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ScienceDirect
Physica E 40 (2008) 516–519
PHYSICA E
www.elsevier.com/locate/physe

Fabrication of submicron magnetic oxide antidot arrays by combining nanosphere lithography with sputtering technology

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Received 17 April 2007; received in revised form 6 July 2007; accepted 25 July 2007
Available online 14 August 2007

Abstract

A simplified way, which combines nanosphere lithography with sputtering technology, to fabricate oxide antidot arrays is reported. Using the resputtering effect of oxygen negative ions during sputtering deposition in oxygen environment, $CoFe_2O_4$ antidot arrays are fabricated directly on a wafer masked by latex spheres, which is self-assembled by nanosphere lithography. The result shows that the coercivity of the $CoFe_2O_4$ antidot arrays increases substantially due to the pinning of domain walls in the vicinity of antidots. This fabrication method can be extended in the fabrication of other oxide antidot arrays.

PACS: 81.16.Nd; 75.75.+a; 75.50.Gg

Keywords: Magnetic material; Magnetic nanostructure; Nanolithography; Resputtering effect

1. Introduction

Magnetic thin films with periodic arrays of nonmagnetic inclusions, referred to as antidots, have been suggested as a possible candidate for recording media in ultra-high density storage [1]. Among them, magnetic antidot arrays are particularly of interest. It introduces the nonmagnetic holes into a continuous magnetic thin film or multilayer system, which significantly modifies the magnetic properties. This results in novel domain configurations, additional magnetic anisotropies, and modification of the magnetization reversal, which in turn affects the switching fields and magnetoresistance [2]. By choosing a specific antidot geometry, with a given antidot size, antidot separation, and lattice symmetry and orientation, it will be possible to control the magnetic properties.

There are various methods for fabricating arrays of magnetic nanostructures including antidots, like KrF deep ultraviolet (DUV) lithography [2], electron beam lithography and lift-off processes [3], focused ion beam (FIB) etching [4], and interferometric lithography [5]. However, the costs of the conventional lithography become extremely high and commercially unacceptable for small magnetic structures with the lateral dimension smaller than 100 nm. Therefore, developing relatively cheap methods for fabricating nanoscale or submicron scale magnetic structures is one of the most important issues in current technology. Templates with ordered structure whose period may be smaller than that achievable through lithography have been developed for making nanostructures. The efficient and cheap anodized alumina template technique is utilized to make antidot arrays [6], but it limits on alumina substrates. On the other hand, nanosphere lithography (NSL) is also a well-known, lost-cost and high-throughout method that is being employed in laboratories around the world [7]. In NSL, the etching/deposition template mask is formed by the self-assembly of monodisperse polystyrene

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doi:10.1016/j.physe.2007.07.021

(PS) latex spheres on flat surfaces. Combining with other techniques, various pattern arrays or antidot arrays could be fulfilled, including angle-resolved NSL [8], ultra-flat NSL [9], shadow NSL [10] and vertical reactive ion etching (RIE) with oxygen-contained gases [11].

The conventional fabrication process of antidot arrays using NSL technique is as follows [11,12]. First, a close-parked single layer of PS latex spheres is self-assembled onto the surface of the substrate. Second, a RIE system in oxygen environment is used to modify the shape and feature spacing of the PS latex spheres. Then, the targeted film is deposited onto the substrate through PS latex sphere mask by either evaporation or electrodeposition. After this step, the PS latex spheres are lifted off, and then the antidot arrays are formed. In this conventional process, the reduction of the dimension of PS latex using RIE system is the key step to form antidot arrays, and usually requires special and expensive equipment. In this paper, based on the mechanism of tailoring the PS surface with low energy ions [13], we use the magnetron sputtering technology directly to fabricate the oxide magnetic antidot arrays.

2. Experimental

The Si (1 0 0) wafers were cut into 10 mm × 5 mm pieces as substrates. They were cleaned by immersing in piranha solution (3:1 concentrated H_2SO_4/30% H_2O_2) at 80 °C for 2 h. Then they were washed in deionized water, immersed in a solution of 5:1:1 H_2O:NH_4OH:H_2O_2 and sonicated at 80 °C for 1 h, followed by extensive rinsing with a copious amount of deionized water. Finally, the substrates were stored in deionized water until required. After removal from the water, the substrates were dried in air at a temperature of 60 °C. Next, fresh ultra-pure water was deposited and dispersed across the substrate. A colloidal nanosphere solution (500 nm diameter, 4 wt% from the Interfacial Dynamics Corp.) was deposited onto the water film and dispersed by a gentle tipping and rotation of the sample until an even concentration was present across the substrate. Then the substrate was enclosed in a small plastic box (around 300 cm^3). The box protects the surface from the external air flow, which will affect the evaporation process. The whole system was tilted about 10° to ensure these PS latex spheres can self-assemble into a hexagonally close-parked monolayer array.

