

Facile preparation and magnetic properties of Ni nanotubes in polycarbonate ion-track templates

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ABSTRACT

Ni nanotubes, with an inner diameter of about 100 nm and different wall thicknesses (approximately 20, 50, 80 and 110 nm), were successfully fabricated in porous polycarbonate (PC) ion-track templates by a novel method including two-step ion-track etching, two-step electrochemical deposition and one-step electrolysis. In our experiment, wall thickness of Ni nanotubes can be effectively controlled through the etching time of templates. The morphologies and crystal structures of the nanotubes were characterized by scanning electron microscopy (SEM), transmission electron microscopy (TEM) and X-ray diffraction (XRD). The magnetic hysteresis loops measured via vibrating sample magnetometry (VSM) indicate that Ni nanotubes with thinner wall thickness possess larger squareness and coercivity value when magnetic field applied parallel to the nanotube's axis, which can be attributed to the shape anisotropy and the formation of multi-domain structure.

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1. Introduction

In recent years, one-dimensional nanostructures, such as nanowires and nanotubes, have attracted extensive interest because of their distinctive physical properties and potential applications in different areas [1–8]. Due to hollow structures with inner and outer active surface, nanotubes are becoming highly attractive functional nanomaterials which can be used in the fields like sensors, catalysis, field emission and energy storage [2,5,7,8]. By combining the unique tubular structure with magnetic property, magnetic nanotubes can further broaden their applications in some specific fields, such as targeting drug and enzyme delivery with magnetic resonance imaging (MRI) capability in biomedicine and biotechnology [7,9]. This has triggered important efforts by materials scientists and technologists to develop excellent controlled synthesis methods and analytically study on the properties of magnetic nanotubes.

Up to now a number of methods, including atomic layer deposition [10], hydrothermal pyrolysis [11] and template-based growth [12–19], have been developed for the fabrication of

nanotubes. The template-based method shows unique advantages in preparation of nanotubes, for which tube diameter and maximal length are mainly dictated by template parameters, and the crystallographic characteristics are controlled via the deposition conditions. Via electroless plating on the pore's inner surface of PC template, some kinds of metal nanotubes have been fabricated by a reducing reaction on the nanochannel walls [15–17]. This technique has been proven to be a straightforward and efficient method for the synthesis of metal nanotubes. Mu et al. [18] reported a multistep template replication and electrochemical fabrication method employed with high temperature to grow uniform Ni nanotube arrays in anodic aluminum oxide (AAO) template. Also by using AAO template, Bridges et al. [19] have synthesized Au nanotubes by sequential deposition of materials, involving sacrificial metal base deposition, electro-polymerization of sacrificial polymer core, core collapse, deposition of Au shell, and removal of all sacrificial materials.

Magnetic nanotubes are the object of current research interest not only in fabrication methods but also in understanding of their basic magnetic properties. Intriguing magnetic features of nanotubes, such as domain wall dynamics, spin wave spectrum, and magnetic switching process, have been extensively investigated [20–22]. Many studies show that the magnetic characteristics of nanotubes are strongly determined by the inner and outer diameters or wall thickness. An angular dependent transition of

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magnetization reversal modes has been experimentally confirmed in magnetic nanotubes [23], and the magnetization reversal is highly influenced by the wall thickness [24]. Propagation of domain wall depending on the internal and external radii of the magnetic nanotube is demonstrated by numerical simulation and analytical calculation [25]. Besides, dependence of basic magnetic parameters, coercivity for instance, on nanotube geometry is also widely proved and studied [26,27]. Therefore, precise control over the geometrical and morphological characteristics of magnetic nanotube will be greatly important in investigating their properties.

In this work, we present a novel well-controlled approach to prepare pure Ni nanotube arrays by using PC membrane as a template. In contrast to the methods mentioned above, the most innovative aspect of this method is through simple electrolysis of Cu cores from Cu–Ni coaxial nanowires to form Ni nanotubes. The complete synthetic procedures can be described as follows.

Cu nanowire arrays were first deposited in the pores of template. Then a concentric channel was broadened around each Cu nanowire by dissolving the surrounding PC by NaOH etching process. And Ni was subsequently deposited in the opened channel to form a Cu–Ni coaxial nanostructure. Ni nanotube arrays were finally acquired by selectively electrolyzing the Cu cores from the Cu–Ni coaxial nanowires. The morphologies, structures and magnetic properties of the grown Ni nanotubes were investigated.

