Electric Field-Directed Assembly of Nanowires on Patterned Electrodes

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Abstract:

Many researchers have shown that the assembly of nanowires could lead to future electronic and optical devices [1]. This project focused on assembly of gold nanowires in an alternating current (AC) electric field between parallel electrodes. Assembling nanowires requires a great deal of control, which is why the electric field system is ideal. The bottom electrode was lithographically fabricated and contained organized micro-patterned pillars made from photoresist on top of a layer of titanium and gold. The top electrode was an indium tin oxide (ITO)-coated glass coverslip. Since this electrode was transparent, the assembly could be monitored in real time. Pillars were 3 μm tall and 3-20 μm in diameter, with spacing varying from 10-55 μm. These pillars acted as nucleation sites for the assemblies. Electric field-induced dipoles aligned the nanowires parallel to the field lines between the two electrodes. By varying different parameters, such as voltage and frequency, specific and controlled placement of the nanowires was possible and could be varied in real time. The assemblies could be reversed and replicated by switching the field on and off. This technique is promising for generating nanowire assemblies for electronic applications.

Patterned Electrode:

The patterned substrate was photolithography fabricated to create photoresist posts with desired diameters and separation distances. Figure 1 shows the fabrication process. First, a layer of 10 nm of titanium (Ti) was deposited by electron beam evaporation onto a glass coverslip, followed by a 30 nm layer of gold (Au). A 3.2 μm layer of positive photoresist was then spin-coated onto the substrate. Using a stepper exposure tool, the area around the desired posts was exposed to high intensity UV light through a patterned mask. The sample was then developed in MF CD 26 to remove the exposed areas of the photoresist. Two designs were used; a hexagonal configuration and a square pattern.

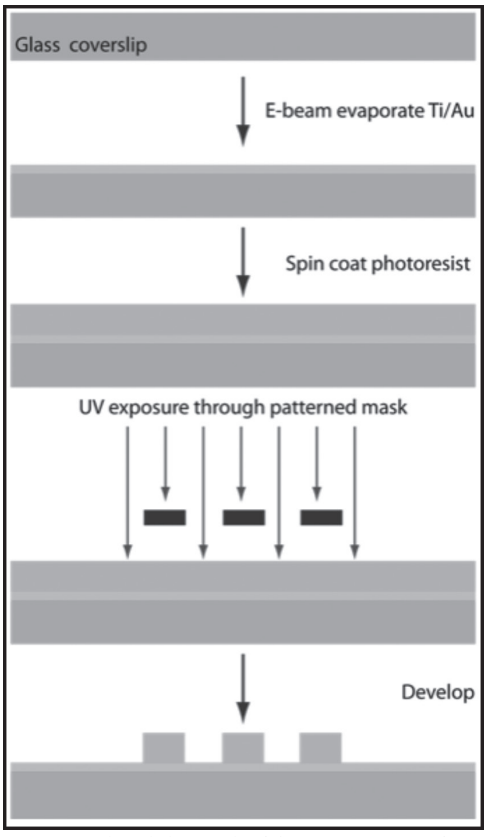

Figure 1: Photolithography fabrication process for patterning photoresist posts atop a gold-coated glass coverslip.

Experimental Design:

As shown in Figure 2, voltage was applied through the patterned Au electrode and a transparent ITO-coated glass coverslip. A spacer was placed in between the two electrodes. This spacer was completely filled with 2.75 μL diluted solution of nanowires in deionized water. The nanowires used were silica-coated gold nanowires that measured 2.5 μm in length and 300 nm in diameter. Frequency and voltage were slowly increased over time to monitor the different assemblies at various conditions.

Results:

Prior to electric field application, the nanowires diffused in solution, lying down above the bottom electrode. Once the field was applied,

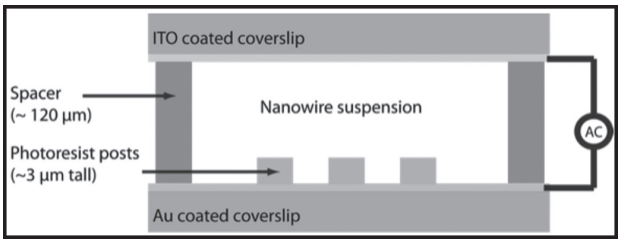

Figure 2: Side view of experimental set-up. Electric field is applied vertically, across the top and bottom electrodes through the nanowire solution.

