Self-assembly and Nanotechnology 10.524

Lecture 2. Methods and Techniques for Self-assembly

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& UML CHN/NCOE Nanomanufacturing Center)

Lecture 2: Methods and Techniques for Self-assembly

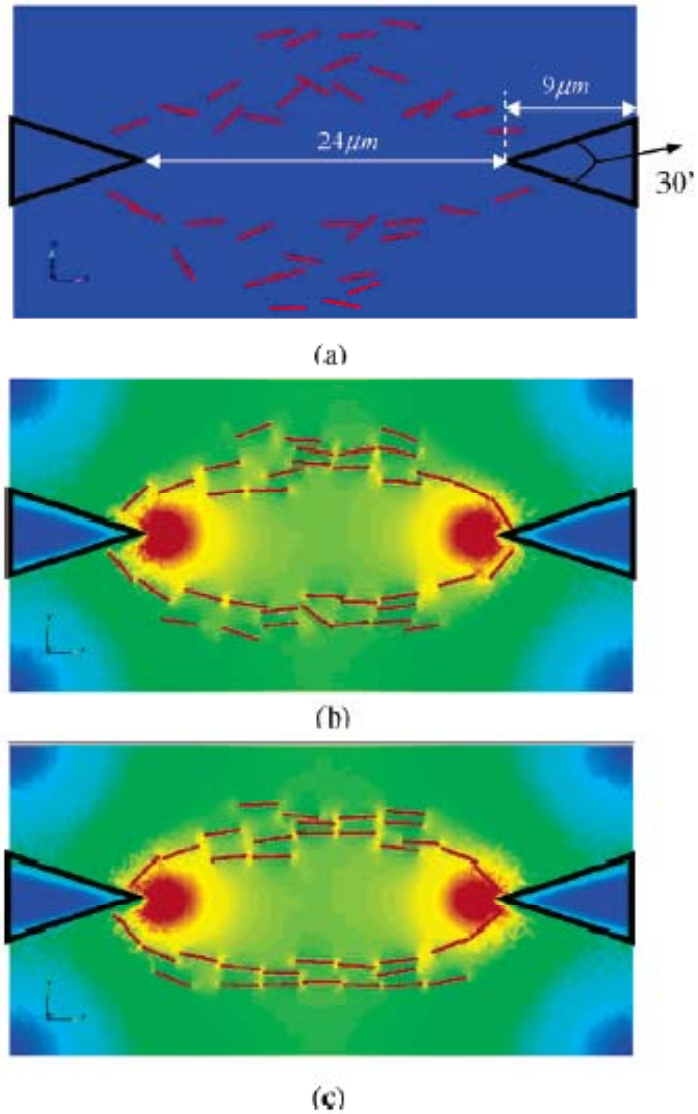
- Principle: **forces/interactions**

Various forces

- Covalent bond (chemical bonding
- Van der Waals
- Electrostatic
- Hydrogen Bonding
- Hydrophobic
- Hydration (structural)
- Steric/polymers
- ●●●

- Magnetic force
- Electrical force
- Gravity
- ●●●

Lecture 2: Techniques for Self-assembly-Examples



Dielectrophoretic Assembly of Nanowires

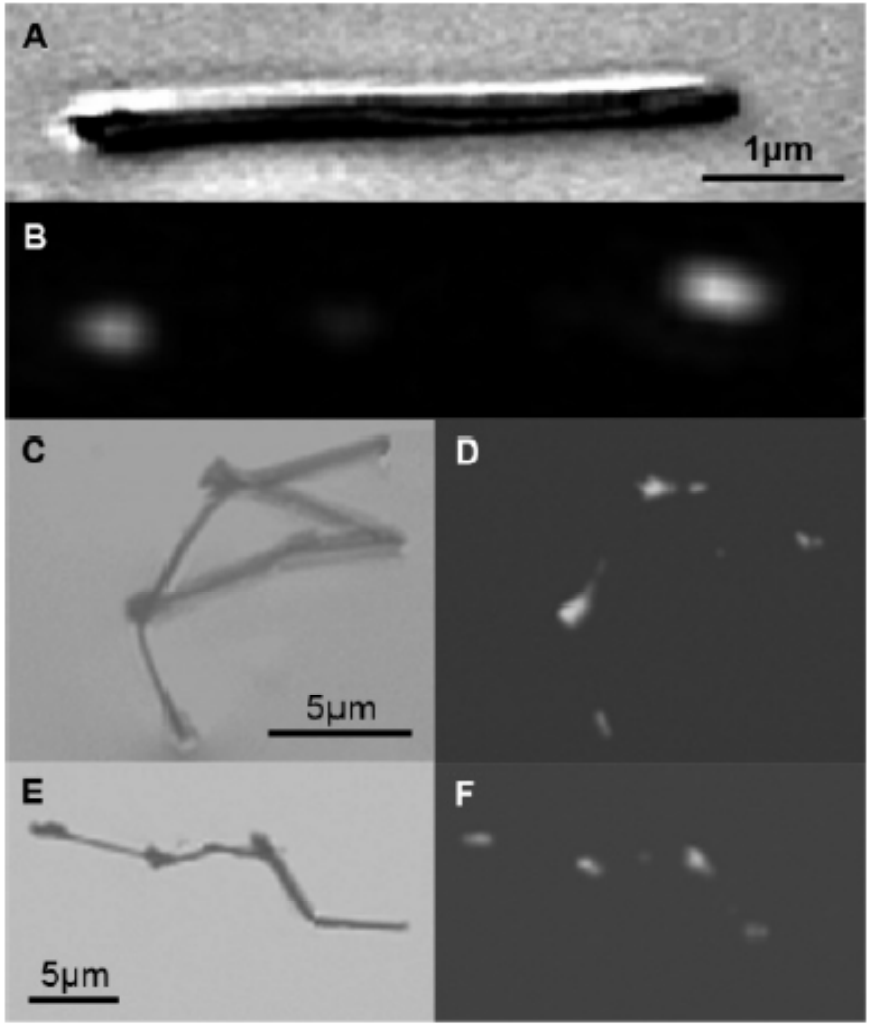
Sequential images of 3 μm-long NWs lining up between triangular-shaped electrodes (angle: 30°). AC field of 5 MHz (0.5V/μm) is applied between electrodes (gap size: 24 μm). (a) t = 0 s; (b) t = 0.5 s; (c) t = 1.0 s.

