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Short communication

Controlled synthesis and diameter-dependent optical properties of Cu nanowire arrays

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Abstract

Using electrochemical deposition, Cu nanowire arrays have been successfully fabricated by home-made polycarbonate ion-track templates. The diameters were well controlled by etching time of templates. The minimum diameter is 15 nm. The morphologies and structures were analyzed by scanning electron microscopy, transmission electron microscopy and X-ray diffraction. The wires prefer [1 1 0] growth direction due to H ions absorption. The optical properties of Cu nanowire arrays are studied by an ultraviolet/visible/near-infrared spectrophotometer. Two extinction peaks were observed in spectra. The optical mechanism is discussed based on surface plasmon resonance.

Keywords: Electrochemical deposition; Cu nanowire arrays; Growth orientation; Surface plasmon resonance

1. Introduction

High aspect ratio metal nanostructures such as nanorods, nanotubes and nanowires have attracted considerable attention [1–5] due to their novel properties and potential applications in electronics, magnetics, photonics, optoelectronics and biological sensors. Copper is of peculiar interest thanks to its important role in the electronic industry based on its excellent electrical and thermal conductivity.

The physical as well as chemical properties of nanowires depend not only on their native materials properties but also on their morphologies and structures. To date, a number of methods have been developed to fabricate Cu nanowires, including template-assisted synthesis [6,7], chemical vapor deposition [8], vacuum vapor deposition [9], hydrothermal reduction [10] and so on [11–15]. Particularly, ion-track template synthesis combined with electrochemical deposition is a versatile and flexible approach and has been widely used to fabricate metallic, semiconductive and conductive polymeric nanowires. On the one hand, heavy-ion irradiation and chemical etching allow one fabricate templates of different materials (polymers, SiO_2 and mica, among others) with pores of controlled density (from single to 10^9 pores/cm^2), shapes (e.g. cylindrical, conical or biconical), diameters from a few nm to several μm and aspect ratios (length over diameter) even more than 10^3. On the other hand, by controlling of deposition parameters, nanowires with well-defined crystallinity and crystallographic orientation can be obtained [3–5].

In addition to developing fabrication methods, over the past few years there were some works related to study the properties of Cu nanowires. For instance, Molares et al. [6] reported the electronic transport properties of Cu nanowires with diameter of 60 nm and length of 2.4 μm, which show a metallic behavior. The transition of resistance behavior from metal to semiconductor was observed in their work caused by the oxidation of metallic Cu to p-type semiconductive Cu_2O. Furthermore, polarization properties of Cu nanowire arrays embedded in alumina templates were also experimentally reported by Pang et al. [7] and theoretically investigated by Zhang et al. [16].

In this work, Cu nanowires have been successfully fabricated within the nanopores of the etched ion-track polycarbonate templates using electrochemical deposition. The wires are cylindrical in shape with diameters between 15 and 95 nm. The preferred orientation of as-deposited Cu nanowires was observed and the formation mechanism is analyzed. Moreover,

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the optical spectra of Cu nanowire arrays were measured and the mechanism of light extinction is discussed.

2. Experimental

The polycarbonate foils (Makrofol N, Bayer Leverkusen) of thickness 30 μm were irradiated at the UNILAC linear accelerator of GSI (Darmstadt, Germany) with Au or U ions (kinetic energy 11.4 MeV/u, fluence 5×10^8 ions/cm^2) in normal incidence. The latent tracks, which are the disturbed regions, were produced by Au or U ions penetrating polycarbonate foils along ions' trajectories. After ions irradiation, each side of polymer films was exposed to UV light for 2 h in order to enhance the ratio of track etching rate over bulk etching rate [17]. This step called track sensitization was used to produce fine cylindrical pores. The UV illuminated films were put in 5 M NaOH solution at 50 °C to etch the latent tracks into nanopores. During etching process, an ultrasonic field was employed to achieve a homogeneous pores etching. A thin gold film was sputtered onto one side of the membrane and then reinforced electrochemically by a Cu layer with thickness of several μm. Then, the Cu nanowire arrays were electrochemically deposited into etched ion-track templates at temperature 50 °C. During electrochemical deposition, the Au layer served as cathode and a Cu cone was used as anode. The employed electrolytes consisted of an aqueous solution of 75 g/l $CuSO_4 \cdot 5H_2O$. The pH value of the solution was 1.2 adjusted by H_2SO_4. In the deposition process, direct current electro-deposition was performed at applied voltage 200 mV. The deposition processes were monitored by recording current versus time curves.

