Metallic Nanowire Transparent Conductive Electrode Fabricated by Template-guided Assembly

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Metal nanowire based transparent electrodes have good transparency, conductivity and also flexibility and low cost. In conventional metal nanowire based conductive films, particularly those using silver nanowires (AgNW), nanowires are dispersed uniformly over the whole coating area with random locations and orientation. In this study, we demonstrate that a template with regular patterns with wettability and morphology contrast can guide the formation of a conductive nanowire network. The nanowire will be assembled under the guidance of underlying patterns by capillary forces induced at the receding meniscus of the droplet containing nanowires. Because the Ag NWs are distributed orderly, less nanowires are needed form a conductive grid. Ideally, the conductivity and optical properties of the transparent conductive electrode will be improved by this method.

To disperse conducting nanowires on an insulating matrix, experimental evidence shows there is a sharp onset of conductivity at a certain density of nanowires, termed as percolation threshold. When the probability of percolation phenomenon occurs is bigger than the critical probability of 50%, the percolation will exist. For randomly distributed metallic nanowires, the threshold area density of percolation is about $n_c = 5.71/l^2$ [1]. Here, l is the length of sticks. In the percolating regime the electrical conductivity depends on the NW density n and follows a power scaling law: $\sigma_{dc} \infty (n - n_c)^t$, where n_c is the density at percolation threshold and t is the universal conductivity exponent.

Figure 1(a) demonstrates the fabrication process of template-guided assembly of AgNWs mesh. SU-8 photoresist is first coated on the glass after surface treatment by adhesion promoter. After photolithography exposure, the surface of the photoresist is treated to enhance the surface hydrophobicity before development. After development, a SU-8 pattern with hydrophobic surface on the top of the pillar and hydrophilic surface on the bottom of the trench was obtained. Then AgNW solution was dropped on the patterned template. By moving and heating the sample under a cover glass, the cover glass drags the contact line over the patterned template and the AgNWs accumulate near the contact line and assembled into the trench by the capillary force. Figure 1(b) shows the experimental results that the AgNWs mesh is successfully patterned by the guiding of underlying trench patterns. AgNW network can be further transferred to a plastic substrate through a heat and press process. 50Ω sheet resistance with 75% transmittance has been obtained on such samples.

We modeled the perclation behavior of template-guided AgNW assembly in Figure 2. We found the percoation threshold will change under different guiding conditions of the AgNW position and orientation. When position of AgNW is guided in trenches, much less threshold density of AgNW is observed. The simulation result means that the ordering distributed AgNWs can from a conductive mesh with lower density than random distribution.

The results of initial experiments and simulations demonstrate the potential of template-guided nanowire networks for low-density conduction. Combined with nanowire sintering and flexible substrate nanoimprint tranfer, the nanowire networks can be used in the fabrication of highly-transparent conductors.

[1] G.E.Pike and C.H.Seager, Phys. Rev. B 10,1421(1974).