J. Phys. Chem. B **2006,** *110,* 14098-14106

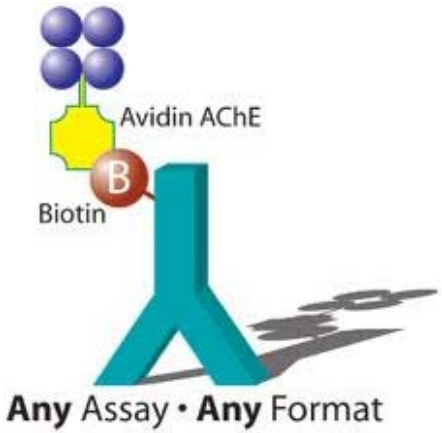
Dielectrophoresis (or DEP) is a phenomenon in which a force is exerted on a dielectric particle when it is subjected to a non-uniform electric field. This force does not require the particle to be charged. All particles exhibit dielectrophoretic activity in the presence of electric fields. However, the strength of the force depends strongly on the medium and particles' electrical properties, on the particles' shape and size, as well as on the frequency of the electric field

Wiki

Lecture 2: Techniques for Self-assembly-Examples

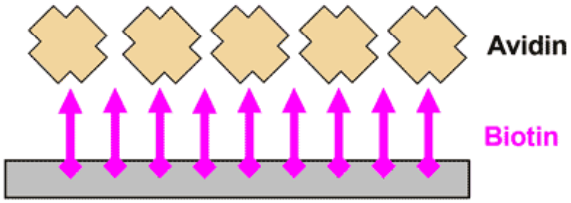


Molecular Linker: Biotin-Avidin

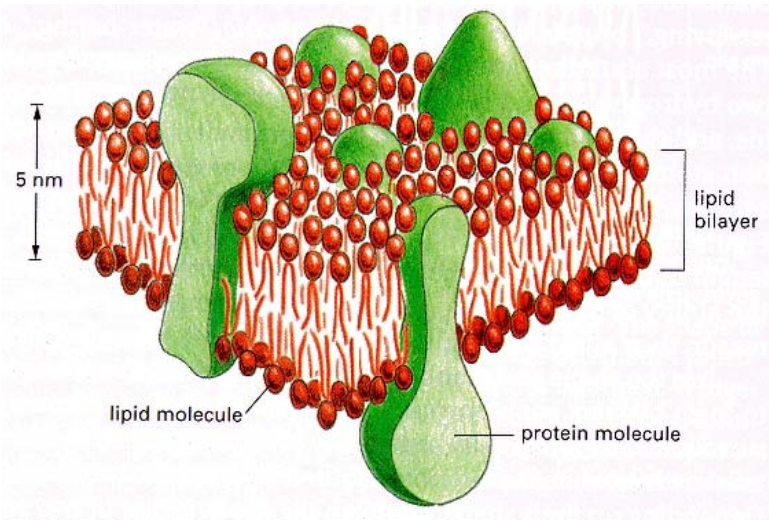


(A) Light and (B) fluorescence microscope images of Au/Pt/Au nanowires functionalized with BIC, biotin-terminated thiol, and exposed to NATR. (C) Light and (D) fluorescence microscope images of a self-assembled cluster of Au/Pt/Au nanowires with 500 nm gold segments. (E) Light and (F) fluorescence microscope images of Au/Pt/Au nanowires with 10 nm gold segments.