2. Experimental

Polycarbonate membranes (Makrofol N, Bayer Leverkusen) of thickness 30 μm were first irradiated at the UNILAC accelerator of GSI with ^{238}U ions of kinetic energy 11.4 MeV/u and the fluence of 5×10^8 ions/cm². In the second step, the membranes were etched

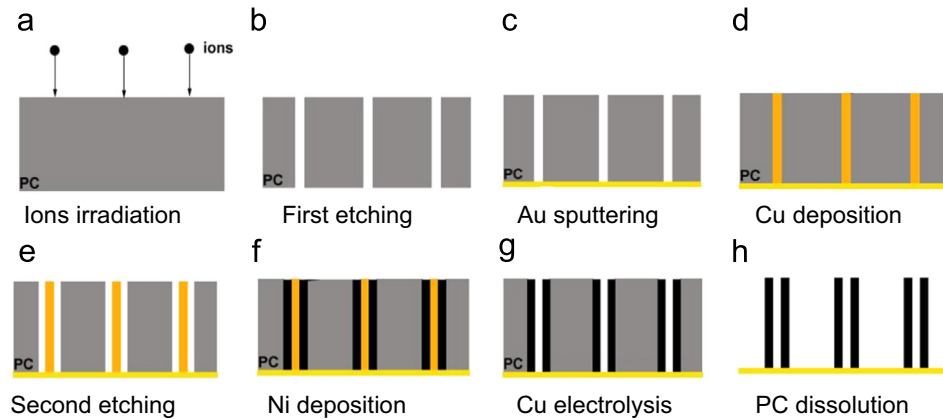


Fig. 1. Schematic diagrams of Ni nanotube growing mechanism.

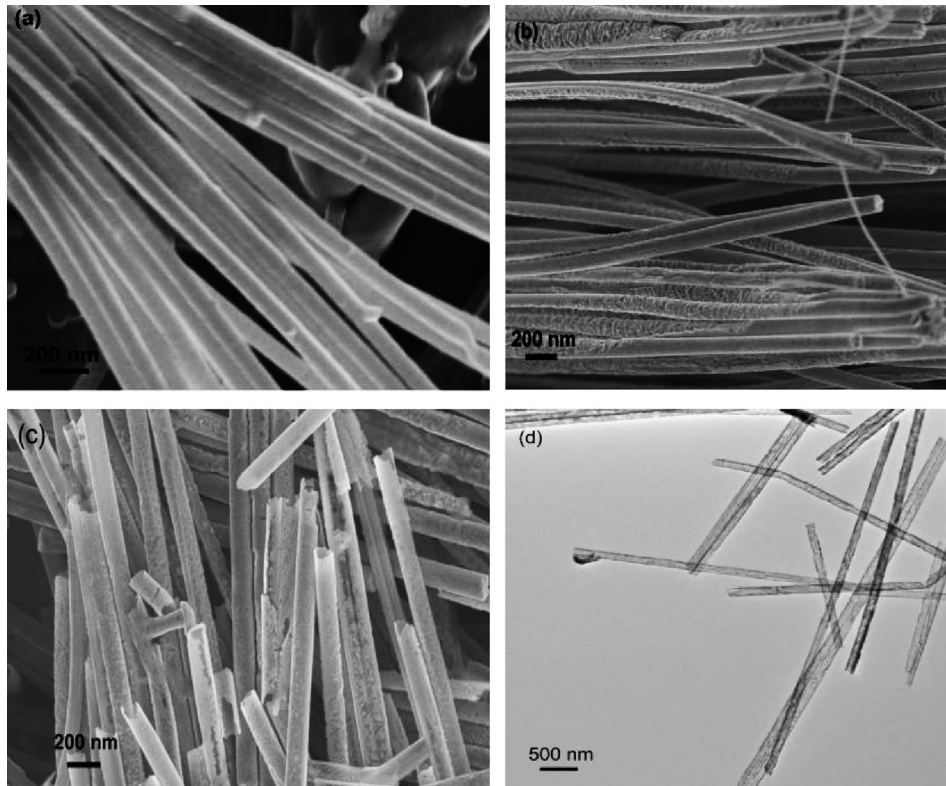


Fig. 2. SEM images of (a) 100 nm diameter Cu nanowires, (b) 140 nm diameter Cu–Ni coaxial nanowires after the deposition of Ni, (c) Ni nanotubes with an inner diameter of 100 nm and wall thickness about 20 nm after Cu core nanowires were selectively electrolyzed from Cu–Ni coaxial nanowires and (d) TEM image of Ni nanotubes.

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