

Scalability and Control of Electrophoretic Directed Assembly of Nanoparticles

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ABSTRACT

The nanoscale directed assembly of nanoparticles has many applications in biotechnology, energy, electronics and nanomaterials. Directed assembly of nanoparticles for biosensor devices, nanowire and interconnects are being conducted at the CHN. The nanoparticle based biosensor is used for the detection of multiple cancers and targeted drug delivery. The sensors require assembly of nanoparticles in specific predetermined locations. Electrophoresis is one of the promising methods for assembling these nanoparticles because of its speed. In order to obtain reliable assembly, it is important to understand the assembly mechanism and the governing process parameters. In this study, we have investigated the effect process parameters on electrophoretic assembly. The results show that the control of the assembly process enables precise and repeatable assembly of 50 nm PSL nanoparticles over large scale at high rate which is crucial for many applications.

Keywords: assembly, electrophoresis, nano- particles, bio sensor

1 INTRODUCTION

The bottom up approach for nanoparticle based biosensor devices [1] for biomarker detection and targeted drug delivery devices involve assembly of nanoparticles functionalized with antibodies. Many methods has been establishe to assemble these nano particles on the templates in various ways such as sedimentation[2], drying[3-5], dewetting[6-7] layer by layer growth[8] and spin coating[9]. However, in most these methods the control of assembly is dependent on various parameters such as particle density, flow speed, flow direction. Moreover, the processes are slow and not suitable for high rate nanomanufacturing. A possible method of assembling these nanoparticles is by employing electrophoresis which utilizes the charge induced on these particles suspended in solution as a result of potential formed at the particle-liquid interface. This method is very promising because of simplicity of use and assembly speed.

It has been shown in the past that by employing electrophoresis functionalized colloidal gold films[10] and spherical latex particles[11] have been assembled into

micro and nanopatterns. The directed nanoparticle assembly rate and the quality of the assembly have been studied by various researchers in great detail as a function of the applied electric field, time period of assembly, concentration and zeta potential[12]. Achieving a controllable and repeatable assembly process is extremely important for manufacturing purpose. To be able to achieve this task, it is important to understand the assembly mechanism and the governing process parameters such as applied voltage, assembly current, applied voltage time. We have investigated the effect of assembly parameters and have seen that the nature of assembly is enormously affected by the change of these parameters. The results showed that the control of the assembly process enables precise and repeatable assembly of PSL nanoparticles over large scale at high rate which is crucial for many applications. Moreover, in the absence of any buffer solution the pH of aqueous solution is not constant as a function of time. Therefore the pH stability of the solution is another critical factor for high-rate manufacturing. In this letter we have studied experimentally the effect of assembly parameters on the rate and the quality of assembly for polystyrene latex (PSL) particles which gives a deep insight into the nature of the electric field directed nanoparticle assembly process and leads a controllable and repeatable assembly process.

2 EXPERIMENTAL PROCEDURE

2.1 Fabrication of nano-template

In order to fabricate the nano-template, firstly Cr/Au (2nm/120nm) is sputtered on SiO₂/Si (470nm/380μm) wafer and it is diced into 12 mm x 12 mm chips. The chips are cleaned with Piranha solution (H₂SO₄:H₂O₂, 2:1) followed by deionized water rinse. Then, PMMA **Poly(methyl methacrylate)** is spinned on the gold chip. The nano-patterns are made by conventional E-beam Lithography technique followed by MIBK(70 sec) and IPA(20 sec) development. The schematic of fabrication process is shown in Figure 1. The resulting patterns are trenches in PMMA with width 250nm and length 100μm.

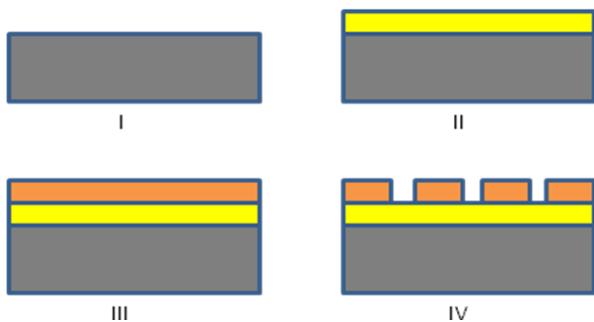


Figure 1: Schematic of fabrication process

2.2 Solution preparation

Commercially available 50nm PSL (Polystyrene Latex, 1% weight ratio) particles purchased from Duke Scientific suspended in an aqueous solution with pH 7.0 is used to prepare the particle suspension solution. 30% Ammonium hydroxide solution is used to adjust the pH of the particle solution from pH 7 to pH 11. Since zeta potential on the PSL particles depends on the pH of the solution[13], pH stability of the particle solution becomes an important factor for controllable assembly of nanoparticles. Once a solution with a desired pH is prepared, as time progresses, the CO₂ in the environment dissolves in the water to form carboxylic acid in the solution resulting in a decrease of pH of the particle solution. A standard method to prevent this is to use a pH stabilizer in the particle solution. The pH buffer solution is used to stabilize the pH which satisfies this requirement. Commercially available pH buffer solutions (Oakton Inc.) consist of highly concentrated salts such as Sodium Phosphate, Potassium Phosphate and Sodium Bicarbonate according to different pH values. We have found that if no buffer solution is used, pH of the particle suspension solution decreases by 0.1 in 10 min because of the carboxylic acid formation in prepared. To prevent this decrement, buffer solution is added to particle suspension solution at different ratios. It is seen that the suspension stability increases from 10 min to 30 min at the ratio of 1:1000(buffer/DI water) is used. When the concentration of buffer solution is set to 1:100, decrement of pH value slows down and pH of the solution drops 0.3 at the end of 24 hours. Finally, we have found that the particle suspension solution becomes 24 hours stable at 1:10 ratio.