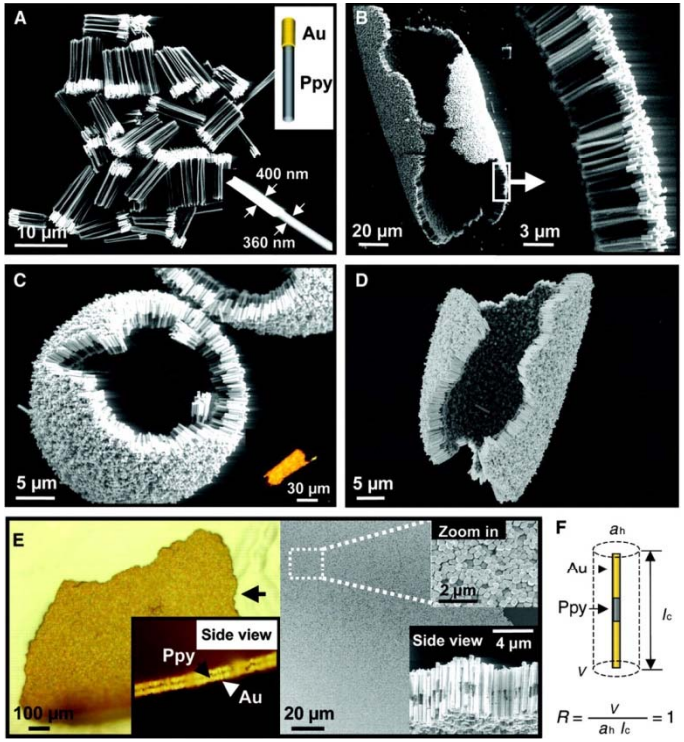
Nano Lett., **2004,** *4*, 1163-1165



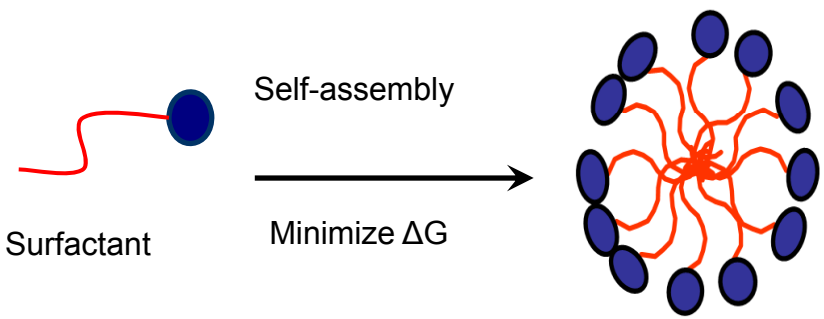
Case Study I: Hydrophobic Force



Lipid bilayer

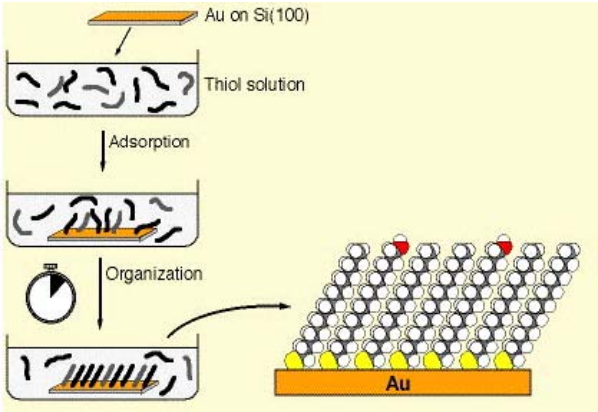


Gold-Polypyrrole nanowires

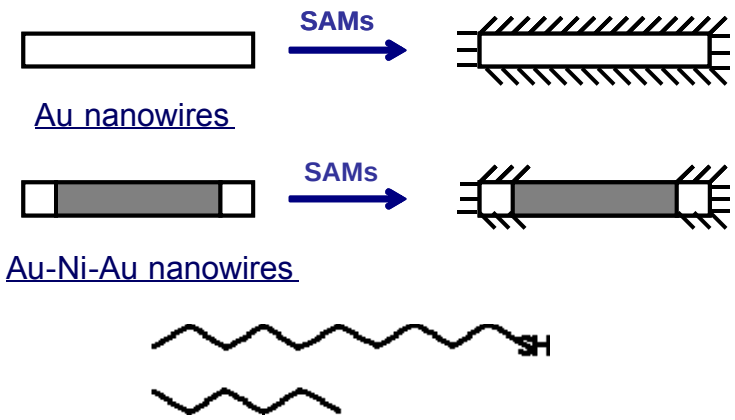


Park, Lim, Chung, Mirkin,
Science **2004**, *303*, 348

Case Study I: Hydrophobic Force



Self-assembled monolayers (SAMs) on metal surface



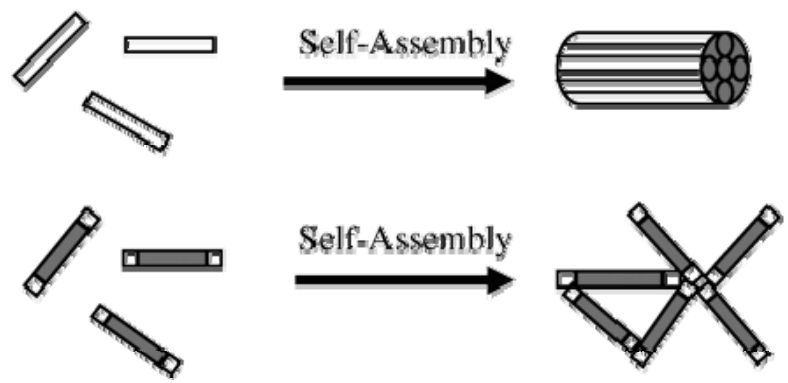
HDT: hexadecyl mercaptan

Au: hydrophobic
Au/Ni/Au: hydrophobic / hydrophillic / hydrophobic

- -SH group only bonds to Au surface
- -SH doesn't bond Ni well since Ni is easily oxidized (NiO)

Contact angle measurements on metal thin films

- Au treated with SAM solution: 104 ± 3 ° (> 90 °)
- Ni treated with SAM solution: 43 ± 10 ° (< 90 °)



Case Study I: Hydrophobic Force

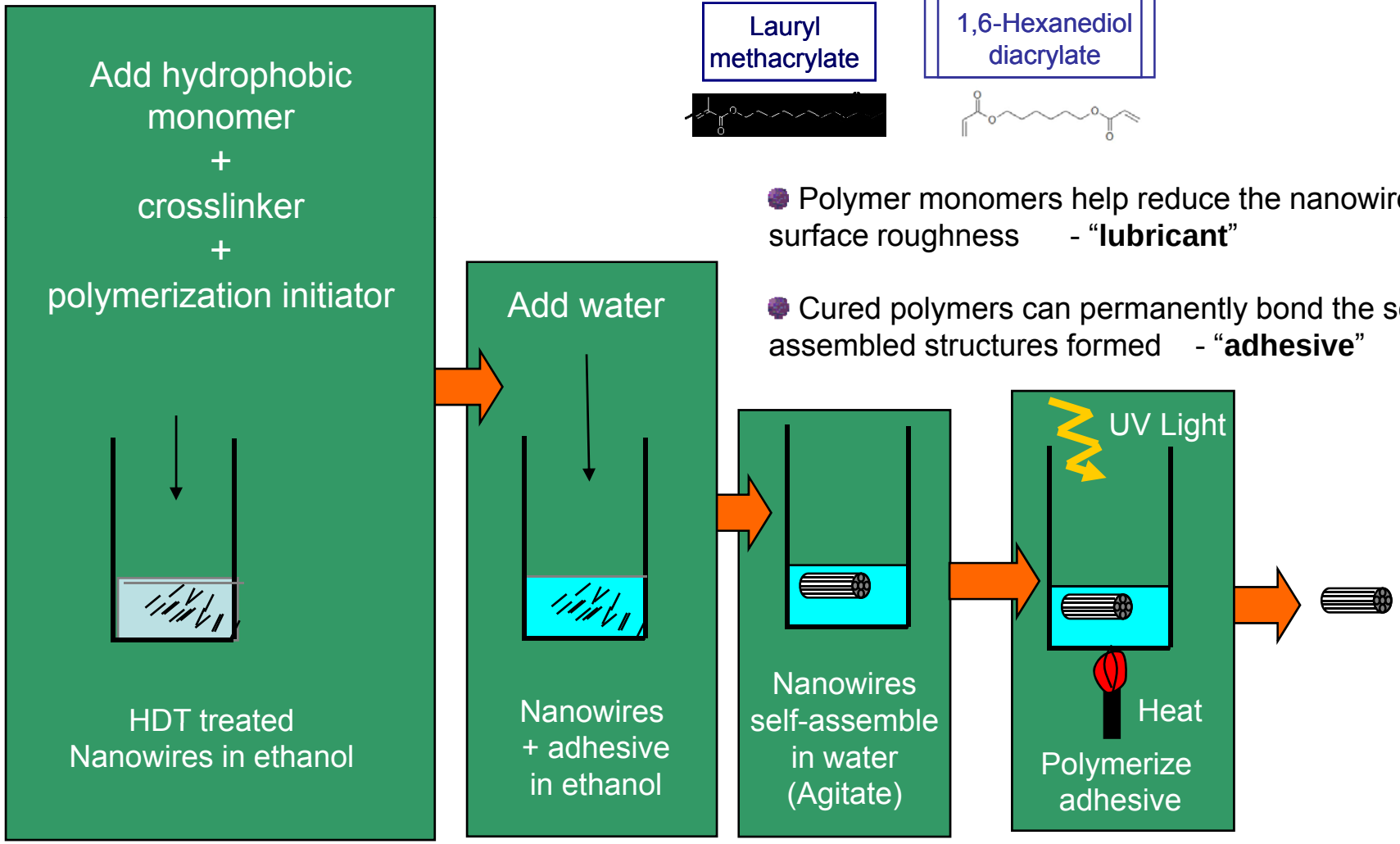
Polymerization

Monomer + cross-linker $\xrightarrow[\text{Or Benzoyl peroxide}]{\text{Benzoin isobutyl ether}}$ Polymerized Adhesive

Lauryl methacrylate

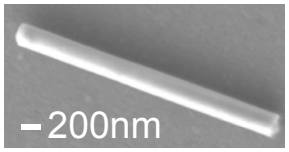
1,6-Hexanediol diacrylate

- Polymer monomers help reduce the nanowire surface roughness - "**lubricant**"
- Cured polymers can permanently bond the self-assembled structures formed - "**adhesive**"

