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Comparative study on the characteristics of network and continuous Ni films

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ABSTRACT

Ni films were deposited on anodic aluminum oxide (AAO) and SiO_2/Si(100) substrates at 300 K by direct current magnetron sputtering with the oblique target. The film thickness was 80 nm, 160 nm and 260 nm. The films grown on AAO substrates have a network structure while those deposited on SiO_2/Si(100) substrates are continuous. The network film consists of granules and is formed by granule connection. The granule consists of many fine grains. The granule size increases with increasing film thickness. The 80 nm-thick network film has a honeycomb-like structure. The continuous films grow with a columnar structure and the transverse size of columnar grains increases with increasing film thickness. All the network films show a Ni(111) diffraction peak while the 160 nm- and 260 nm-thick continuous films exhibit the Ni(111) and Ni(200) diffraction peaks. The network films have higher coercivity and residual magnetization ratio compared with the continuous films. The coercivity and the residual magnetization ratio increase with increasing film thickness for the network films while they are almost independent of the film thickness for the continuous films. A temperature dependence of the resistance within 5–200 K reveals that the 80 nm-thick network Ni film exhibits markedly a minimal resistance at about 40 K. A logarithmic temperature dependence of the conductance is verified at temperatures below 40 K. The temperature coefficient of resistance is smallest for the 80 nm-thick network film and is largest for the 260 nm-thick continuous film.

1. Introduction

Nanostructured magnetic network films have attracted considerable attention for their potential applications in magnetic recording devices because they have a higher coercivity compared with the continuous films. Weston et al. [1–4] reported that the magnetic network films such as Fe, Co, Ni and their alloy films had a higher coercivity compared with the same continuous films. Tofail et al. [5] found that a coercivity of the network Fe film was higher than that of the continuous Fe film. Lee et al. [6] observed an enhancement of the coercivity in the network Co film relative to the continuous Co film. It was explained by the pinning of domain walls due to the hole edges in the vicinity of which the demagnetizing field was significant. Sun et al. [7] reported that the CoO/NiFe bilayer network films exhibited larger exchange bias and coercivity compared to the continuous bilayer films with the same layer thickness. Demirel et al. [8] used a chemical method to deposit nanoporous Ni films on nanostructured poly(chloro-*p*-xylylene) film templates. The morphology and topology of the nanoporous Ni films could be controlled by tailoring the poly(chloro-*p*-xylylene) film templates.

As mentioned above, previous comparison studies on the magnetic network and continuous films were mainly focused on their magnetic properties. On the other hand, a comparative study on the electrical and electrical transport properties of the magnetic metal network and continuous films is significant for fundamental and practical viewpoints. The magnetic metal particles connect with each other forming the electrically conducting network in the insulating atmosphere. As it is well known, the percolation theory can be used to explain the conducting mechanism for the conductive network. Aprili et al. [9,10] prepared network Ni films on SiO_2 layers by evaporating and annealing in ultra-high vacuum. They found that for the network Ni film near the percolation threshold an anomaly decrease in the conductance with temperature for temperatures below 4 K was due to the enhancement of the Coulomb electron–electron interactions.

Anodic aluminum oxide (AAO) substrates have been used to prepare some network films such as Fe, Ni, Co, NiFe and FeCo [1–5]. Amorphous SiO_2 substrates are often used to deposit the continuous thin films because they have the flat surface and the SiO_2 layer is a part of the semiconductor device. Therefore, in the present work, Ni films are deposited on AAO and SiO_2/Si(100) substrates by direct current (DC) magnetron sputtering with the oblique target. The network and continuous films are obtained. The film structure is studied using field emission scanning electron microscopy (FE-SEM) and X-ray diffraction (XRD). The magnetic property of the films is measured using a vibrating sample magnetometer (VSM). A temperature dependence of the resistance is measured in 5–200 K using a Cryogen–Magnet system with the four-point probe in order to investigate the electrical transport property in the films. A comparative study on the structural,

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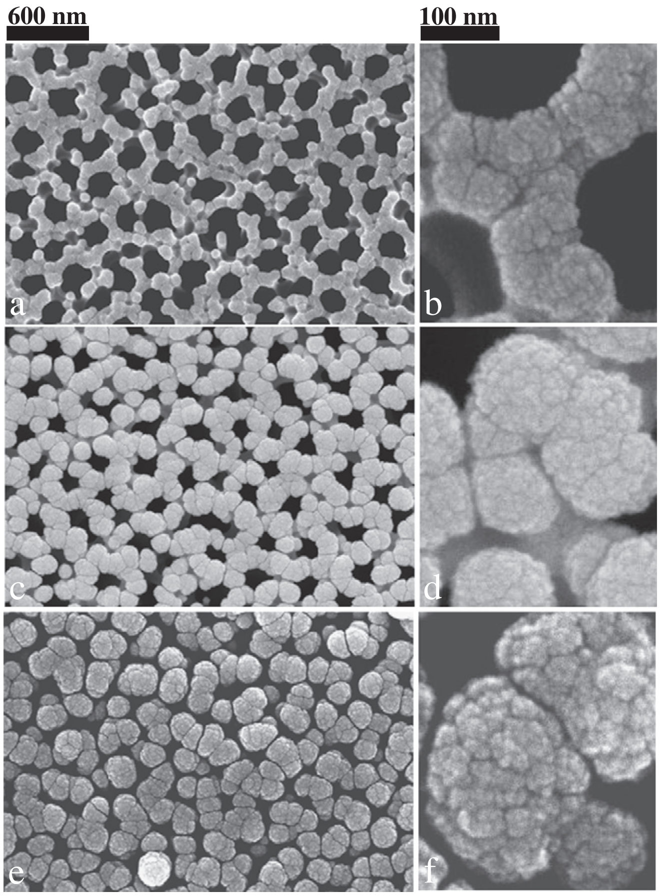

Fig. 1. FE-SEM micrographs of the Ni films grown on AAO substrates; (a, b) 80 nm-thick film, (c, d) 160 nm-thick film, and (e, f) 260 nm-thick film.

