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Magnetic domain patterns in a zigzag nanowire

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Abstract

Nanowires of modulated widths are potential candidate for the study of shape dependence of nanoscale magnetic properties. A study of magnetic domain arrangement in zigzag nanowires fabricated by self-assembly of nanoparticles and etching technique is presented. Thin necks in the zigzags create an anisotropy which allows domains to distribute between adjacent triangles. Magnetic force microscopy shows unique magnetization patterns for different orientations of the applied field.

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1. Introduction

Nanoparticles self-assembly has been widely explored in nanostructure fabrications due to its cost-effective nature and high-resolution capability. Its applications have been extended to fabricate new structures such as bars, pillars and rings by combining self assembly of nanoparticles with the etching, annealing and evaporation techniques [1–5]. Zigzag nanostructures of modulated widths have drawn attention of researchers for their unique properties [6–8]. We have fabricated zigzag wires by utilizing the shadow effect of nanoparticles during etching process. In this paper, we will present the magnetic force microscopy (MFM) study of domain arrangements in an isolated zigzag wire. Object Oriented Micro Magnetic Framework (OOMMF) simulations [9–11] have been widely used for the explanations of properties in magnetic nanostructures. We performed OOMMF simulations on zigzag wires to obtain spin arrangements and the results are found in agreement with the MFM domain patterns.

2. Experimental details

In our experiments, a suspension of polystyrene nanoparticles of diameter 500 nm from Duke Scientific Corp. was dispensed on 5 mm × 5 mm Si(1 0 0) substrates by the tilting method [5]. Fig. 1(a) shows the self-assembled monolayer deposited on the substrate. After the formation of the monolayer mask on the Si surface, oxygen etching of hexagonally close-packed nanoparticles was performed using a Roth and Rau Electron Cyclotron Resonance (ECR) etching system. The substrate was tilted at an angle of 50° with respect to the incident ion beam. Tilting of the substrate created a shadow effect during etching and as a result a zigzag feature was created in the mask. Fig. 1(b) shows the nanoparticles mask with zigzag feature obtained after shadow effect of etching. More details of fabrication process have been reported elsewhere [12].

A permalloy ($Ni_{80}Fe_{20}$) film of thickness 40 nm was deposited by electron-beam evaporation on the nanoparticles mask followed by a lift-off process by dissolving the nanoparticles in dichloromethane. Fig. 1(c) shows the scanning electron image of deposited zigzag wires obtained after lift-off. Zigzag patterns have equilateral triangular sections of dimensions ~200 nm connected with narrow necks of width ~10 nm. The inset in Fig. 1(c) shows the

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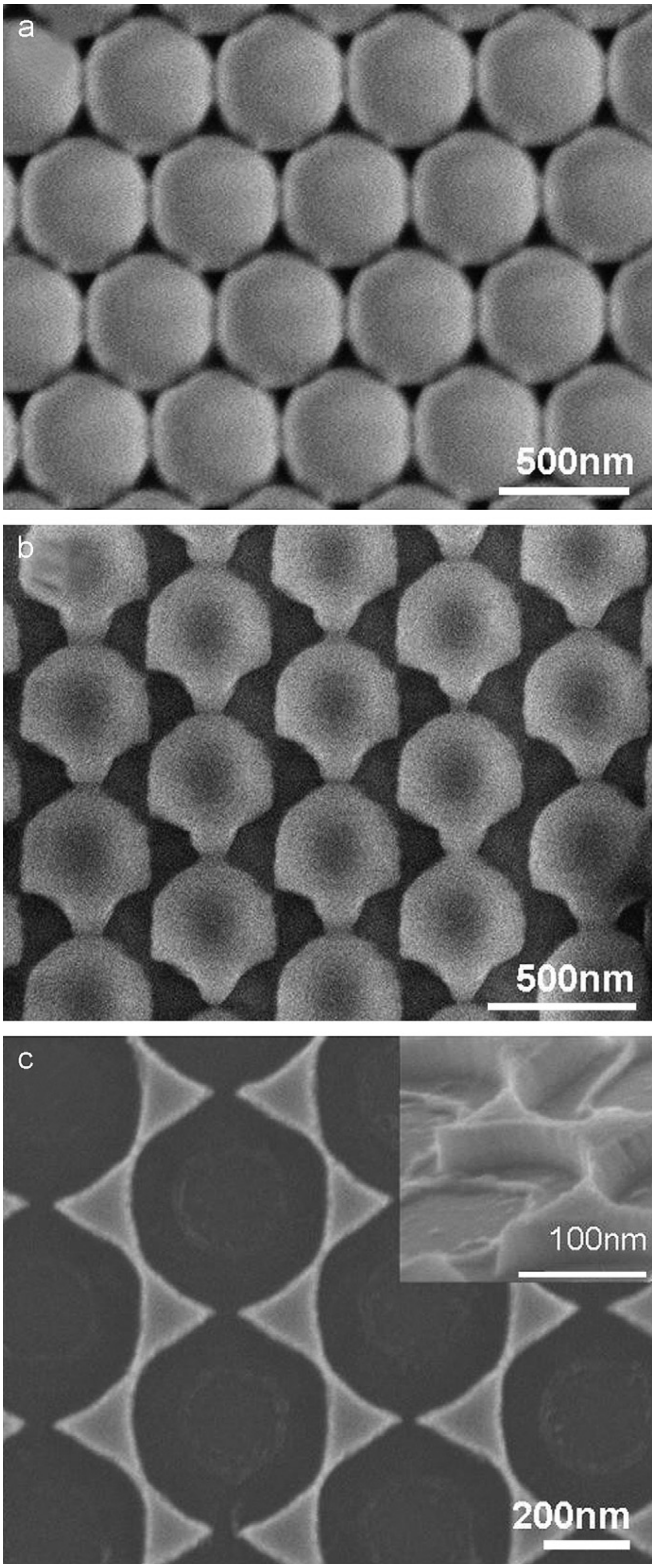