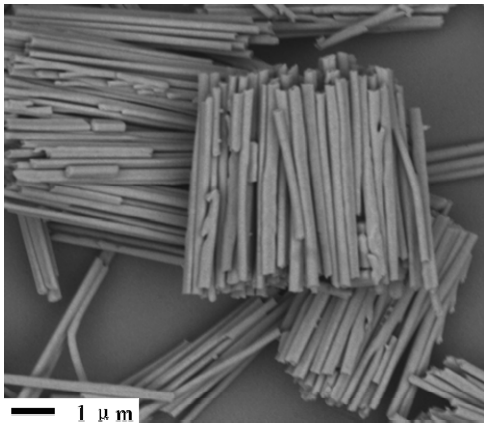


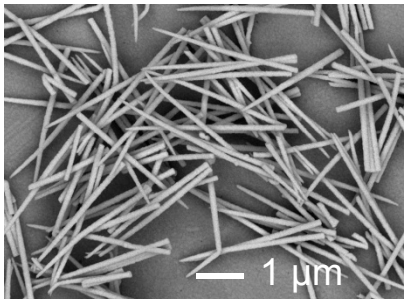
Case Study I: Hydrophobic Force

Au nanowires

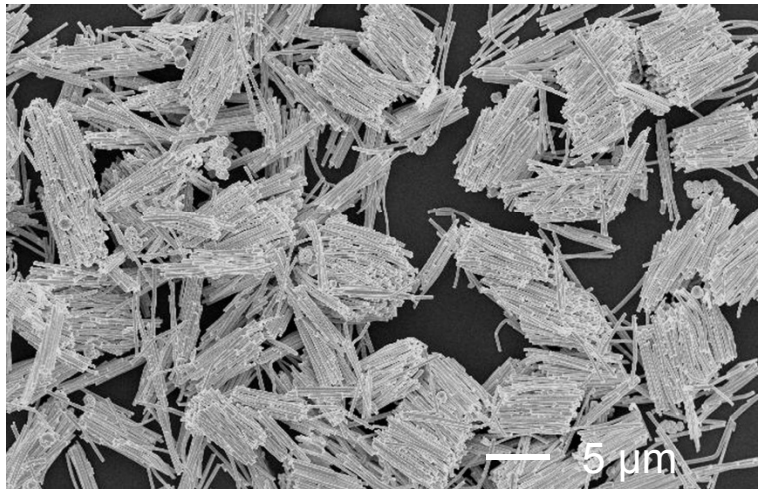


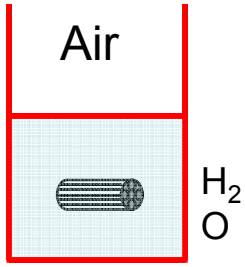
3D Bundles



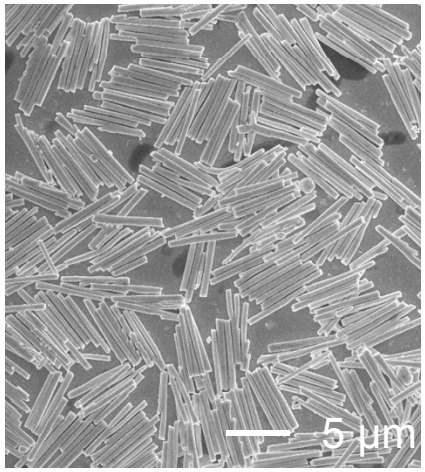


Not assembled nanowires

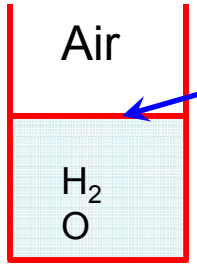




Assembly in bulk water



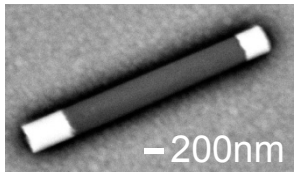
2D self-assembled structures



Assembly at interface

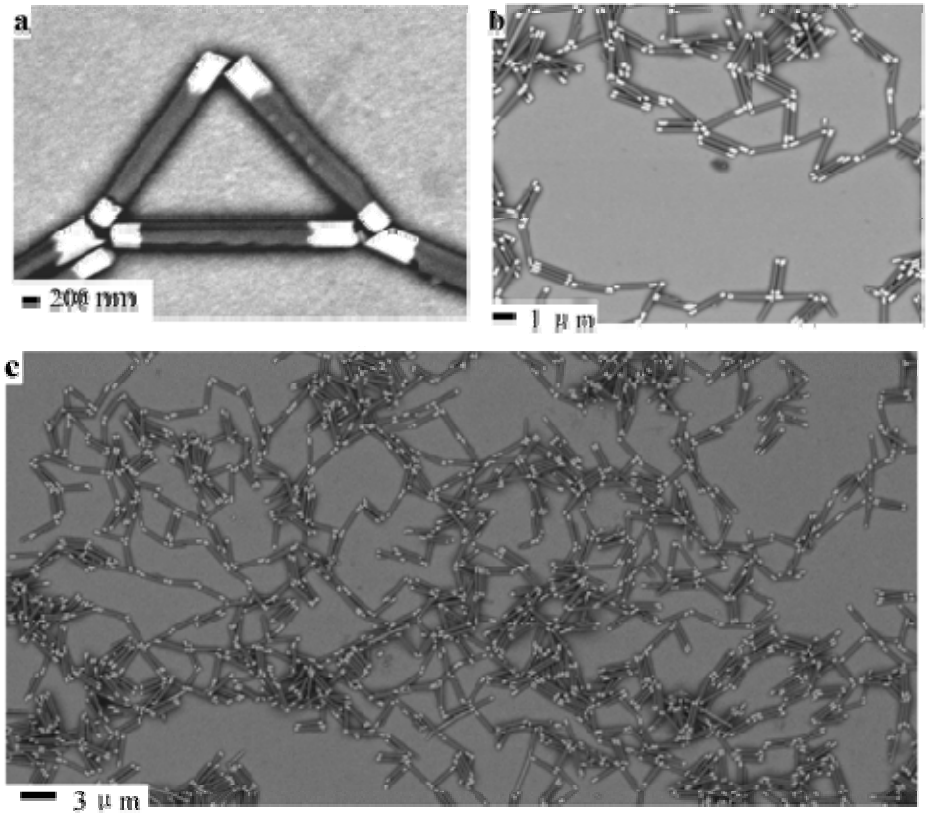
Gu, Chen, Gracias. *Langmuir* **2004**, *20*,11308-11311