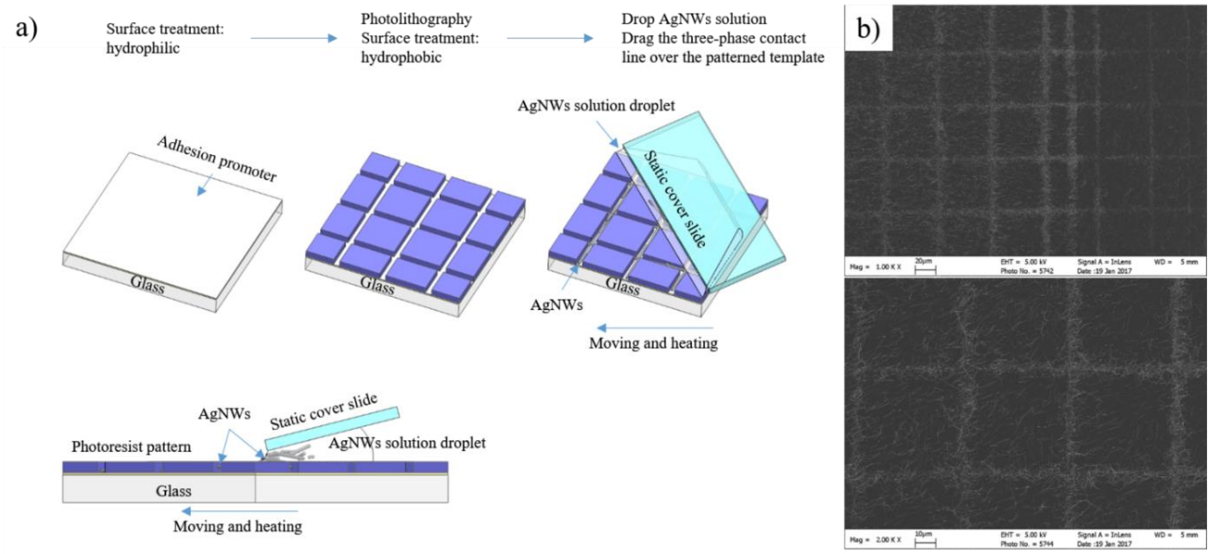

Fig 1. a) Schematic illustration of the fabrication of a template and self-assembly of the silver nanowires (AgNWs). b) SEM micrograph of the AgNWs network guided by the underlying microstructures.

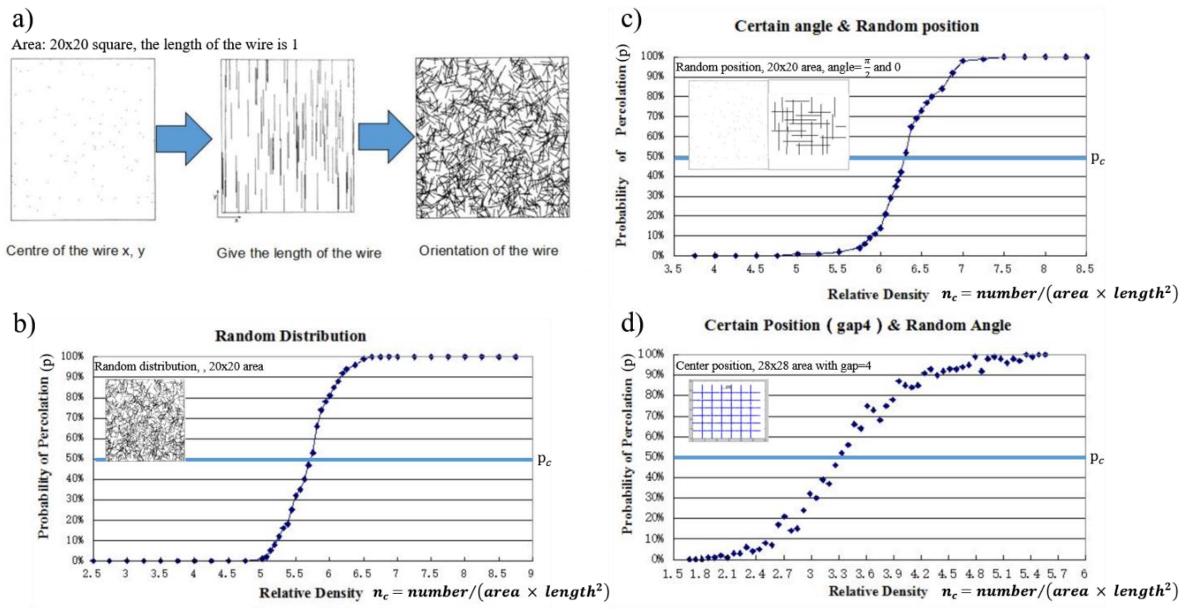

Fig 2. a) Definition of the simulation. Firstly, select center points of AgNWs in a certain square; secondly, assign the length of AgNWs; thirdly, assign the orientation to AgNWs: $-\pi/2 \le \theta_i \le \pi/2$; Area: 20x20 square, length of the wire: 1. b) Random distribution, threshold is about 5.71, Y axis: probability of the percolation (p), X axis: relative density (n_c). (c) Guided orientation and random AgNW centers, threshold is about 6.4. (d) Guided AgNW centers and random orientation, area is 28x28, the gap is 4, the simulation threshold is about 3.3.