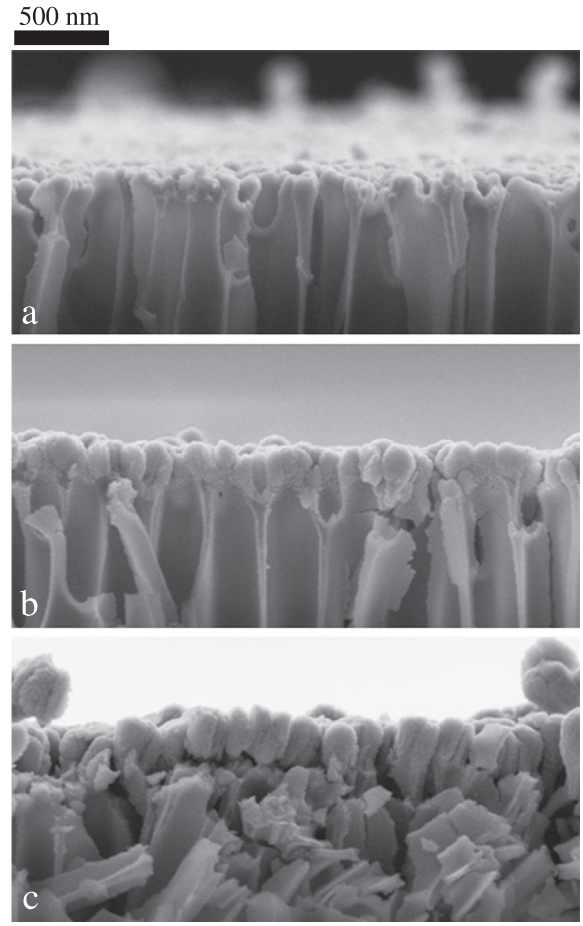

Fig. 2. Cross-sectional FE-SEM micrographs of the Ni films grown on AAO substrates; (a) 80 nm-thick film, (b) 160 nm-thick film, and (c) 260 nm-thick film.

electrical and magnetic properties of the network and continuous Ni films is given.

2. Experimental procedure

The DC magnetron sputtering system (KYKY Technology Development Ltd.), which has the target inclined to the substrate at an angle of about 45°, has been described elsewhere in detail [11]. The commercial AAO substrates (Whatman Ltd.) have an average pore diameter of 100 nm. The pores are pseudohexagonal ordering. The average pore wall width on the substrate surface is 25 ± 3 nm. The SiO_2/Si(100) substrate is a 400 nm-thick SiO_2 layer prepared by thermal oxidation of the Si(100) surface. The SiO_2/Si(100) substrates were ultrasonically rinsed in acetone, in deionized water and in ethanol, respectively. Prior to deposition, the working chamber was evacuated to a pressure of 8×10^{-4} Pa using a turbo molecular pump. The AAO and SiO_2/Si(100) substrates were placed in the working chamber via a load-lock chamber, which prevents the working chamber from air during changing the sample. Ar gas (99.9995% in purity) was injected into the working chamber and the Ar gas pressure was adjusted to 1.0 Pa. Then a sputtering power of 100 W was applied to the Ni target (99.99% in purity) of 50 mm in diameter. Ni films with a thickness of 80–260 nm were sputter-deposited on the AAO and SiO_2/Si(100) substrates at 300 K. A distance between the target and the substrate was about 100 mm. The substrate holder was rotated at a rotary rate of about 8 rotation/min by using a stepping motor during deposition in order to obtain the uniformly thick film. The average deposition rate was about 11 nm/min. The deposition time determined the film thickness.

FE-SEM of SUPRA 55 (Zeiss) was used to observe the morphology and the crystalline structure of the films. The FE-SEM operating voltage was 10 kV. XRD (Rigaku) was used to investigate the crystalline orientation of the films. The XRD measurements were performed in a standard θ–2θ scan using a Cu Kα radiation filtered by a crystal monochromator (wavelength $\lambda = 0.15404$ nm). The X-ray source was operated at a power of $40\ kV \times 0.1$ A. A scan speed was 0.1°/s and a scan step was 0.02°. Magnetic hysteresis loops of the films were measured at room temperature using VSM (Quantum Design). The magnetic field was applied in the direction parallel or perpendicular to the film surface during the VSM measurements. A resistance of the films was measured in the temperature range of 5–200 K using the Cryogen–Magnet system of CFM-5T-H3-CFVTI-1.6K-24.5 with the four-point probe (Cryogenic Inc.).

3. Results and discussion

3.1. Structure

Fig. 1 shows FE-SEM micrographs of the Ni films grown on AAO substrates. As can be seen from Fig. 1, all the films consist of granules and have a network structure. The network structure is formed by granules connecting with each other. The granule consists of many fine granular grains. The granule size increases with increasing film thickness whereas the grain size is almost independent of the film thickness. As the granules grow, the pore size of the network film becomes small. For all the network films, the granule size is larger than the pore wall width on the substrate surface. Furthermore, the 80 nm-thick film exhibits a honeycomb-like network. Fig. 2 shows