Case Study I: Hydrophobic Force

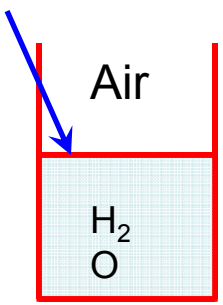


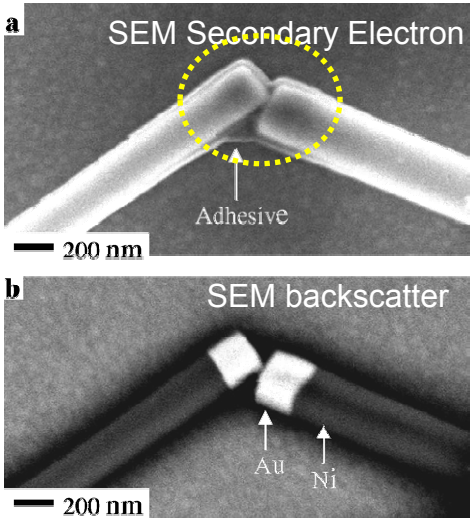
Au / Ni / Au nanowires

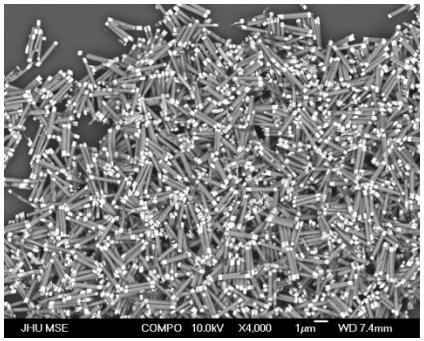
2D Networks



Assembly at interface



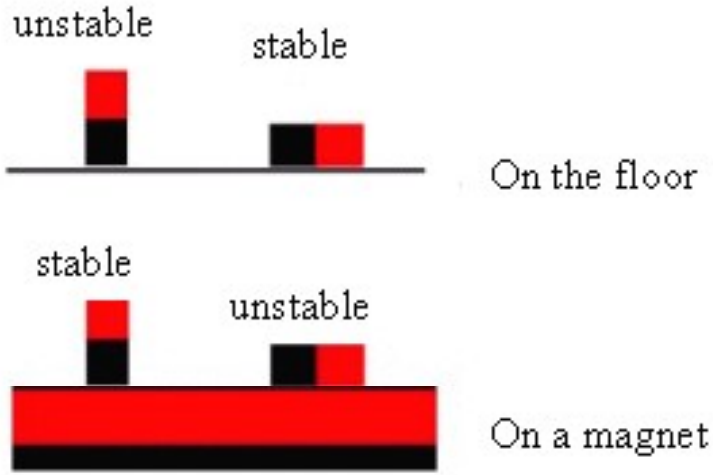




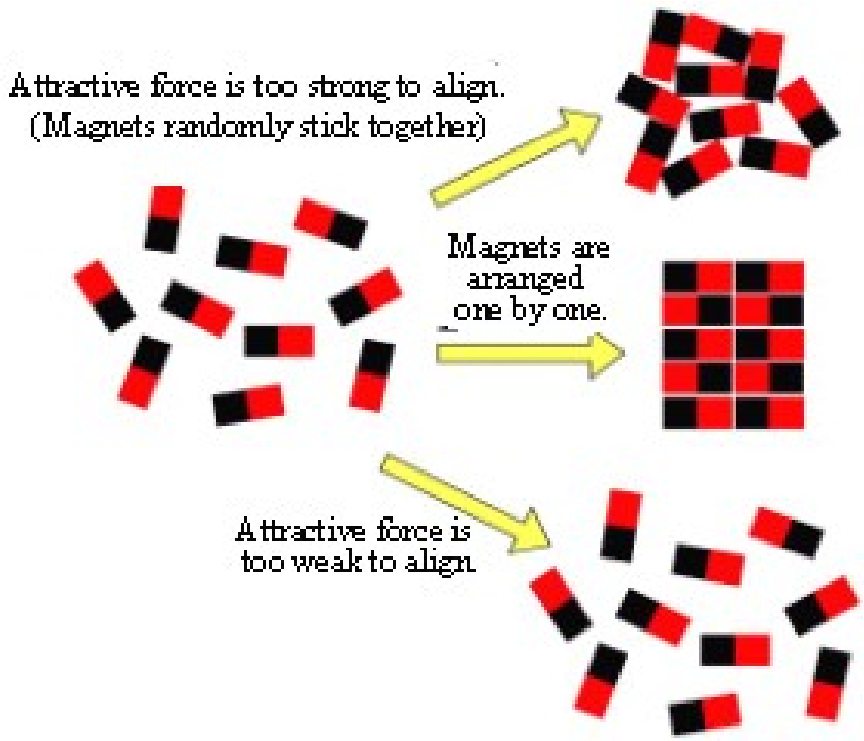
Not assembled

Gu, Chen, Gracias. *Langmuir* **2004**, *20*,11308-11311

Magnetic Self-Assembly



Stable configuration of a bar magnet



Assembled magnets

http://www.nanonet.go.jp/english/kids/k-make/organization.html

Case Study II: Magnetic Force

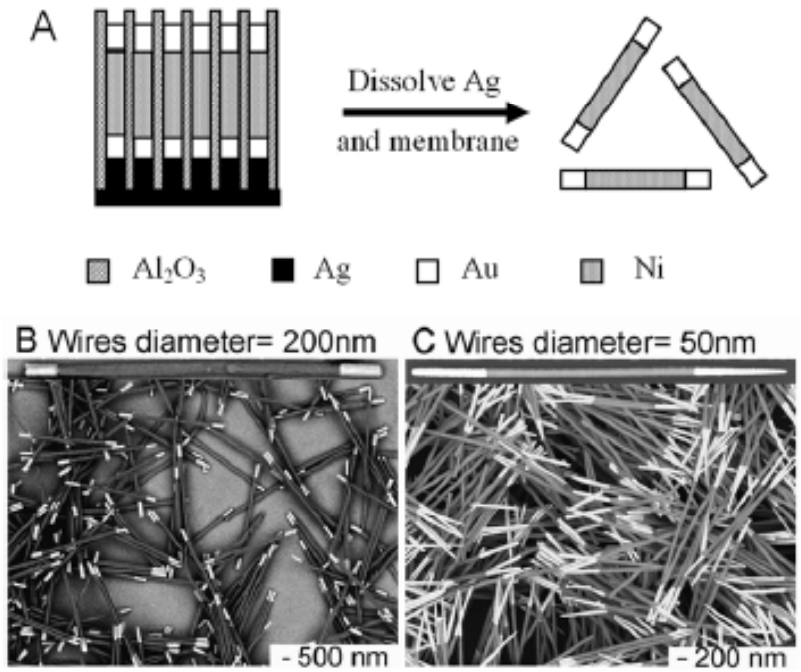


Fig. 1. (a) Schematic diagram of the strategy used to fabricate nanowires using electrodeposition in a nanoporous membrane. Scanning electron microscope (SEM) images of: (b) 200-nm and (c) 50-nm diameter Au–Ni–Au wires fabricated in nanoporous membranes. (The back scatter contrast is brightest for metals with higher atomic numbers; Au ends appears brighter than Ni.)

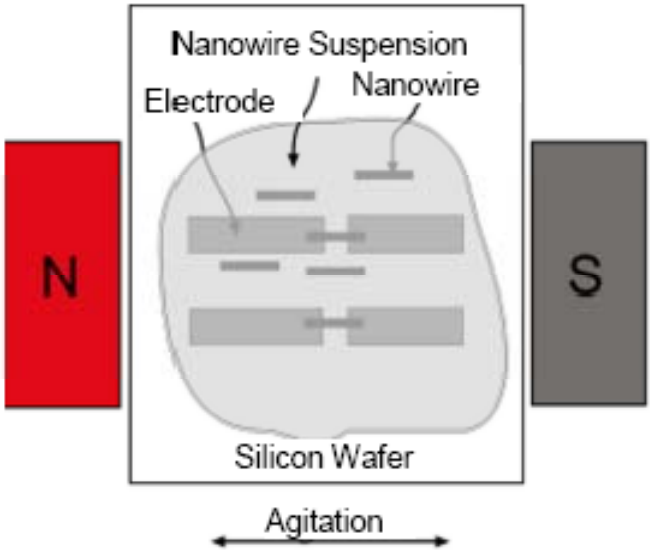
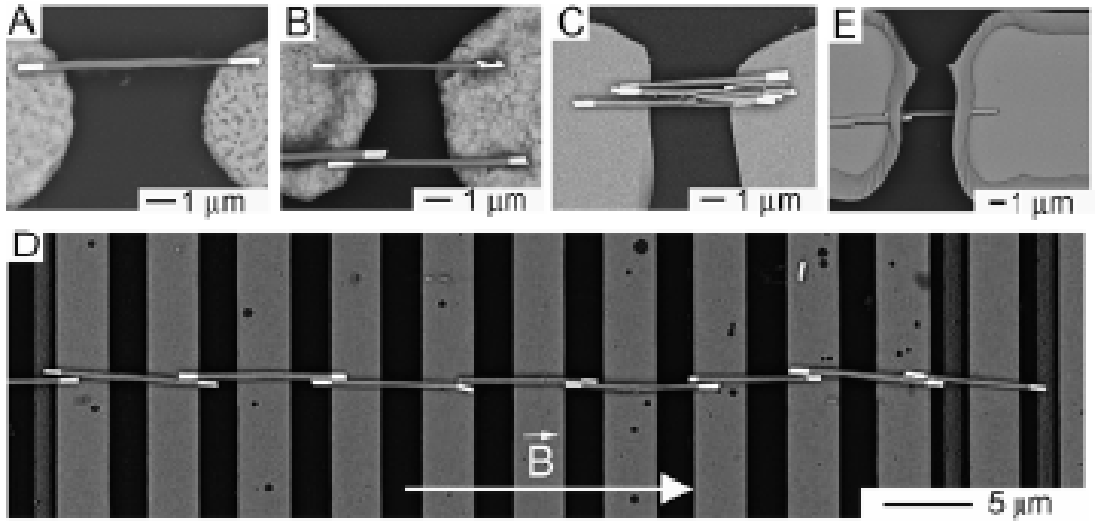


