drop formation was low. The drop diameter was small in case of high voltage application. The mode of droplet formation was changed when the applied voltage was over the corona threshold voltage.[3] The threshold voltage was high in case of large air gap. Pictures of droplet formation were shown in Fig. 3. The Taylor cone [2] was formed at the tip of the tube and the tip of the cone was separated periodically and the frequency of the droplet formation was high. The droplet diameter was large in case of high voltage application.



(a) 0 s (b) 40 ms (c) 80 ms

Figure 2: Droplet formation captured by a high speed camera. (2.5 kV, 5.0 mm)

(a) 0 s (b) 20 ms (c) 40 ms (d) 60 ms

Figure 3: Droplet formation captured by a high speed camera. (2.8 kV, 5.0 mm)

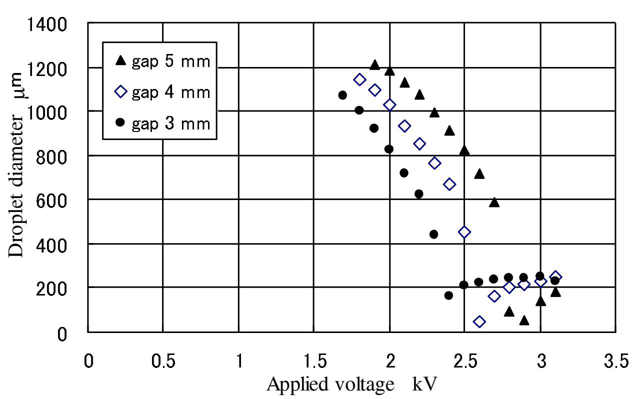
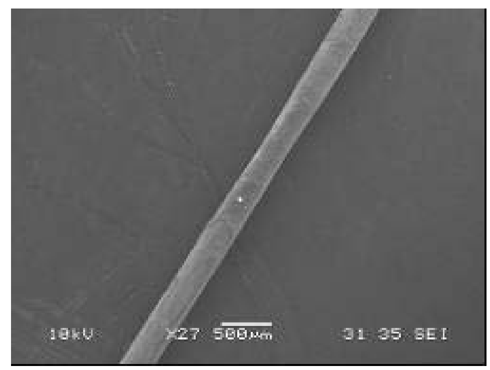


Figure 4: Droplet diameter when the applied voltage was changed. (parameter: air gap)

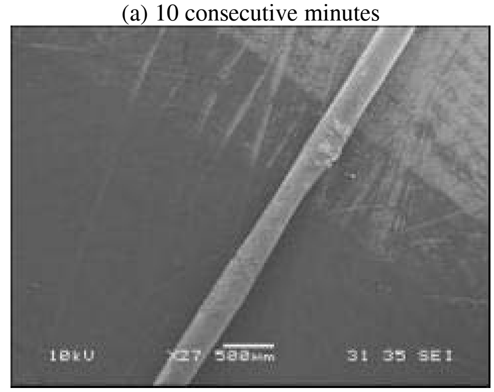
Micro Fabrication

To Thin Metal Rod

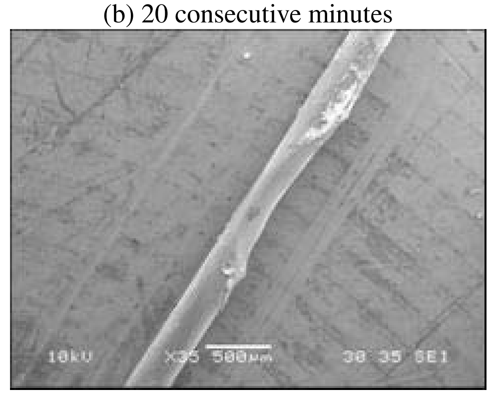
A cupper rod was thinned by the electrostatic inkjet phenomena. Voltage was applied for over 10 minutes continuously because one droplet that diameter was about 10 μm can dissolve a little. Figure 5 shows a picture of a thinned rod. The rod became thinned much in case of long-term voltage application. Figure 6 and 7 show diameter of the thinned rod in case that the air gap was 3.0 mm and 4.0 mm, respectively. These figures indicated that the diameter did not depend on the applied voltage and the air gap. Because when the electric field was strong, the amount of droplets during a given time was constant although the droplet diameter was large. Figure 8 shows a picture of punching in a metal tube. The diameter of the hole on the tube depended on the time of voltage application.



