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Patterned Metal Nanowire Arrays from Photolithographically-Modified Templates

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The unique physical and chemical properties of nanosized materials have inspired extensive studies over the past decade.[1,2] A variety of techniques including arc-growth, vapor-phase, solution methods, and template directed growth have been developed for synthesis and structure control.[3−11] Further efforts in tuning structures have lead to dramatic enhancement of properties and performance, and thus have resulted in the appearance of micro-devices including transistors, sensors, field emitters, motors, and barcode devices.[12−19] Additionally, directed assembly and self-assembly techniques have been developed to organize nanomaterials into designed structures.[20−32] On the basis of such techniques, scientists have successfully patterned nanowires on substrate surfaces for applications such as nanojunctions.[33] Other efforts have involved the direct formation of patterned arrays of nanowires. Patterned catalysts have lead to the high-temperature growth of selected types of nanowires perpendicular to substrate surfaces.[26,34−38] Also, patterned porous templates have been made by heavy ion irradiation of masked polycarbonate films; electrochemical growth into these membranes then resulted in millimeter-wide striped arrays of ferromagnetic nanowires.[39] Additional techniques that can readily direct the patterned growth of nanowire arrays of a variety of materials, however, would help to further advance the utility of such structures in microelectronics, optoelectronics, and sensor devices. Herein, we report an effective procedure for the fabrication of patterned nanowire arrays with micron-sized features. First, photolithographic methods are utilized to form set patterns onto porous anodic alumina membranes (AAM). Then, these modified membranes can be used in the electrochemical nanowire growth. This approach readily allows the formation of a variety of nanowire array patterns with line widths down to several microns.

The fabrication of metal nanowire patterns through the combination of photolithography and electrodeposition is outlined in Figure 1. Initially, the membrane is spin-coated with a layer of photoresist to seal the pores of the AAM. Then this composite is covered with a photolithographic mask and exposed to UV (Figure 1a). By soaking the composite in developer, the pores of AAM are selectively opened only in those exposed areas (Figure 1b). Subsequently, the same side of the membrane is sputtered with a layer of Au or Ag to convert the sample into an electrode; electrodeposition then allows one to selectively fill the open pores (Figure 1c). Finally, the patterned nanowire arrays are revealed by removal of the AAM in a NaOH solution (Figure 1d).

Electrochemical deposition takes place in the pores of AAM opened selectively by photolithography and thus producing patterns of metal nanowire arrays with defined structures. Au nanowire patterns with different features are shown in Figure 2. The line

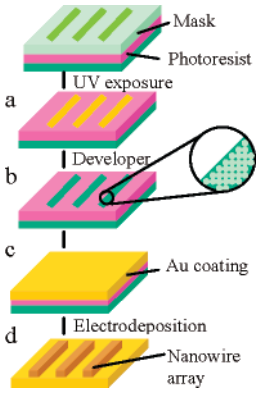

Figure 1. Fabrication procedure of metal nanowire patterns: (a) photoresist is coated on the surface of AAM, the composites are covered by mask, and exposed to UV; (b) the pores of AAM are then selectively opened by dissolving the exposed areas in a developer; (c) patterned nanowire arrays are then produced by electrochemical deposition; (d) nanowire arrays are released from the template with a NaOH solution.

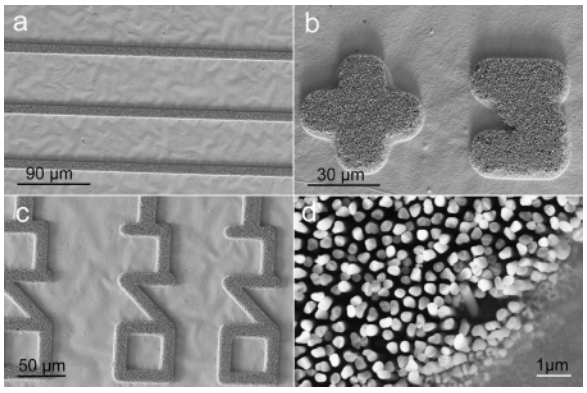

Figure 2. FESEM images of Au nanowire pattern with line width of 15 μm: (a−c) nanowires patterns with different features can be fabricated; (d) higher magnification image shows the diameter of the nanowires is about 200 nm (length about 3 μm).

width of the patterns in Figure 2a−c is about 15 μm. The wires themselves are about 200 nm in diameter and 3 μm in length (Figure 2d). The diameter and length of the nanowires in the patterns can be adjusted by varying the pore size of AAM and the time for electrochemical deposition, respectively.[28,29]

We can readily vary the nanowire patterns by varying the dimensions of the mask used in photolithographic processing. Figure 3a−c presents patterns of Ni nanowire arrays produced from a mask with 5 μm features (the wires themselves average about 15 μm in length). Higher magnification shows (Figure 3c) that the line width of the patterned nanowires is actually over 7 μm, compared to the line width of the 5 micron mask where a series of nanodots have been deposited along the edge of the patterns. This is likely due to

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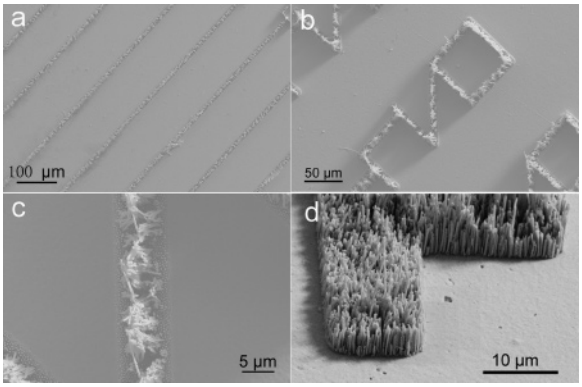

Figure 3. (a−b) FESEM images of Ni nanowire patterns with different features. The line width of the patterns is about 5 μm. (c) High magnification image of line pattern shows the width of the line is increased by nanodots around the nanowires. (The length of the nanowires is about 15 μm in this case.) (d) Ni nanowire pattern produced with AAM template modified with slightly thicker photoresist.

a small amount of bleeding of UV light beyond the edge of mask; dissolution of the exposed resist creates small openings above some of the adjacent pores in the AAM. By simply increasing the thickness of the resist slightly, this effect disappears and much better definition along the edge is seen (Figure 3d).

A novel procedure has been developed to fabricate free-standing patterns of metal nanowire arrays through combining photolithography and electrochemical deposition at room temperature. Controlling the thickness of photoresist can improve the quality of nanowire patterns. The structure of nanowire patterns with line widths bigger than 5 μm can be readily prepared with photolithography. While only metal nanowires of 200 nm in diameter have been synthesized in this work, the approach described here will be applicable to wafer size fabrication of nanowire patterns of a variety of materials (metals, oxides, and semiconductors) in a wide range of diameters and lengths.[7−11] Our group is working on the design and fabrication of microdevices such as high frequency microwave filters where strict control of magnetic wire dimensions and their relative spacing can greatly influence absorption properties.[40]

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Supporting Information Available: Details on fabrication methods are provided. This material is available free of charge via the Internet at http://pubs.acs.org.

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