Fig. 2. Schematic diagram of directed assembly using magnetic fields.

Case Study II: Magnetic Force



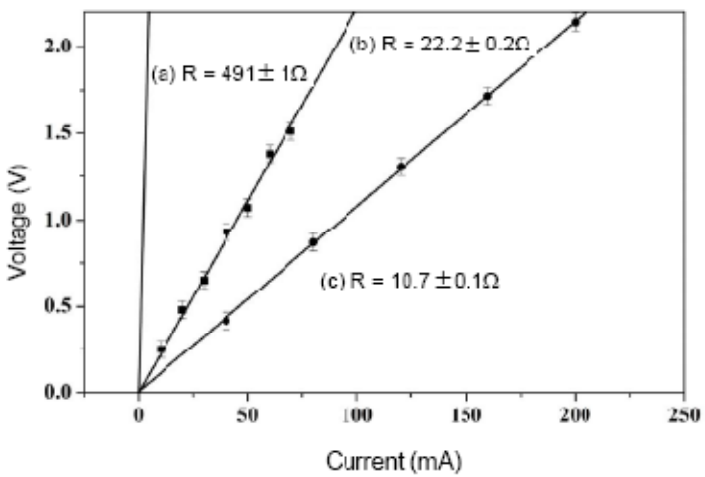
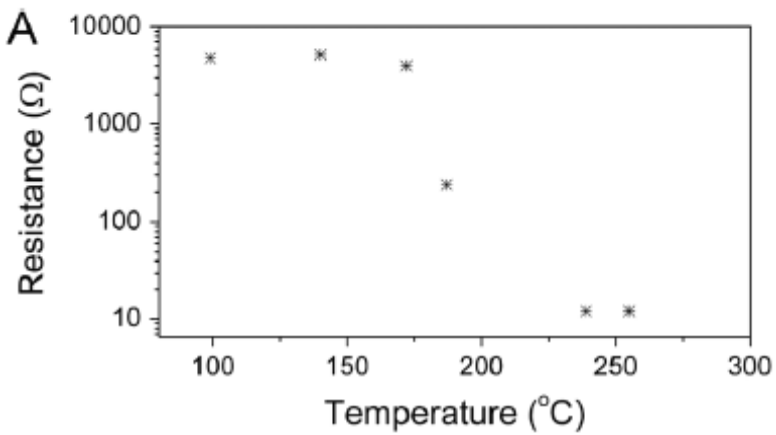


Fig. 4. Typical nanowire resistance curves. (a) A wire on top of contact pads before reflow with a high contact resistance, (b) a wire on top of contact pads after reflow with a small contact resistance, and (c) a wire underneath the contact pads with minimal contact resistance.



Proc. 5th IEEE Conf. Nanotech. **2005**, 715-718

IEEE Trans. Nanotech. **2006**, *5*, 62-66.

Case Study III: Electrical Force

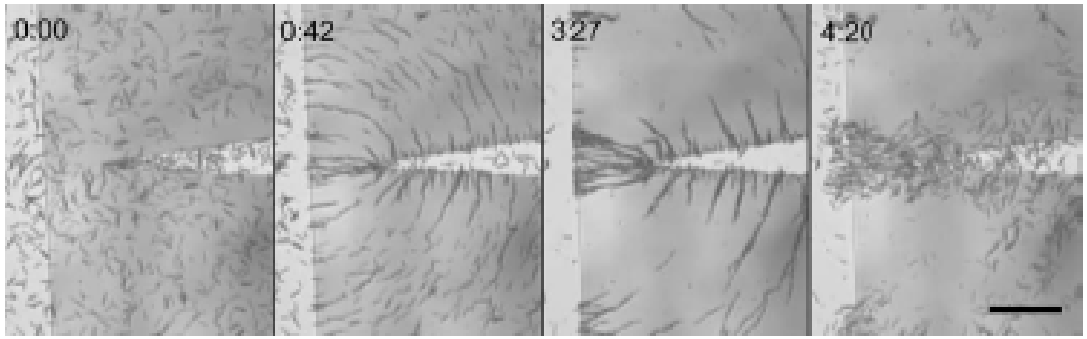


FIG. 1. Reversible Ag nanowire network formation from a suspension in water, with DEP at 0.2 V and 100 kHz (Ref. 21). The frames are labeled with the time (min:s) after the first frame. The first frame is taken just before initiation of DEP, and the third frame is taken just before ending DEP. The scale bar corresponds to 30 μm.

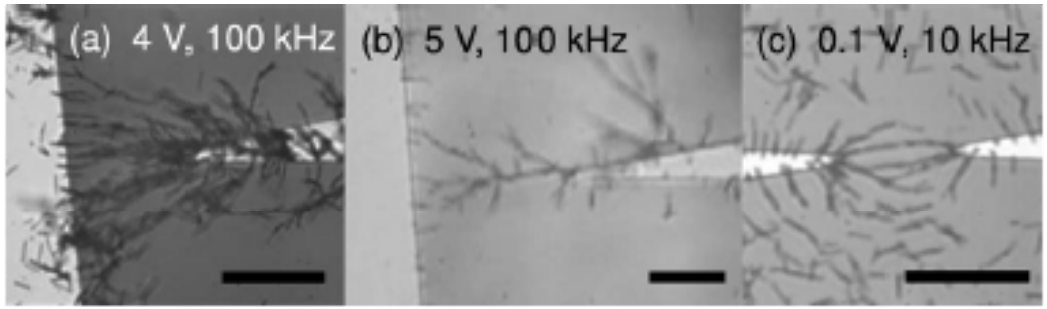


FIG. 2. Examples of nanowire structures formed by dielectrophoresis of nanowires in liquid suspension. (a) Dense, overlapped network (Ref. 21). (b) Sparse, branching network. (c) End-to-end joined, predominately unbranched network. The scale bars correspond to 30 μm.

