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Investigation of particle formation and superstructure development in FePt nanoparticles and their effect on magnetic properties

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Abstract

FePt nanoparticles with perpendicular magnetic anisotropy embedded in non-magnetic matrices M (M = Ag, C) have been fabricated by sputtering FePt/M multilayer films onto single crystal MgO [0 0 1] at temperatures above 300 °C. Particles with controlled particle size down to a few nanometers and tailored microstructure and magnetic properties can be obtained by varying the bilayer thicknesses, the substrate temperature, the type of substrate material and the post-annealing conditions. Ordered FePt nanoparticles have also been prepared directly by gas phase condensation techniques (cluster gun).The cluster gun allows a better control of particle size and distribution, and enables an in situ heat treatment of the particles to transform their structure into the desired phase before they are deposited onto the substrate, thus avoiding the undesirable effects of alloying and oxidation.

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Keywords: FePt nanoparticles; Magnetic recording media; Annealing temperature

1. Introduction

FePt nanoparticles with the $L1_0$ phase are excellent candidates for ultra-high density magnetic recording because of their high magnetocrystalline anisotropy (K_1 equals 6.6×10^7 ergs/cm^3 for bulk FePt) which makes them thermally stable

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down to a particle size of 2.5 nm [1–4]. Particles with a size less than 7 nm, a uniform particle size distribution and preferred out-of-plane texture are desirable for magnetic recording applications. Conventionally FePt nanoparticles embedded in different matrix material M (M = Ag, BN, C, etc.) have been fabricated by a sputtering technique using multilayer precursors, followed by subsequent annealing in order to transform the FePt nanoparticles from the disordered FCC phase to the ordered $L1_0$ phase. The particle size and the degree of atomic ordering can be controlled by adjusting the FePt to M ratio as well as the annealing conditions [2–5]. Films fabricated with this method showed low coercivity as compared to those predicted by the Stoner–Wohlfarth model for isolated non-interacting single domain particles, indicating that the particles have a low atomic ordering after the short annealing at high temperatures (which was done purposely) in order to keep the size small. Certain matrix materials (Ag, B_2O_3, C) and special bilayer thickness are usually required in order to obtain particles with a perpendicular texture [6–8]. FePt nanoparticles sputtered onto heated substrates, on the other hand, showed a much higher atomic ordering and when deposited onto single crystal substrate such as MgO [0 0 1], the FePt nanoparticles can epitaxially grow with their *c*-axis perpendicular to the film plane. The temperature needed for the disorder–order transformation is about 500 °C for FePt and can be reduced to about 300 °C by the addition of small amounts of other elements (such as Au and Ag) [9–12].

FePt nanoparticles have also been prepared using other techniques. Chemical synthesis has created arrays of FePt nanoparticles with tunable size and very narrow particle size distribution (standard deviation less than 5%) [13,14]. A relatively lower transformation temperature was also observed when annealed under forming gas [14,15]. However, it is still a challenge to create particles with preferred texture using this synthesis technique. Recently, electrodeposition and ion irradiation have also been reported to prepare FePt nanoparticles with perpendicular texture [16,17].

In this paper, $L1_0$ FePt nanoparticles have been prepared by both sputtering FePt/M (M = C, Ag) onto heated MgO substrates and by gas condensation using a heater stage to transform the as-made FCC particles to the $L1_0$ phase. The formation of FePt nanoparticles and the structure transformation from the disordered FCC to the ordered $L1_0$ phase will be discussed.

2. Experimental details

(FePt/Ag) and (FePt/C) multilayers were fabricated by DC magnetron sputtering onto heated MgO [0 0 1] substrates using $Fe_{50}Pt_{50}$, Ag and C targets. The base pressure of the chamber was 2×10^{-7} Torr and a high purity Argon gas flow with a pressure of 5 mTorr was used during sputtering. The substrate was attached to a ceramic heater with adjustable temperature up to 650 °C. FePt/Ag thin films with different bilayer thickness ($t_{FePt} = 1$–10 nm) were sputtered in order to study the effect of film thickness as well as the effect of Ag addition on the magnetic and structural properties of the films. A 20 nm Carbon capping layer was sputtered on all the samples in order to protect them from oxidation.

FePt nanoparticles have also been prepared using a gas condensation process by DC magnetron sputtering in a high Ar gas pressure with typical values of 200–1000 mTorr. The particles were then released to the main chamber (with a pressure of 5 mTorr) through a small orifice on top of the cluster gun towards a water-cooled Si substrate. Heating of the particles was performed in the main chamber by four 260 W quartz halogen lamps.

The magnetic hysteresis loops were measured with a SQUID magnetometer. The structure of the films was examined with a Philips CM20 X-ray diffraction unit and the microstructure by a Jeol JEM-3010 TEM transmission electron microscope.

3. Results and discussion

3.1. FePt films on MgO single crystal substrates

Due to a similar lattice parameter between FePt ($a = 0.38, c = 0.37$ nm) and MgO ($a = 0.42$ nm),