(a) 10 consecutive minutes



(b) 20 consecutive minutes



(c) 30 consecutive minutes

Figure 5: Pictures of thinned metal rod. (air gap: 3.0 mm, applied voltage: 3.0 kV)

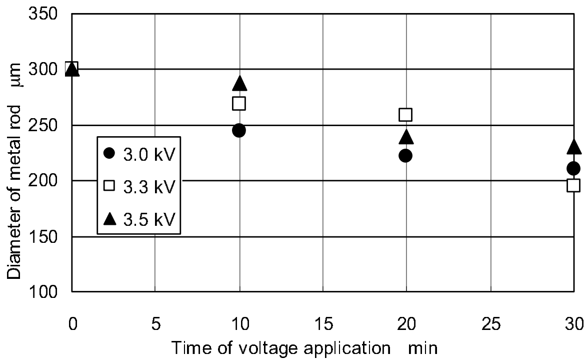


Figure 6: Diameter of thinned metal rod. (air gap: 3.0 mm)

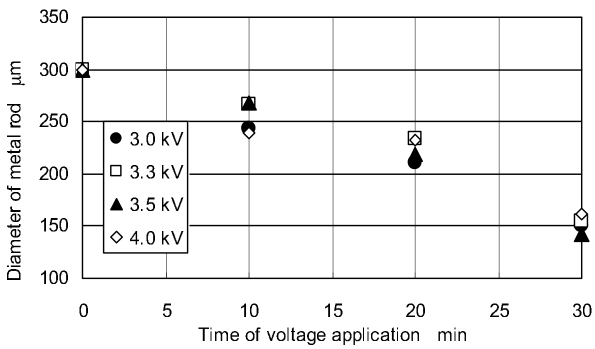


Figure 7: Diameter of thinned metal rod. (air gap: 4.0 mm)

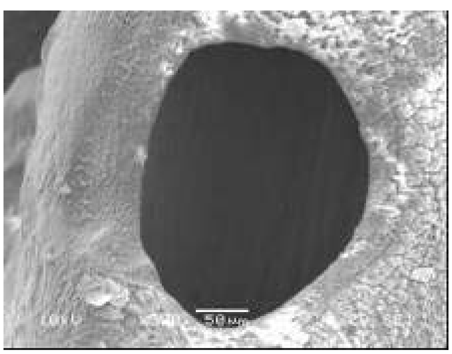


Figure 8: Picture of punched hole in metal tube.

To Punch a Hole in Thin Metal Sheet

A small hole was punched in a shin metal sheet by the electrostatic inkjet phenomena shown in Fig. 9. The material of this sheet was tin. One droplet was enough to punch a hole on the sheet because the thickness of the sheet was several µm. Figure 10 shows measured diameter of the hole. This figure indicated that the hole diameter was large in case of high voltage application because the droplet diameter was large when the applied voltage was high in mode 2. When the applied voltage was less than 2.0 kV, the diameter of the hole was very large because the formed drop was very large. In this case, 2.0kV was threshold of the corona threshold voltage. However Fig. 4 indicated that the corona threshold voltage was 2.8 kV in case that the air gap was 5.0 mm.

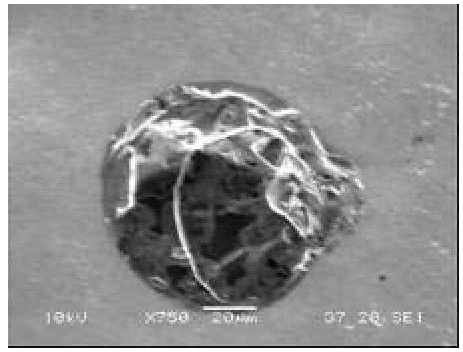


Figure 9: Picture of punched hole in shin metal sheet. (gap: 5.0 mm, 2.2 kV, material: Sn)