Case Study III: Electrical Force

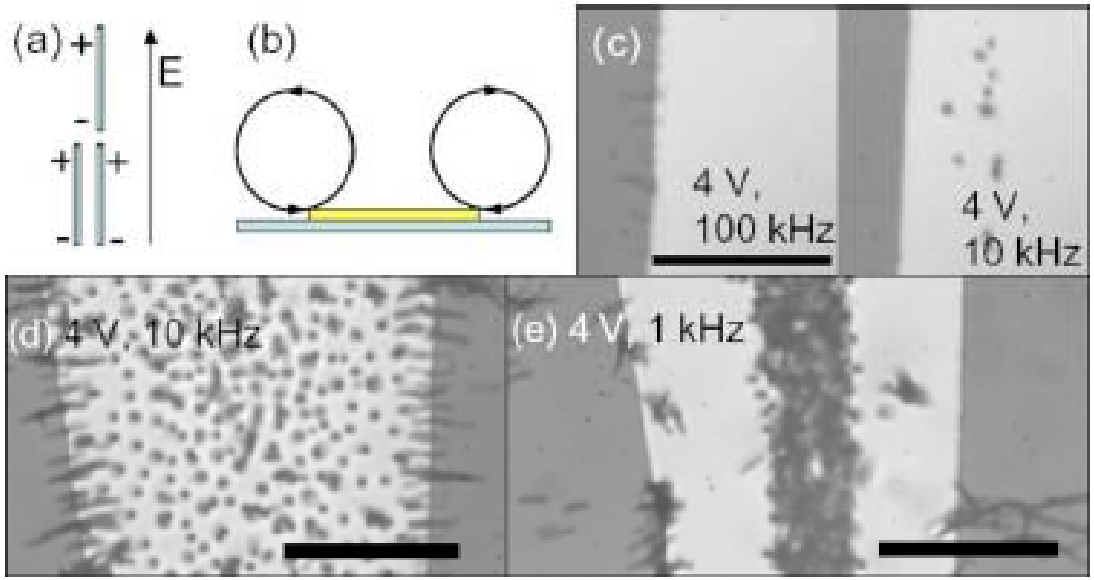
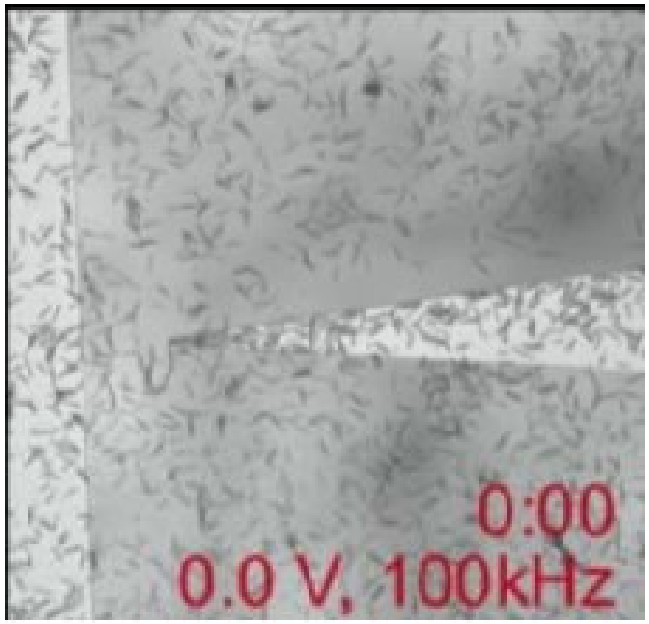


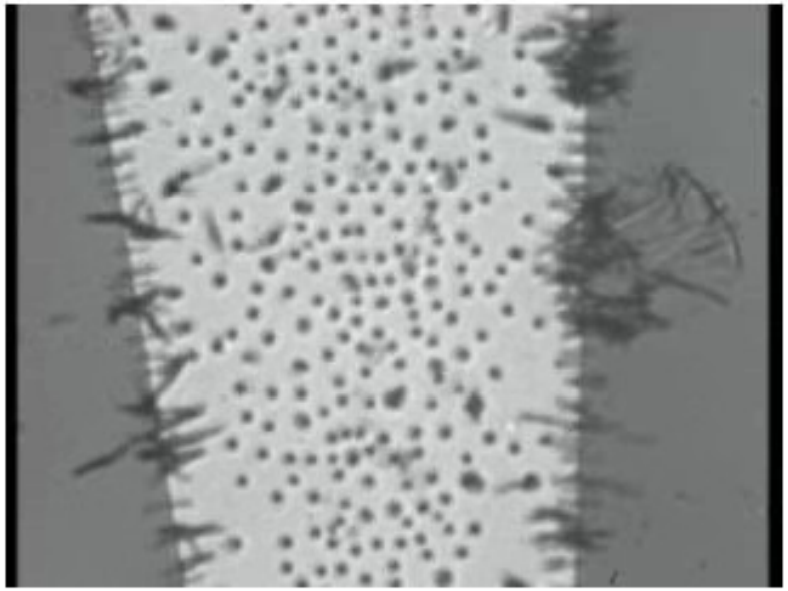
FIG. 3. (Color online) (a) Schematic of induced dipoles in nanowires. (b) Schematic of the circular flow pattern generated at the edges of the electrodes. (c) 50 nm diameter nanowires aligned at the edge of the pointed electrode, a few hundred microns from the point, with 100 kHz E-fields; then standing vertically on top of it with 10 kHz E-fields (the dots are the nanowires seen end on). (d) 200 nm diameter nanowires standing on top of the electrode, a few hundred microns from the point. (e) Vertical nanowires pushed towards the center of the electrode by flow. The scale bars correspond to 30 μm.

Papadakis et al., *Applied Physics Letters* **2006**, *88*, 233118

Dielectrophoretic Assembly of Nanowires

Live example I: Reversible and Irreversible Metal Nanowire Networks and Vertically-Aligned Arrays

