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Morphological and magnetic characterization of electrodeposited cobalt nanowires

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In recent years much attention has been paid to the understanding of nanostructured materials (such as nanoparticles, nanowires, multilayers, etc.), which exhibit interesting new magnetic properties [1–6]. The miniaturization of the magnetic systems with nanometric scale makes it possible to obtain magnetic properties, which do not appear in the bulk material and are of great scientific and technological interest. Electrochemical techniques, which are relatively simple and cheap, make possible the synthesis of objects in the nanometric scale.

Template synthesis is an elegant chemical approach to the manufacturing of nanostructured materials, in particular for different kinds of nanowires [1–10]. It may be considered as an alternative to conventional lithography methods. Arrays of cobalt nanowires have been obtained by filling a porous polycarbonate membrane, which contain a large number of cylindrical holes with a narrow size distribution. The filling is carried out by electrochemical deposition from a solution. Electrodeposition is of interest because it works under atmospheric pressure, does not require expensive equipment, and may be used in geometries where conventional deposition processes would fail.

8 μm thick foils of polycarbonate were irradiated with heavy ions ^{238}U (11.6 MeV/n) at normal incidence utilizing the UNILAC facility at GSI, Darmstadt, Germany. The fluence was of the order of 10^6 ions/cm^2. Using these conditions, the penetration range of the ions in polycarbonate was larger than the thickness of the foils and the dE/dx of the ions was well above the threshold required for homogeneous etching. The irradiated polycarbonate foils were etched chemically at 50 °C in a 6 N NaOH solution containing 10% methanol for 6 min. The resulting pores are cylindrical, their diameters increase linearly with time of etching. In the present work we produced the pores with average diameter 100 nm.

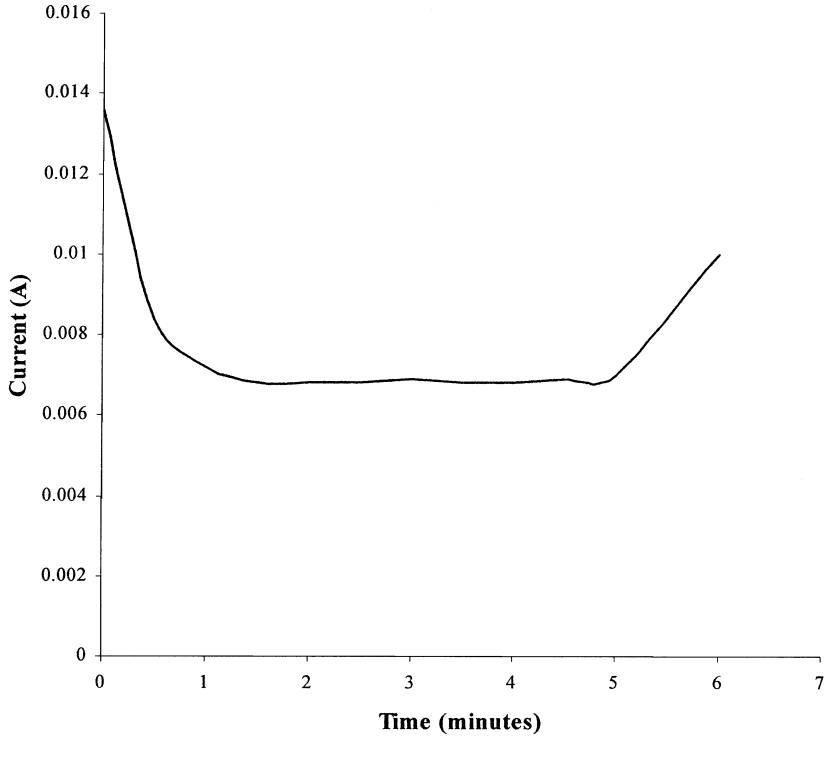

Figure 1 Variation of current with time during electrodeposition through nanopores in polycarbonate.