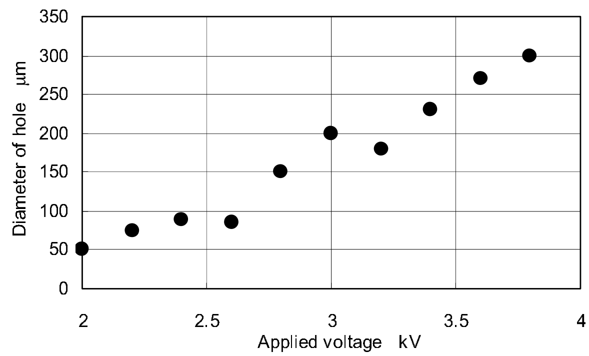


Figure 10: Diameter of punched hole in shin metal sheet. (gap: 5.0 mm, material: Sn)

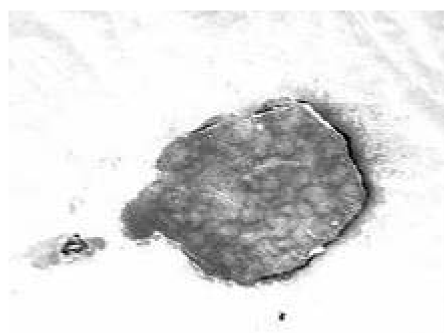


Figure 11: Picture of punched hole in shin metal sheet. (material: Ag)

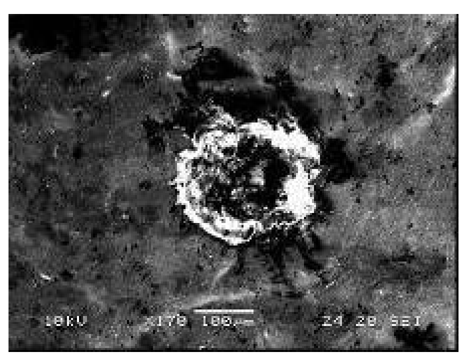


Figure 12: Picture of punched hole in shin metal sheet. (material: Al)

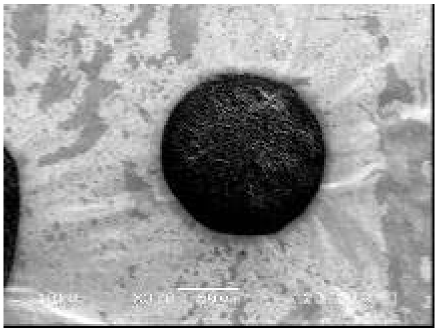


Figure 13: Picture of punched hole in shin metal sheet. (material: Au)

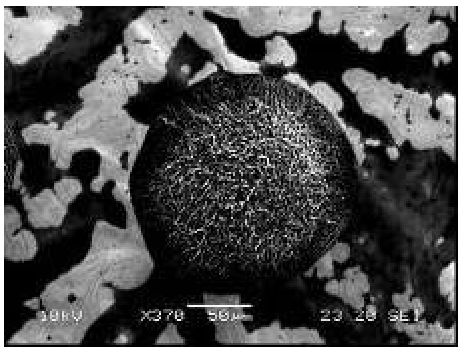


Figure 14: Picture of punched hole in shin metal sheet. (material: Pt)

We thought it was the reason why the thin metal sheet was lifted up and the electrostatic field was strong.

Figure 11, 12, 13 and 14 show pictures of shin metal sheets when droplet of etching liquid was injected on the metal sheet in case that the material of the sheet was changed. When the material was silver or aluminium, sheet was dissolved. However, when the material was gold or platinum, sheet was not dissolved.

Conclusion

We applied the electrostatic inkjet phenomena for new micro dissolve fabrication techniques, those are to thin metal rod and to punch hole in shin metal sheet after we investigated the droplet formation of etching liquid.

The mode of the droplet formation of etching liquid was divided into mode 1 (low voltage region) and mode 2 (high voltage region). In mode 1, the drop diameter was large. In mode 2, the droplet diameter was small. In this region, The Taylor cone was formed at the tip of the tube and the tip of the cone was periodically separated. When the applied voltage was high, the droplet diameter was large.

We demonstrated and investigated the fundamental characteristics of two new micro dissolve techniques. One is to thin metal rod. The rod was thinned much in case of long-term voltage application. The diameter of the thinned rod did not depend on the amplitude of the applied voltage and the air gap. The other is to punch a hole in a shin metal sheet. The hole diameter was large when the applied voltage was high in mode 2.

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