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Atomic ordering and magnetic properties of polycrystalline $L1_0$-FePd dot arrays

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ABSTRACT

The polycrystalline $L1_0$-FePd (0 0 1) films considering a highly ordered dot array with various sizes have been successfully prepared by using a microfabrication process. The lateral size of square dots was changed in between 1 and 10 μm. The coercivity (H_c) of patterned $L1_0$-ordered FePd films was found to be slightly reduced compared to that of continuous film. Furthermore, H_c was slightly decreased after annealing at 500 °C. In the pinning mechanism, H_c can be determined by strong pinning sites for domain walls, which are the grain boundary regions in $L1_0$-ordered polycrystalline FePd films. These results indicate that the dot size dependence of H_c before and after annealing may be related to the pinning mechanism. The long-range ordering parameter (S) was increased after annealing. This demonstrates that post-annealing accelerates $L1_0$-FePd ordering, but there is no clear correlation between S and H_c.

1. Introduction

Currently, the most important issue in developing ultra high density of magnetic recording media is how to increase the areal storage density, i.e. the number of bits per in^2, and thermal stablity. In order to achieve beyond Tbit/in^2, it was required to develop a recording media with smaller particles [1]. However, a thermal fluctuation of magnetization becomes serious as the reduction of the bit size (superparamagnetic limit). One of the possible solutions is to use a high magnetic anisotropy material. Accordingly, $L1_0$-ordered FePt and FePd films have been recently paid attention for a magnetic recording media because of their high uniaxial magnetic anisotropy [1]. Highly ordered $L1_0$-FePt and FePd films can be deposited with an anisotropy axis perpendicular to the film plane that makes them suitable for the application of high density magnetic recording. Therefore, there have been many reports on high magnetic anisotropy of $L1_0$-FePt [2–4]. However, because the $L1_0$ ordering of FePd forms at a temperature lower than that in FePt, $L1_0$FePd may be more preferable for the application of magnetic recording media [5]. Recently, nanoscale patterned and particulate magnets are considered as one of the methods for ultra high density of magnetic recording media. In particular, the development of the microfabrication techniques enables us to fabricate the magnetic dot array with well-defined geometry. There are a number of research works on investigating the magnetic properties of FePt dots [6–13]. Furthermore, it is of great interest to study the coercivity and magnetic reversal mechanism in nanocrystalline films.

In this paper, a possible coercivity mechanism of polycrystalline FePd continuous film and dot arrays was discussed. The polycrystalline $L1_0$-FePd (0 0 1) dot arrays with various dot sizes were fabricated on MgO (0 0 1) substrates by using the microfabrication process. The magnetization process in the dot arrays was compared with that of continuous film. In addition, the effect of post-annealing on the magnetic properties was investigated.

2. Experimental procedure

FePd alloy thin films were deposited on MgO (0 0 1) substrate using DC magnetron sputtering system. The basic pressure during sputtering was kept below 5×10^{-7} Torr and the Ar working gas was controlled at 15 mTorr. A Fe layer of 1 nm and an epitaxial Cr (0 0 1) layer of 30 nm were deposited prior to depositing FePd alloy as a seed and a buffer layer, respectively. Monoatomic layers

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of Fe (1.4 Å) and Pd (1.9 Å) were deposited alternately at 350 °C on the Cr (0 0 1) buffer layer. The repetition of both Fe and Pd layers was 89 times. The layer structure was MgO/Fe/Cr/[Fe/Pd]$_n$/Pd. The film composition was determined at $Fe_{48}Pd_{52}$ by energy dispersive X-ray spectrometer (EDS). In a previous paper, it was reported that $Fe_{48}Pd_{52}$ films showed a large perpendicular magnetic anisotropy [5].

The microfabrication of FePd films was carried out by using electron beam lithography (EBL) and Ar ion etching. A negative resist (TGMR) was spin-coated on the thin film, which was patterned into the dot array by EBL. The sample was etched through the patterned resist by Ar ions. The shape of dots was square, and the lateral size of dots was changed between 1 and 10 μm. The distance between dots was the same as the lateral size of dots. The dot arrays were annealed at $T_{ann}=500$ °C for 2 h in a high vacuum atmosphere.

The crystal structure of FePd alloy for continuous film and patterned dot arrays were analyzed by X-ray diffractometry (XRD) with Cu-Kα radiation. The magnetic properties were characterized by magneto optical Kerr effect (MOKE).

3. Results and discussion

3.1. FePd dot arrays

Fig. 1 shows a typical scanning electron microscopy (SEM) image for FePd (0 0 1) dots with a 1 × 1 and a 5 × 5 μm^2 sizes. As can be seen in Fig. 1, it was confirmed that the patterned dot arrays have a well-defined geometry. And it shows that polycrystalline FePd dots were formed as shown in the inset of Fig. 1(a).