After dissolving host membrane by dichloromethane (CH_2Cl_2), the morphologies and sizes of the as-deposited Cu nanowires were obtained by a field emission scanning electron microscope (FESEM, JSM-6700F, JEOL) and a transmission electron microscope (TEM, JEM-3010, JEOL). After removing the wires' caps and substrate layers of Au and Cu, the structures and optical properties of Cu nanowire arrays embedded in polycarbonate ion-track templates were analyzed using an X-ray diffractometer (XRD, XRD-7000, Shimadzu, Cu Kα, λ = 0.154178 nm) and an ultraviolet/visible/near-infrared spectrophotometer (Lambda 900, PerkinElmer), respectively.

3. Results and discussion

3.1. Morphology

The typical FESEM images of Cu nanowires of diameter 95 nm are shown in Fig. 1a and b. The template was etched for

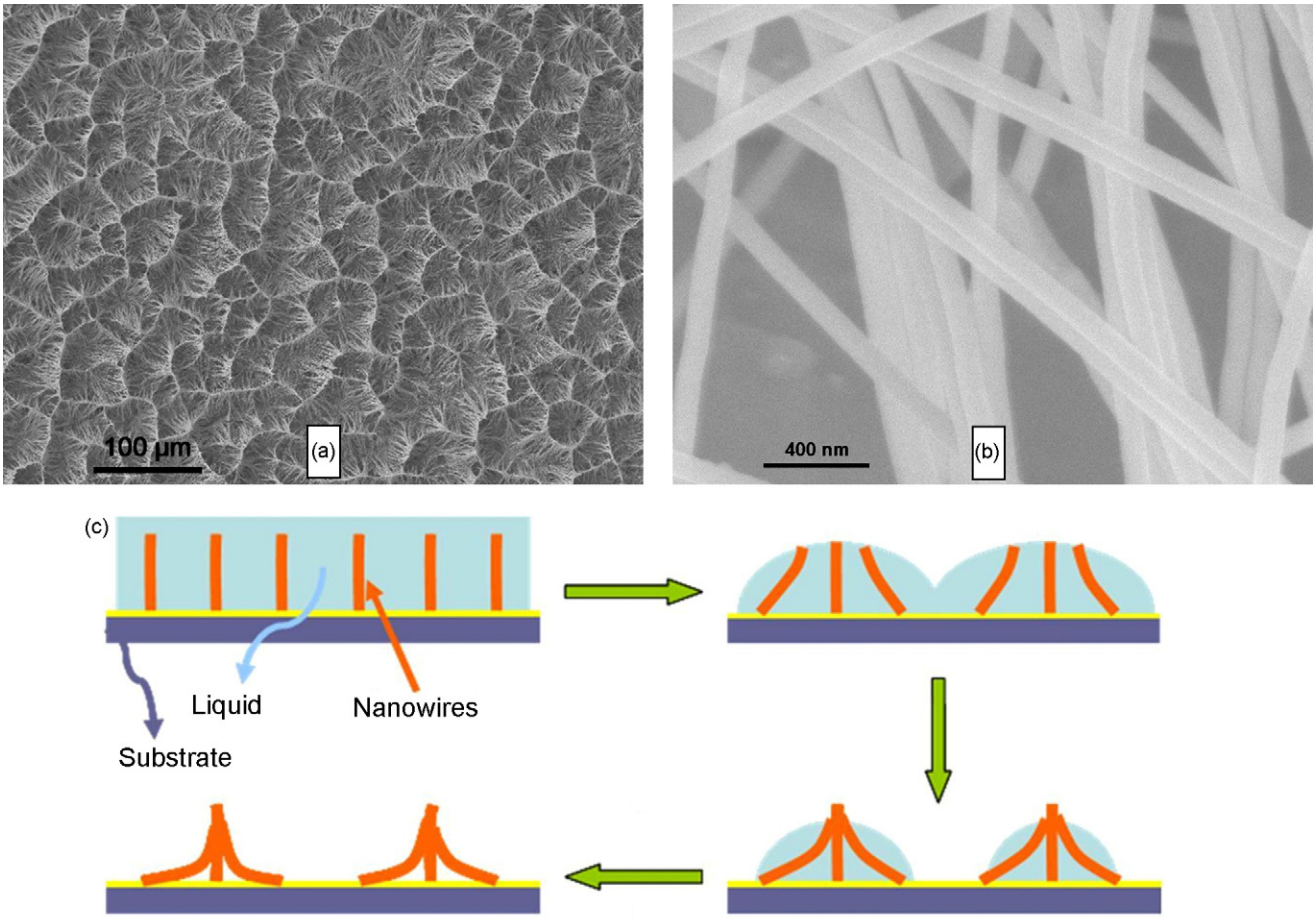

Fig. 1. FESEM images of Cu nanowires with: (a) a low magnification; (b) a high magnification; (c) a schematic description of the aggregation process of nanowires aggregation.