Once the 2D colloidal crystal deposition mask was formed, the substrate was placed in vacuum deposition chamber of radio frequency (RF) magnetron sputtering system. $(CoFe_2)O_x$ film was deposited from an alloy target of $CoFe_2$ (99.9%) in an Ar–O_2 atmosphere with pressure ratio of $O_2/Ar = 0.1$ at an RF power of 50 W. The base pressure was 2.5×10^{-7} mbar, and the total sputtering pressure was 8.0×10^{-4} mbar. The thickness of $(CoFe_2)O_x$ film was controlled to 20 nm by the duration of sputtering. After deposition, the PS spheres were removed by sonication in 100% ethanol for 3 min.

The surface morphology of the oxide antidot arrays was imaged by a SEIKO SPA-300 HV atomic force microscope (AFM) in tapping mode. The oxide antidot arrays were also annealed in air for 2 h at 700 °C. The microstructure was analyzed by grazing incidence angle X-ray diffraction (XRD) (X'Pert Pro, Philips), and the magnetic property was measured by a BHV-50 vibrating sample magnetometer (VSM) from Riken Denshi Co.

3. Results and discussion

The usual way of reducing the PS latex sphere diameter is thinned by RIE in O_2 atmosphere [12]. Sputtering of certain compounds, or sputtering targets at oxygen environments, has been found to generate large quantities of negative ions [14]. Those negative ions resputter the film/substrate and cause the composition of the deposited films to be quite different from that of the target [15]. When fabricating an oxide film through sputtering the oxide target or metal/alloy target in oxide gas, the negative oxygen ions are produced at the target and accelerated to the full dark space potential. Subsequently, the ions are quickly neutralized in the plasma region and drift toward the substrate to sputter the film/substrate. Therefore, it is possible to fabricate the antidot arrays with sputtering technology directly combining with NSL.

Fig. 1 is a typical AFM image of oxide antidot arrays at low sputtering pressure after lifting off the PS latex sphere. As shown in the figure, the latex particles are arranged in the 2D hexagonal structure. Due to the reactive sputtering in O_2 gas, there are negative oxygen ions in the sputtering

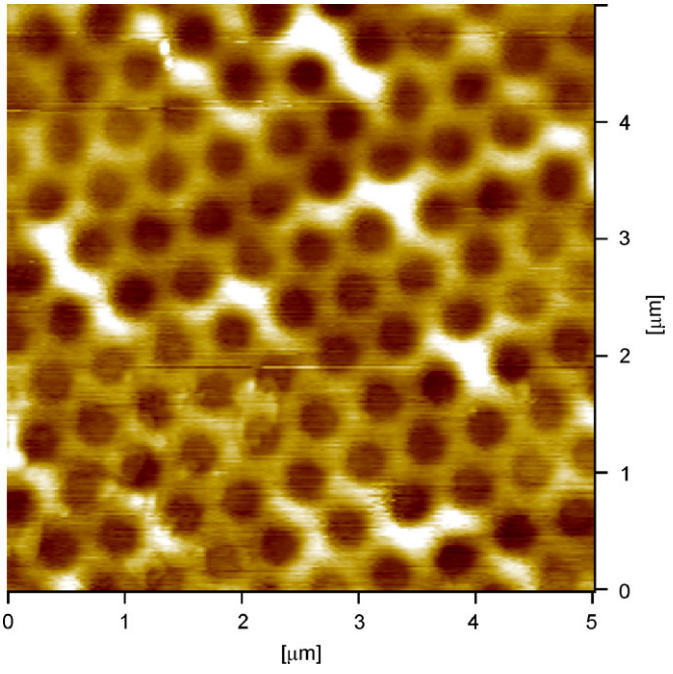

Fig. 1. AFM image of the $(CoFe_2)O_x$ antidot arrays fabricated by combining nanosphere lithography with sputtering in oxygen environment.