Pattern Deposition of Nanoparticles of Different Shapes by an Aerosol Route

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Introduction:

The electrospray system disperses highly-charged, monodisperse droplets which can be showered over a plate of large area. By varying the liquid feed flowrate and voltage of the system, nano-sized particles can be distributed over the area. Using the soft lithography technique of micro-contact molding, a certain pattern can be imprinted on a polymer coated plate. This molding reveals a silver substrate in the pattern outlined by the nonconductive polymer. The electrospray apparatus can be used to spray highly positively-charged nanoparticles that are then deposited on the surface in the respective pattern. An electric field is established between spray head and substrate, assisting the containment of the sprayed particles in the desired area. Before spraying particles the polymer-coated surface is charged by electrospraying a highly conductive solution. The gold nanoparticles used range in size from 10 to 20 nm and are generally conglomerated inside the desired pattern after spraying. Being able to control the positioning and patterning of nanoparticles by use of the electospray system will allow a much larger area to be covered in a much shorter time compared to existed deposition experiments.

There has been much research done in the field of controlling the size, shape and phases of nanoparticles, but controlling the placement of these particles has presented itself as a challenge [1]. A precise patterning of nanoparticles would be greatly beneficial in some areas of interest, and even a loose patterning of a large amount of these particles would prove to be practical in some applications.

This experiment attempted to find an efficient way to quickly and accurately deposit nanoparticles in a given pattern. An electrospray device developed in our lab was used to shower highly charged nanoparticles onto an opposite charged patterned substrate outlined with nonconductive polymer, consequently depositing them in the desired pattern.

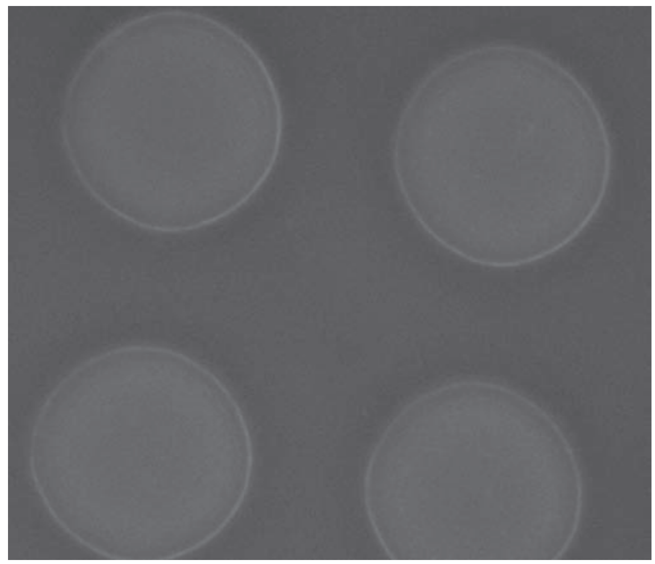

Figure 1: 10 μm hole pattern in the substrate.

Experimental Procedure:

An elastomer stamp was created from a master with our micron-sized pattern on it (in this case, 10 μm holes). This stamp was used for micro-contact molding to imprint the pattern on our photoresist, which was a silicon wafer coated with silver. This left a pattern on the highly conductive silver that was outlined by a nonconductive polymer (see Figure 1). This process was set up so we could mass produce our patterned plates in a quick and efficient manner. In one hour, as many as 15 plates could be patterned and ready for spraying.

After the plates had been patterned, they were ready to be sprayed by the electrospray device. This device is a particle generation/dispersion system used to shower monodisperse droplets over a large area. In this experiment, we were able to use it to shower individual nanoparticles over the prepared patterns. The particles being used were 10-20 nm gold colloid nanoparticles. The liquid in which the nanoparticles were suspended was fed into the system by a syringe pump so the flow rate could easily be controlled. As the suspension flowed through a capillary towards a very sharp tip, the particles were subjected to an divergent electrical field established by applying a high voltage between the capillary and plate. The established electric field was also used to help contain the particles and keep them focused in the desired area [2].

Before the gold particles were sprayed, we introduced a highly conductive pre-spray solution of nitric acid and ethanol to charge the surface of our plates. The plate charging helped to target the spray particles towards the highly conductive silver patterns and away from the non-conductive polymer. After 30 minutes of the pre-spray and 30 minutes of electrospray by the nanoparticles, the process was complete.

Results were then obtained by use of the scanning electron microscope (SEM) to inspect deposited particles on the plates, and to obtain data of the distribution of deposited nanoparticles.

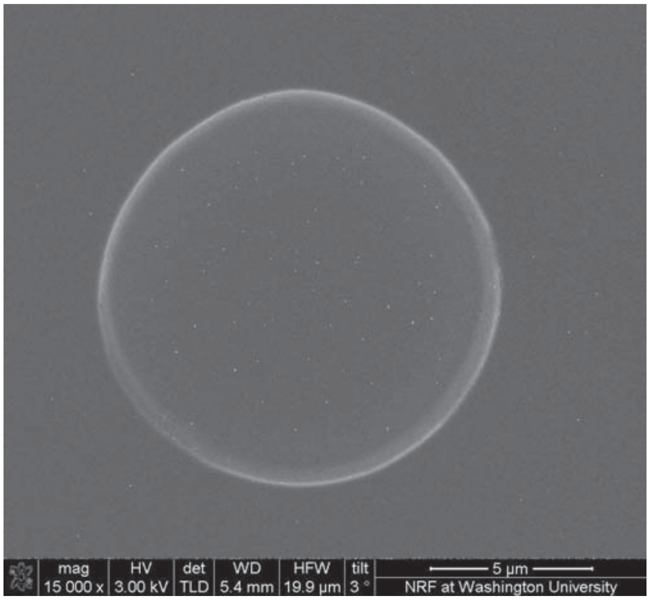

Figure 2: Nanoparticles mainly located in the holes.

Results and Discussion:

After many trials, our experiment eventually led to a 75% successful rate of nanoparticles in the holes, compared to being outside of the holes. Figure 2 shows a close up of the holes with the particles enhanced in size for better viewing. This success was mainly attributed to the correct combination of our lithography method for producing the patterns, the use of the unipolar charger, and the introduction of the pre-spray solution to help charge our surface before the shower of nanoparticles. Micro-contact molding replaced micro-contact printing which had produced silver holes with a silicon outline, which didn't work because the silicon provided a semi-conductive surface that attracted particles. The unipolar charger resulted in a successful but random distribution of particles on our molded plates, compared to using no charger and a bipolar charger, which had yielded no particles on the surface. After the success of the unipolar charger, the pre-spray solution allowed a much more accurate focusing of particles into the patterned holes. Increasing the conductivity of this solution produced even better results.

Future Work:

This experiment demonstrated that a large percentage of the particles could be conglomerated inside the target holes compared to being outside on the nonconductive surface. We weren't able to achieve full accuracy, but future experiments will be geared toward reaching that goal. Also, new patterns and different types of particles will be used to conduct the experiment.

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References:

[1] H. Kim, J. Kim, H. Yang, J. Suh, T. Kim, B. Han, S. Kim, D. S. Kim, P. Pikhitsa, M. Choi. "Parallel patterning of nanoparticles via electrodynamic focusing of charged aerosols." Nature. Vol. 1, November 2006.

[2] Chen, Pui, and Kaufman. "Electrospraying of Conducting Liquids for Monodisperse Aerosol Generation in the 4 nm to 1.8um Diameter Range." Journal of Aerosol Science. Vol. 26, No. 6, pp. 963-977, 1995.