Fig. 2 shows XRD patterns for (a) FePd continuous film and FePd (0 0 1) dots with sizes (b) 1 × 1 μm^2, (c) 5 × 5 μm^2, and (d) 10 × 10 μm^2. It was verified that FePd (0 0 1) superlattices were well grown on MgO (0 0 1) substrate. Furthermore, it was clearly observed that all the samples have FePd (0 0 2) peaks. This implies that FePd dot arrays have a strong $L1_0$-ordered phase after microfabrication. The intensities of superlattice peaks for as-patterned arrays were smaller than those for the continuous film. The long-range ordering parameter (S) is determined from the ratio of the integrated intensities of superlattice to fundamental peaks giving $S=0.71$–0.75 for as-patterned arrays and $S=0.80$ for continuous film (see Table 1). In spite of reducing the $L1_0$ ordering due to structural defects caused by microfabrication, S did not change significantly.

Kerr hysteresis loops for $L1_0$-FePd continuous film and dot arrays are shown in Fig. 3 (a–d), respectively. The symbol θ_K is generally used for Kerr rotation angle. The coercivity (H_c) for as-patterned arrays was slightly decreased compared to that of continuous film. Fig. 3 shows that H_c decreases with the decrease of the dot size. It is considered that pinning mechanism results in decrease of H_c.

In the case of nucleation-type magnetization process, H_c is determined by the distribution of nucleation sites and the nucleation fields generate a reversed domain at each nucleation site. Once a reversed domain appears in a continuous film, the domain wall propagates all over the film resulting in the decrease in H_c. In polycrystalline thin films, the grain boudary can be strong pinning sites for suppressing the domain wall propagation.

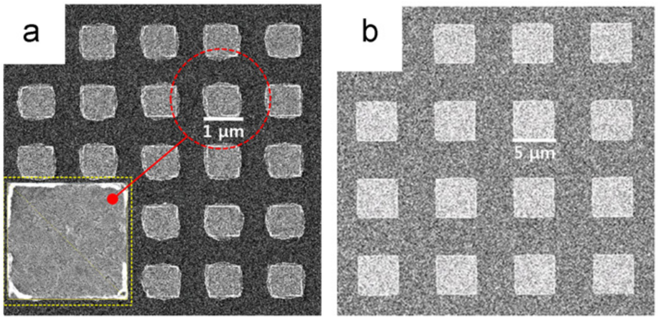

Fig. 1. SEM images for FePd dot arrays with sizes of (a) 1 × 1 μm^2 and (b) 5 × 5 μm^2. Inset in (a) is a magnified image of circled region.

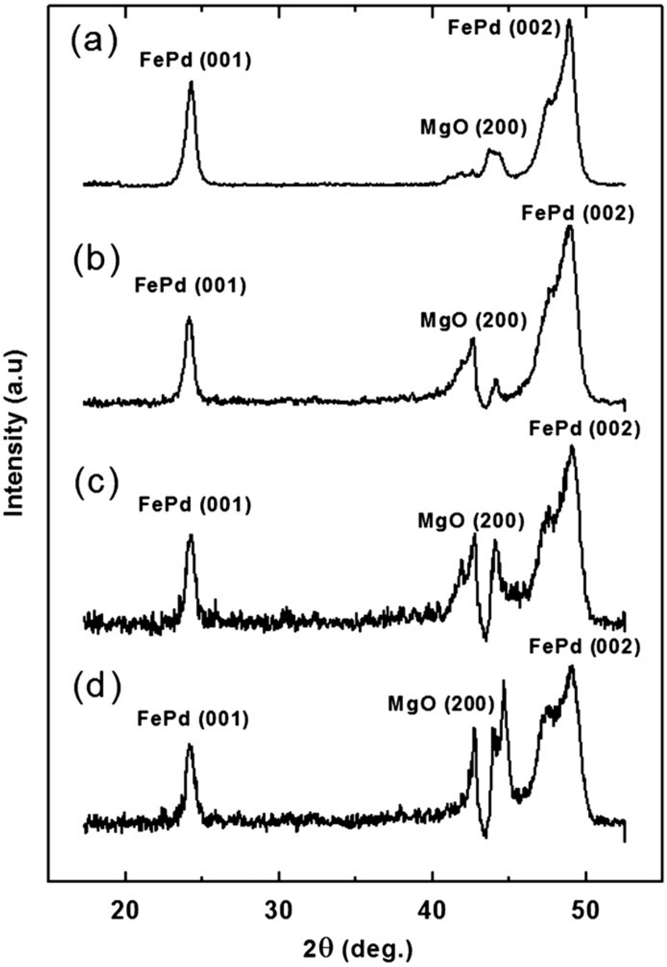

Fig. 2. XRD patterns for FePd continuous film and dot arrays: (a) continuous film, (b) 1 × 1 μm^2, (c) 5 × 5 μm^2, and (d) 10 × 10 μm^2.

Table 1
The long-range ordering parameter (S) and the coercivity (H_c) for FePd continuous film and dot arrays before and after annealing.

	Before annealing		After annealing	
	S	H_c (Oe)	S	H_c (Oe)
Continuous film	0.80	1613	0.95	1086
$L1_0$-FePd dot size 1 μm	0.71	938	0.98	565
$L1_0$-FePd dot size 5 μm	0.75	1391	0.85	950
$L1_0$-FePd dot size 10 μm	0.75	1402	0.91	787