2.3 Assembly Process

The schematic diagram of the electrophoretic assembly experimental setup is shown in Figure 2. The nano-patterned Au template together with a gold chip serves as the positive and negative electrodes respectively for the electrophoretic process. The distance between the electrodes are maintained at certain distance throughout the

experiment. These two electrodes are submerged into prepared particle suspension solution with known chemical properties. Then, a constant DC voltage of 2V is turned on. Then, the electrodes are pulled out of the solution while the voltage is ON. Once they are out of the solution the voltage is turned OFF and the sample is ready for analysis.

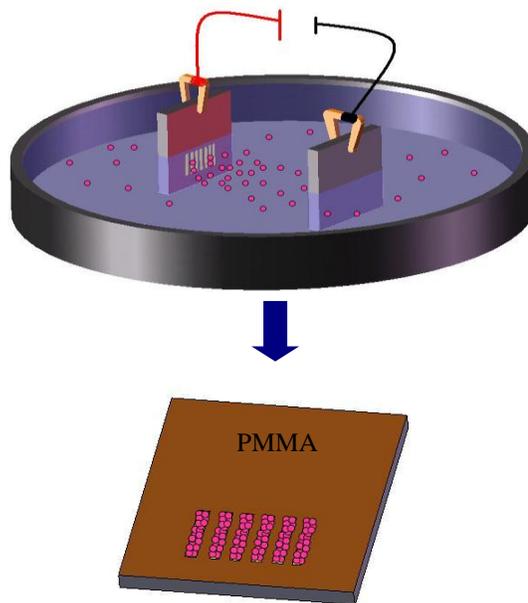


Figure 2:(A)Schematic of assembly process and (B) Resulting nanoparticle assembly into trenches

3 RESULT AND DISCUSSION

The assembly of 50 nm PSL particles into fabricated 250nm trenches is shown in Figure 3. It is seen that the trenches are fully covered (100%) with 50 nm PSL particles. The optimum condition for assembly of fully covered trenches is achieved by changing the governing parameters experimentally so that the charge on the particle maximum. By achieving maximum charge, the force exerted on the particle by electric field is increased. The velocity of particle in the liquid also increases since the fluid properties is same and drag force on the particle remains constant.

4 CONCLUSION

In conclusion, we have studied experimentally the effect of parameters on the rate and the quality of electrophoretic assembly for polystyrene latex (PSL) particles. The results showed that the control of the assembly process enables precise and repeatable assembly of PSL nanoparticles over large scale at high rate which is crucial for many applications.

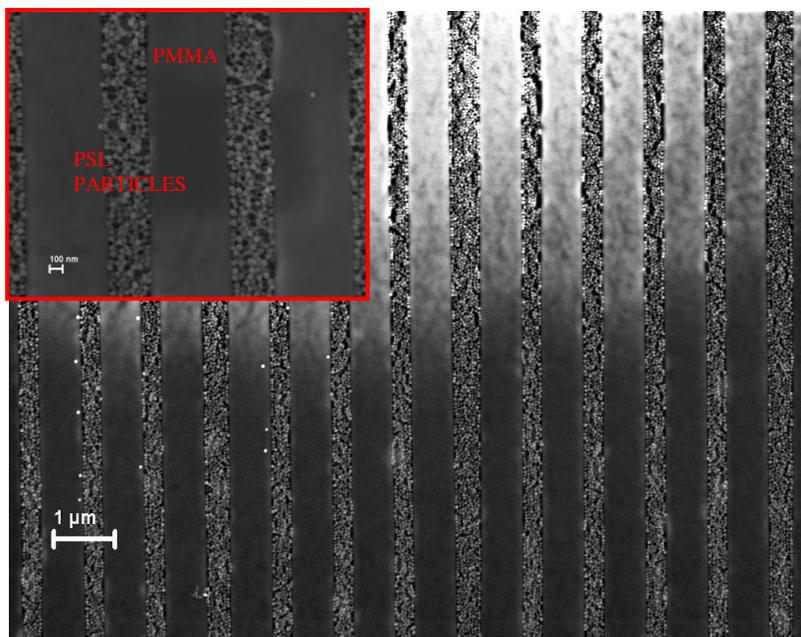


Figure 3: Controllable assembly of 50 nm PSL particles into 250nm trenches over 100µm² area

5 ACKNOWLEDGEMENT

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