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Research articles

Patterned FePt nanostructures using ultrathin self-organized templates

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ABSTRACT

Patterned magnetic thin films are both scientifically interesting and technologically useful. Ultrathin self-organized anodic aluminum oxide (AAO) template can be used to fabricate large area nanodot and antidot arrays. The magnetic properties of these nanostructures may be tuned by the morphology of the AAO template, which in turn can be controlled by synthetic parameters. In this work, ultrathin AAO templates were used as etching masks for the fabrication of both FePt nanodot and antidot arrays with high areal density. The perpendicular magnetic anisotropy of $L1_0$ FePt thin films are preserved in the nanostructures.

1. Introduction

Bit-patterned Media (BPM) have been proposed to address the issues of transition noise as well as the superparamagnetic limit associated with conventional continuous granular media for magnetic recording [1–3]. BPM includes both nanodot and antidot arrays. For nanodot arrays, each nanodot is used to store a single bit, which is separated by non-magnetic materials. This not only eliminates the transition noise, but also mitigates the superparamagnetic effect since the limit applies to a bit rather than the grains within the bit [4]. Magnetic antidot arrays with perpendicular anisotropy, which consist of densely packed nonmagnetic nano-columns within exchange-coupled magnetic grains, can be regarded as percolated perpendicular media [5]. The nonmagnetic nano-columns can serve as pinning sites which can influence the magnetic properties of films. $L1_0$-FePt with perpendicular anisotropy is a promising material candidate for the fabrication of both nanostructures, due to its high magnetocrystalline anisotropy (K_u) [6]. However, obtaining large scale, high areal density nano-arrays with tunable dimensions and controlled magnetic easy axis orientation remains a great challenge.

Several techniques have been developed to obtain magnetic nano-arrays, which can be broadly divided into two categories: (a) top-down approaches, such as electron beam lithography [7] and nano-imprinting lithography [8]; and (b) bottom-up approaches, such as nanoparticle self-assembly [9]. Although top-down approaches exhibit high precision, the etching process is slow, of high cost and difficult to realize large scale with extremely high density. On the other hand, nanoparticle self-assembly runs into issues such as sintering upon annealing and difficulty to control the easy axis orientation. Compared with these preparation methods, templated technique combining both top-down and bottom-up approaches possesses certain advantages [10]. Self-organized anodic aluminum oxide (AAO) can be used as such a template [11,12]. The preparation is simple and of low cost, and highly ordered arrays in large area can be obtained. The pore diameter, inter-pore distance and pore length of the AAO template can be continuous adjusted by changing the preparation conditions of the template. Thus the morphology of the nanostructures fabricated using the AAO template can be readily controlled. Meanwhile AAO templates have high thermal stability, which can withstand the high temperature needed to realize the phase transformation to chemically ordered alloys.

In this work, ultrathin self-organized AAO template combined with sputtering and etching processes are employed to fabricate both FePt nanodot and antidot arrays. The dimension of the nano-arrays (size and spacing) can be well controlled by the AAO templates, and thus the magnetic properties of the arrays can be regulated. This technique integrating bottom-up and top-down approaches can be extended to fabricating large area nano-patterns with a variety of materials.

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2. Experiment

2.1. Sample preparation

2.1.1. Deposition of FePt thin films

Pt(4 nm)/FePt(20 nm) film was deposited on a single crystal MgO (0 0 1) substrate at 450 °C by co-sputtering Fe and Pt targets using dc magnetron sputtering. The sputtering was done at an Ar gas pressure of 7.5×10^{-3} Torr when the base pressure is lower than 6×10^{-7} Torr. All samples were annealed in-situ for 30 min at 450 °C to realize the phase transformation from chemically disordered A1 to ordered $L1_0$ phase with hard magnetic properties.

2.1.2. Preparation of ultrathin AAO templates

The AAO templates were prepared by the classical two-step anodization method in acidic solutions such as oxalic acid and phosphoric acid under constant voltages [13]. To make ultrathin templates suitable as deposition/etching masks, the anodization time for the second anodization were kept short, typically less than 5 min. After the two-step anodization, highly ordered porous array was formed. In order to obtain ultrathin free-standing AAO templates with through pores, a polymethyl methacrylate (PMMA) layer was spin-coated onto the top of AAO template as the protection. The un-oxidized Al and a dense barrier layer of Al_2O_3 at the bottom were removed by immersing the templates into an acid mixture of $CuCl_2$ and HCl, and H_3PO_4 solution, respectively. After thorough cleaning to remove any debris and chemical residue, the AAO template was transferred onto a substrate, and PMMA was removed by acetone. During the transfer and cleaning processes, we used a filter paper to assist the transfer of the ultrathin template. Due to the van der Waals forces between the template and substrate, the transferred ultrathin AAO template maintains close contact with the $L1_0$-FePt film. This facilitates the deposition and etching of the FePt films, using AAO as masks. The ultrathin AAO template transferred onto the $L1_0$-FePt film were then used as masks to obtain nanodot arrays and antidot arrays, respectively, as shown schematically in Fig. 1.