Fig. 1. (a) Self-assembled monolayer of polystyrene nanoparticles. (b) Modified monolayer mask after etching. (c) Deposited nanowires obtained after lift-off process. Inset shows the oblique view of a nanowire.

side profile of the zigzag nanowire showing the thickness uniformity of permalloy film and vertical side walls of the nanowire. A magnetic field of strength $H = 2000\,\text{Oe}$ was applied to saturate the sample and reduced to zero before loading the sample for domain imaging by MFM. A low moment tip was used in order to minimize the stray field effect from the tip during scanning process.

3. Results and discussion

Fig. 2(a) shows the topography of an isolated zigzag nanowire studied for its magnetic domain distribution. The nanowire image looks blur due to resolution artifacts from the MFM scanning process. Fig. 2(b) is the remanent domain distribution in the zigzag nanowire obtained after applying a field of strength $H = 2000\,\text{Oe}$ along the length of nanowire. The field direction is shown by the black arrow. The topography of zigzag wire in Fig. 2(a) acts as a visual guide for the correlation of domain patterns along its length. The triangular section of the nanowire shows a single-domain arrangement of the magnetization observed by presence of black and white contrasts within each triangular section (shown by dotted circles). Magnetic moments are aligned from right to left direction along the applied field direction as seen by alternating black/white contrasts. Fig. 2(c) is the magnetic domain image obtained after applying a reverse field of $H = -2000\,\text{Oe}$. The opposite arrangement of contrast observed in Fig. 2(b) confirms the magnetization reversal. For permalloy films, the effect of crystal anisotropy is negligible. Due to the anisotropy created by the zigzag shape, the magnetization in the triangular sections is aligned parallel to the length of the nanowire. The thin neck section in the zigzag acts as a link for magnetization to align between two triangular sections.

Fig. 2(d) shows the domain arrangement at remanance obtained by OOMMF simulations. A cell size of 5 nm was used for the micromagnetic calculations. The arrows show the magnetic moments aligned along the zigzag nanowire. An $H = 2000\,\text{Oe}$ field, was applied along the direction shown by the arrow and reduced to zero in a single step. The moments in the first half section of the triangle are aligned in upward direction following the direction of the magnetic moment from the incoming neck and the moments in the right half sections of the triangle are aligned downward following the direction of the magnetic moment to the next neck. This change in the alignments of magnetic moments is shown as the two different black and white contrasts in the MFM image and appears as a single-domain arrangement. If we look at the neck sections between any two neighboring triangles, we see that moments are following the alignment from the second half of the first triangle section to the first half of the next triangle forming a dipole. It explains the observation of black and white regions along the neck section as shown by the white arrow. The net alignment of moments is in the applied field direction along the nanowire as a whole.

The results of the domain distribution at remanence after saturating the nanowire in direction perpendicular to the length of nanowire are shown in Fig. 3. Fig. 3(a) shows the