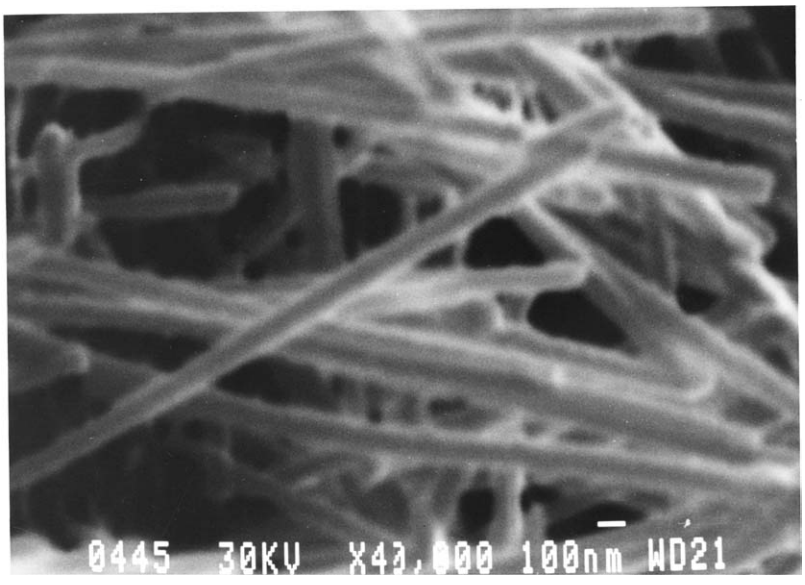

Figure 2 SEM micrograph of cobalt nanowires having diamater 100 nm and length 3.5 μm.

In general a suitable cell design is required and the lay-out design of such electrodeposition cell along with other relevant details of the technique has been discussed previously [3]. Two-electrode electrochemical cell was used for cobalt deposition in the pores of template membrane. The work was carried out at a constant potential in the range 1.20–1.25 V at $T = 25\,^{\circ}$C. The aqueous electrolyte used was cobalt sulphate salt ($CoSO_4 \cdot 7H_2O$) (40 g/l) in a boric acid solution (H_3BO_3) (40 g/l). The latter was used as a buffer. During the deposition process, the time dependence of electrical current was recorded (Fig. 1).

For the characterization of the cobalt nanowires by means of SEM, cobalt nanowires, freestanding on the copper tape, were observed by dissolving the polycarbonate matrix in dicholoromethane. The cleaned and dried samples were mounted on the specially designed aluminum stubs with the help of double adhesive tape, coated with a layer of gold palladium alloy in Jeol, Fine Sputter JFC 1100 sputter, coated and viewed under Jeol, JSM 6100 scanning microscope at an accelerating voltage of 30 KV. Images were recorded on the photographic film in the form of negatives at different magnifications. Fig. 2 shows a scanning electron microscopy (SEM) image of a sample in which all the nanowires are misaligned perpendicularly to the polycarbonate membrane plane. The majority of cobalt nanowires tilt randomly a few degrees, with respect to the normal of the polycarbonate membrane plane.

In order to confirm the crystalline quality, X-ray diffraction was performed on cobalt nanowires of diameter 100 nm. X-ray diffraction measurements were carried out using a Philips PW1710 diffractometer with Cu-K_α radiation in 2θ mode. As indicated in the diffraction pattern (Fig. 3), the material deposited is essentially in the fcc structure instead of the hexagonal one. SEM images revealed that the length and average diameter of the cobalt nanowires produced was 4 μm and 100 nm repectively.

Magnetic characterization of array of cobalt nanowires was performed using an LDJ vibrating sample magnetometer (VSM). The DC hysteresis loops were measured at room temperature, with the maximum applied fields ($H_{max} \geq 10$ kOe) parallel or perpendicular to the axes of the nanowires. Figs 4 and 5

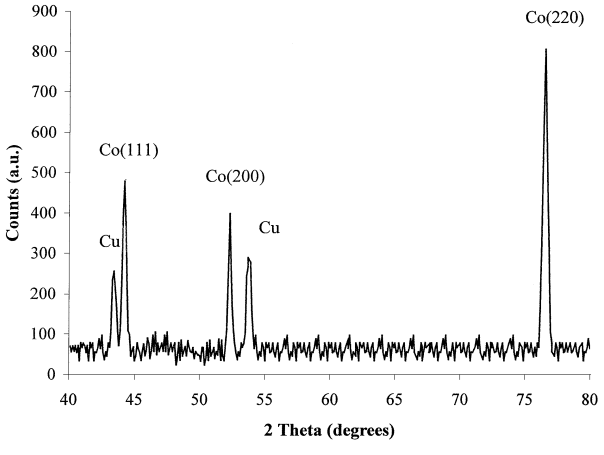

Figure 3 XRD diffractogram for the electrodeposited cobalt nanowires.