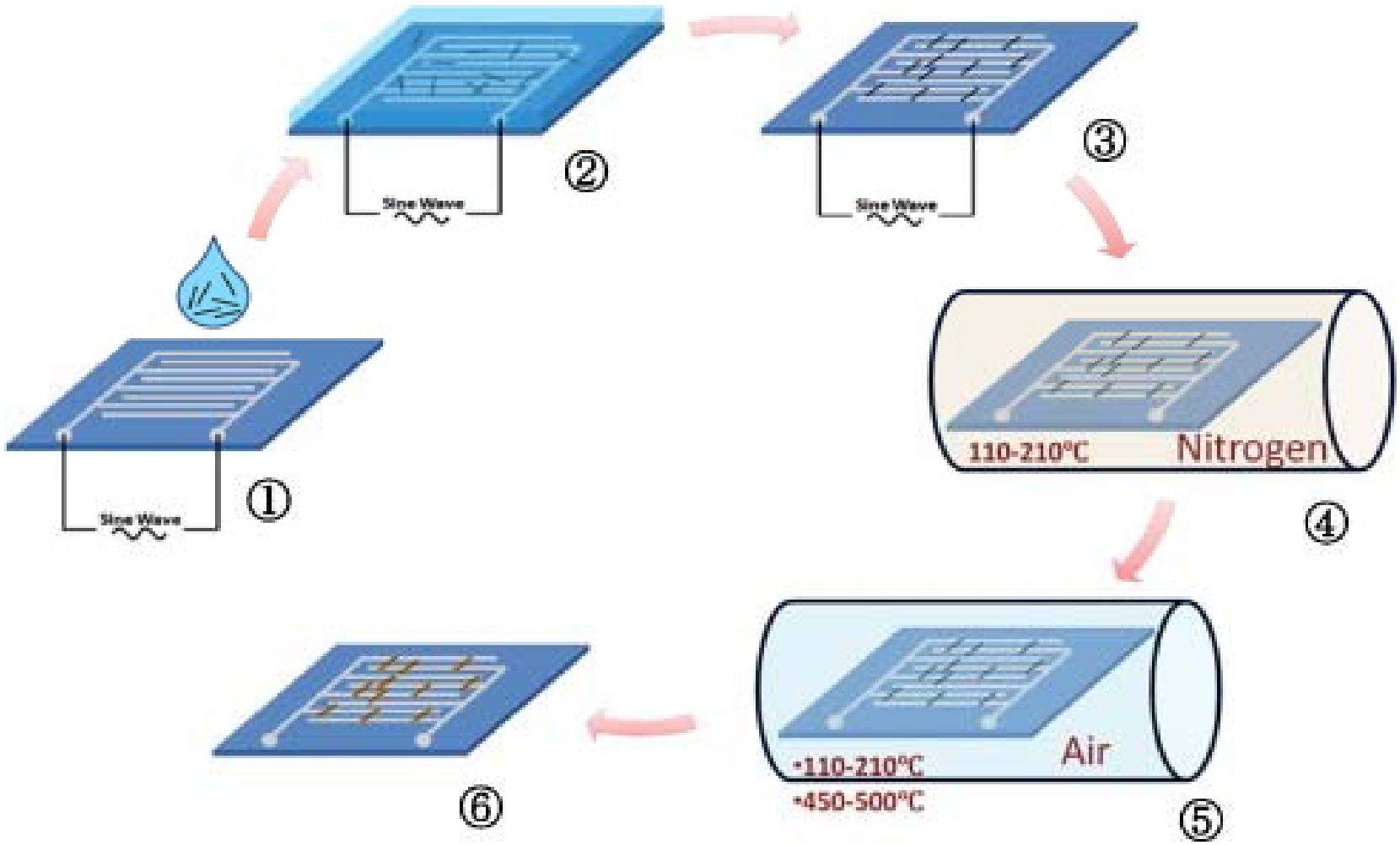




Papadakis, Gu, Gracias. *Applied Physics Letters* **2006**, *88*, 233118

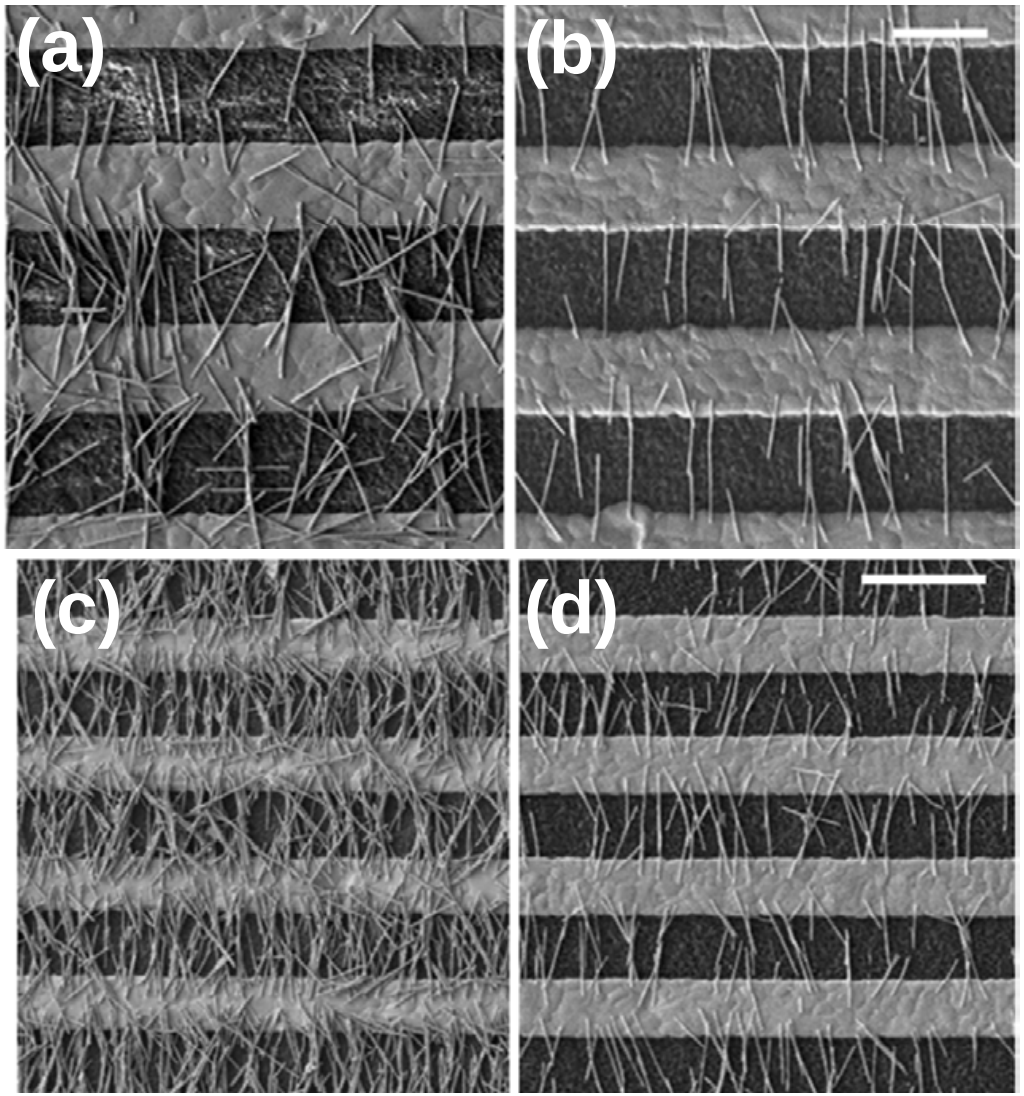
http://netserver.aip.org/cgi-bin/epaps?ID=E-APPLAB-88-202623

Case Study III: Electrical Force



X. Li, E. Chin, H. Sun, P. Kurup, Z. Gu. ***Sensors and Actuators B: Chemical*** 2010, *148*, 404-412.

Case Study III: Electrical Force



SEM images of nanowires assembled on the electrode substrate using DEP method. (a) non-optimized setting; (b) optimized
setting; (c) dense; (d) dilute.

X. Li, F. Gao, Z. Gu. "Nanowire Joining Methods", ***The Open Surface Science Journal*** 2011, 3, 91-104.