2.1.3. Fabrication of FePt nanodot arrays

First, an FePt film with a Pt underlayer was deposited on a MgO (0 0 1) substrate. The sample was annealed in-situ for 30 min to form the $L1_0$ structured hard phase. An ultrathin AAO template was then transferred onto the film. The pore diameter, interpore distance and pore depth of the template are 50, 100 and 180 nm, respectively. A 30 nm Al_2O_3 capping layer was deposited on the FePt film through the AAO template. After Al_2O_3 deposition, AAO template was removed by ultrasonication in acetone, leaving an ordered array of Al_2O_3 nanodots on the FePt film. The obtained sample was then subjected to an Ar ion beam etching process under ion energy of 300 eV, and ion beam current of 60 mA for 3 min. Due to the different etching rates of the metal and oxides, FePt exposed to the ion beam were completely removed, leaving an FePt nanodot array protected by the Al_2O_3 capping layer. Finally Al_2O_3 can be either removed or retained according to needs.

2.1.4. Fabrication of FePt antidot arrays

First, FePt thin films with designed composition was deposited on a MgO (0 0 1) substrate, followed by subsequent annealing to convert the A1 disordered phase to $L1_0$ ordered phase. Then, the ultrathin AAO template was transferred onto the FePt film followed by ion beam etching process under ion energy of 300 eV, and ion beam current of 60 mA for 3 min. Finally AAO template was removed by ultrasonication in acetone, leaving an FePt antidot arrays, as shown schematically in Fig. 1.

2.2. Characterization

The structural and magnetic properties of the FePt nanodot and antidot arrays were characterized using a Scanning Electron Microscopy (SEM), Atomic Force Microscopy (AFM), X-Ray Diffraction (XRD), and Superconducting Quantum Interference Device (SQUID)

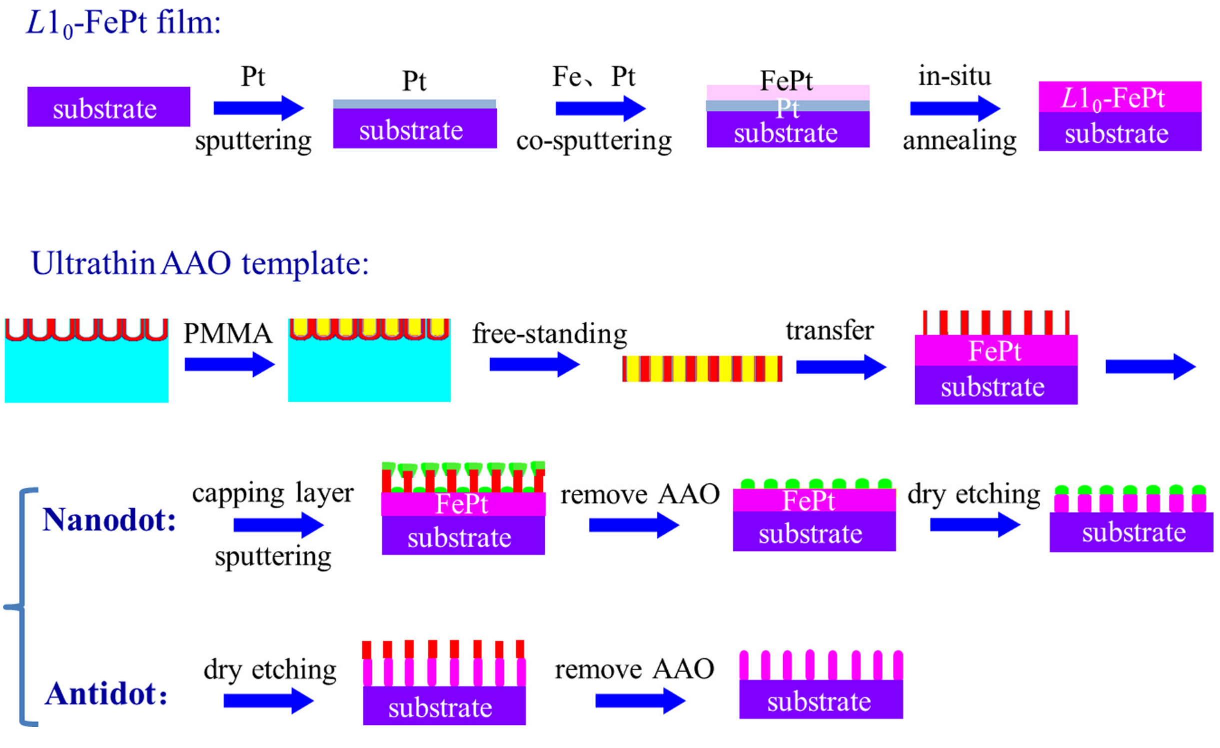

Fig. 1. A schematic of the fabrication procedures of the $L1_0$-FePt film, the nanodot and antidot arrays.