Fabrication and Contacting of Single Wires by Ion Track Etching and Electrochemical Deposition

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The creation of nanowires is acquiring increasing importance due to the efforts of microtechnology to reduce structures to sizes as small as 100 nm and less. Nanowires have been produced with various techniques, for example, laser-assisted catalytic growth [1], scanning tunneling microscopy [2], and electrochemical or electroless deposition in templates [3,4]. In particular the latter method has been used by several groups to create large arrays (10^6 cm^{-2} - 10^{12} cm^{-2}) of different kinds of structures such as conductive polymers, metallic wires or multilayered needles. Due to the limited size, nanowires exhibit novel optical, electrical or magnetic properties. In some cases, they can be investigated as large ensemble of nanowires embedded in the template matrix [4,5]. However, in particular for electric and magnetic studies, it is necessary to select individual wires and produce reliable electrical contacts.

In this paper, we demonstrate a new possibility to create single nanowires that can easily be contacted for further studies e.g. transport measurements. The technique is based on ion-track etching in combination with electrochemical deposition as schematically shown in Fig.1.

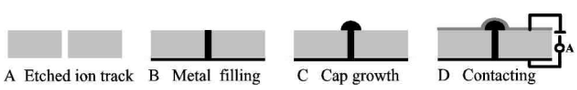

Fig. 1 Schematic of template method for electrochemical deposition of copper in a single-pore membrane.

To produce single-pore membranes, 30 µm thick polycarbonate foils were irradiated with individual heavy ions (e.g. Xe, Au, U) of several hundred MeV energy at the linear accelerator (UNILAC) of GSI [6]. The irradiations were performed through a mask with a 0.1mm orifice allowing the controlled production of a single track per membrane. The defect zone created along the ion trajectory can preferentially be dissolved in a suitable etchant. Cylindrical pores with diameters between 200 nm and 1 µm were obtained (Fig. 1A). After etching, a thin gold film was sputtered onto one side of the membrane and subsequently electrochemically reinforced with copper. The polymer foil was then mounted in a two-electrode electrochemical cell, where the conductive membrane surface acts as cathode and a copper piece serves as anode. The cell was filled with a simple-salt electrolyte consisting of an aqueous solution containing 238 g/L $CuSO_4$ $5H_2O$ and 21 g/L sulphuric acid. The copper deposition in the pore was performed potentiostatically and at room temperature.

Chronoamperometric curves recorded during the filling process are presented in Fig. 2 for various applied voltages (90-110 mV). The data originate from the growth of individual 1-µm diameter wires and show the typical evolution as also observed for large ensembles of nanowires [7]. The integral of the current-vs-time curves between the beginning of the deposition and the steep current increase corresponds to the total charge necessary to fill up the pore, as given by Faraday's law.

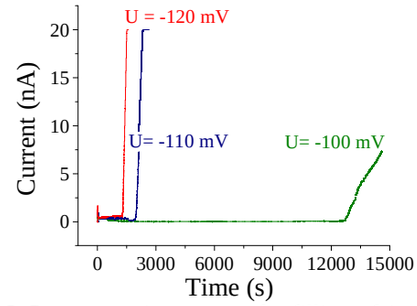

Fig. 2 Current-vs-time curves for filling of 1-µm diameter pore at different overvoltages.

When the nanowire reached the upper membrane surface (Fig. 1B), the deposition process was continued for some time, in order to grow a copper cap of about 10 µm in diameter (Fig. 1C). Caps of single nanowires grown at different overvoltages are shown in Fig. 3A-C. The different morphology indicates that larger grain sizes are formed for lower voltages, i.e., for lower current densities, as discussed earlier [8]. For electrical measurements, the cap and therefore the wire can easily be contacted by evaporating another metal layer (e.g. gold) on the membrane surface (Fig. 1D) avoiding large contact resistances. Up to now, single wires with diameter 300 nm have been successfully produced and contacted. Our technique eliminates the laborious procedure of selecting and contacting single wires e.g. by lithographic methods. Further investigations will focus on electrical properties not only of polycrystalline but also of single-crystalline nanowires. From our earlier studies [7,8], suitable condition for the growth of single-crystalline wires as small as 50 nm in diameter (Fig. 3 D) are known.

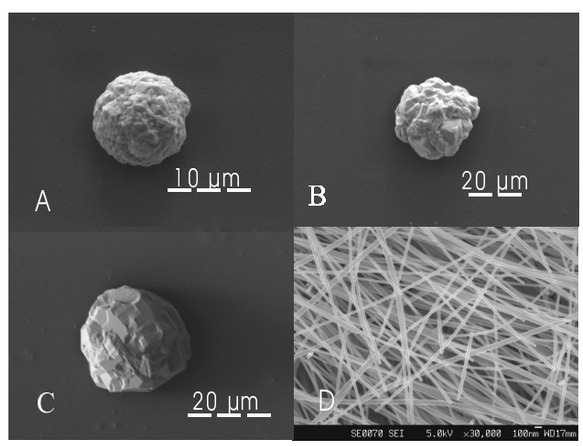

Fig. 3 A, B, C: Micrographs of caps of 1 µm single wires grown at different current densities, D: 50 nm diameter copper nanowires after dissolution of the polymer membrane.

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