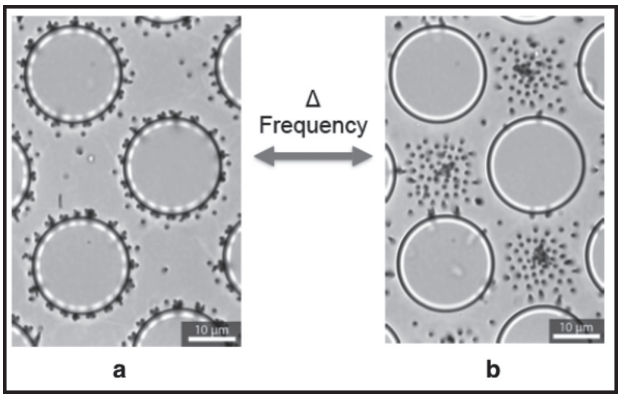

Figure 3: Optical microscope images taken from the bottom of the assembly using transmitted light. The large grey circles are the photoresist posts and the small black dots are the standing nanowires. This shows the different assemblies at two field conditions, (a) 330 V/cm, 400 kHz, and (b) 330 V/cm, 25 kHz.

the nanowires stood between the two electrodes, parallel to the electric field lines (Figure 3a). As the frequency increased, the dielectrophoretic (DEP) force increased. DEP occurred when the electric field caused the nanowires to obtain a field-induced dipole causing them to stand [2]. The local electric field strength around the fabricated posts was intensified, which caused the nanowires to nucleate around them. The posts with a smaller diameter required a higher field strength to nucleate these nanowires than the posts with larger diameters. As the frequency decreased, the electrohydrodynamic flow within the solution increased. This flow caused the nanowires to assemble in the stagnation areas between the posts (Figure 3b).

These assemblies could be reversibly formed and disassembled. When the field conditions were turned off, the nanowires separated from one another and diffused (Figure 4b). When the electric field was turned back on, the nanowires stood parallel to the field lines once again (Figure 4c). The nanowires reassembled not into the same exact positions as before but into similar organizations. However, the time it took for the nanowires to change orientation varied depending on the field conditions. This allowed for the assemblies to be reversible. When the field conditions were turned off, the number of visible nanowires increased. When the field was on, what appeared to be two nanowires (circled in Figure 4a), ended up being three nanowires when the field was turned off (circled in Figure 4b). Since the assemblies were being viewed from the bottom, the extra nanowires were not visible.

It can be hypothesized that since the nanowires had a field-induced dipole-dipole interaction, chaining in the z-direction occurred [3]. Figure 4d shows the possible chaining in the z-direction of a pair of nanowires. This kind of cluster trend occurred within every pattern organization and was not affected by the field conditions.

Conclusions and Future Work:

Overall, using a photoresist-patterned electrode successfully served as nucleation sites for nanowires to assemble around. By tuning the electric field conditions, different assemblies could be created. The AC electric field is ideal for assembling these nanowires because it enables control and tunability in real time.

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References:

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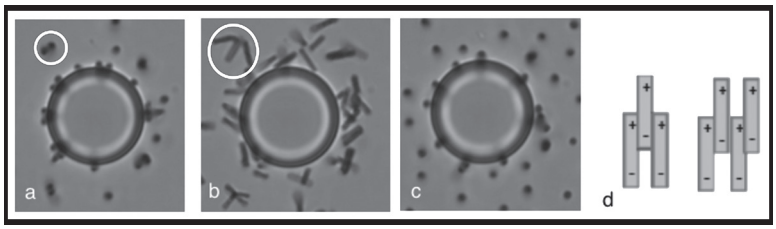

Figure 4: Images of when the field conditions are turned on (a), turned off (b) and turned back on (c). Possible chaining of pairs (d).