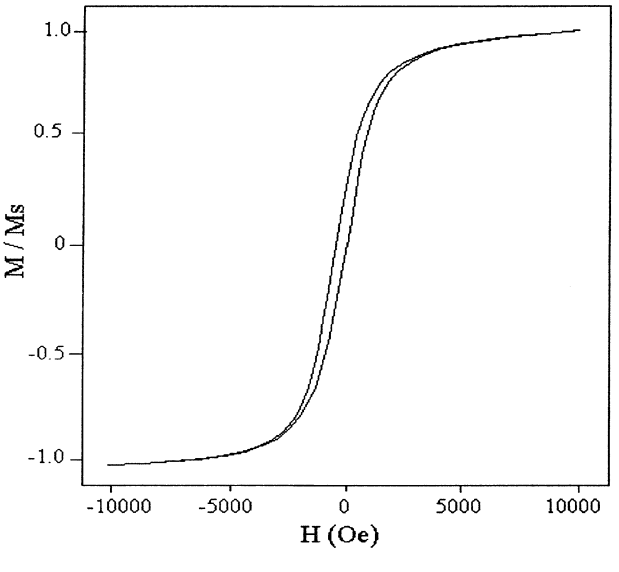

Figure 4 Hysteresis loop of the cobalt nanowires with the applied field parallel to the nanowires.

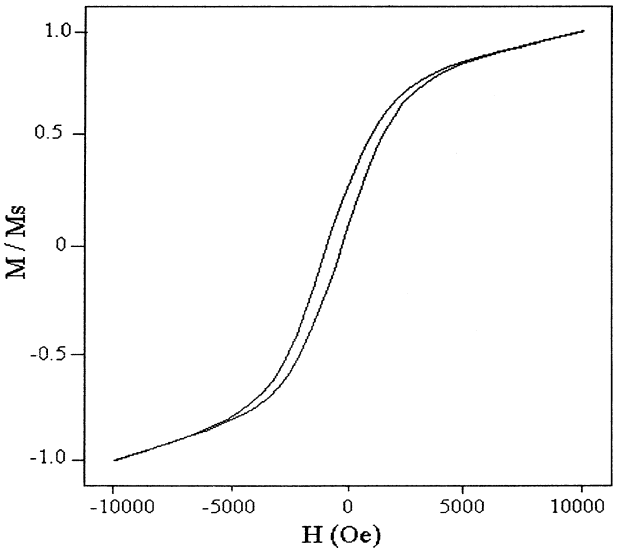

Figure 5 Hysteresis loop of the cobalt nanowires with the applied field perpendicular to the nanowires.

show two hysteresis loops of the array of nanowires with the membrane support: when the applied field is parallel to the nanowires (perpendicular to the surface of the membrane) and when the applied field is perpendicular with respect to the nanowires (so, in the plane of the membrane) respectively. It can be observed that maximum remanent magnetization is obtained for an applied field, which is parallel to the nanowires, while the coercivity of the array is maximum when the field is applied in a perpendicular direction with respect to the nanowires. The array of cobalt nanowires exhibits an easy axis which is parallel to the nanowires, but with the anomaly that the coercive field is minimum in that direction. The decrease of coericivity along the easy axis can be analyzed with a simple model, which considers magnetic interactions among the nanowires. This in turn acts as a demagnetizing field inside the wires hence reducing the remanent magnetization value.

In conclusion we have fabricated and characterized an array of electrodeposited cobalt nanowires. The magnetic properties of the array have been explained considering shape anisotropy and magnetic dipolar interactions among nanowires. The easy shape anisotropy direction in each nanowire is parallel to the nanowire axis. However, when the nanowires are set in the form of an array, the dipolar interactions among the nanowires change drastically the magnetic behavior, producing a decrease of the coercive field in the easy axis of the nanowires when the interaction is strong enough.

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