ENHANCEMENT OF $L1_0$ ORDERING IN ELECTRODEPOSITED FePt NANODOT ARRAYS

S. WODARZ[1], S. HASHIMOTO[1], M. KAMBE[1], G. ZANGARI[2], and T. HOMMA[1]

[1] Waseda University, Tokyo, Japan, t.homma@waseda.ne.jp

[2] University of Virginia, Charlottesville, USA, gz3e@eservices.virginia.edu

I. INTRODUCTION

Electrodeposition processes have been widely used to fabricate magnetic thin films and micro/nano structures. In this work, we have attempted to utilize this process to fabricate ferromagnetic nanodot arrays [1] by combining electron beam lithography (EBL) and electrodeposition for use in bit patterned media (BPM) [2]. The equiatomic FePt alloy with $L1_0$ order phase has been considered as one of the most promising candidates for use in BPM due to its high magnetocrystalline anisotropy, K_u [3], which enables recording density beyond several Tbit/in^2. In previous work, we have succeeded in achieving structural ordering and magnetic hardening of electrodeposited FePt films [1], however, high temperature annealing up to 650 ºC was needed for the phase transition to $L1_0$ ordered structure, which caused degradation of uniform geometry of nanodot arrays; lowering of annealing temperature of FePt was therefore strongly needed to enhance the $L1_0$ ordering. In order to solve this problem, in this work, we have attempted to fabricate uniform $L1_0$-FePt nanodot arrays by synthesizing a multilayer FePt structure [4] and FePt-Cu alloy structure [5] to enhance the ordering process of FePt under lower annealing temperature or heating time requirements.

II. EXPERIMENTAL METHODS

Nanopore patterned substrates were prepared by EBL, which has a high resolution for fabricating single nanometer-sized pores onto sputter deposited Ru (60 nm thick) / Ti (5 nm thick) / n-Si (100) substrate. Electrodeposition of FePt was carried out into the nanopores to fabricate nanodot arrays with 15 nm diameter and 35 nm pitch under the conditions summarized in Table 1. Post annealing treatment of deposited FePt was carried out using a rapid thermal annealing system under forming gas (Ar 90 % and H_2 10 %). The multilayer structure consisted of Fe- and Pt-rich layers with various thickness, deposited sequentially in the same electrolyte by changing the applied potential and deposition duration for each layer; pulse deposition of Fe- and Pt-rich layer was performed with -1.4 and -0.8 V (vs. Ag/AgCl), respectively. Single layer FePt films were deposited with constant potential of -1.0 V (vs. Ag/AgCl). For the fabrication of FePt-Cu alloy, $CuSO_4$ was added into the bath condition of Table1. The composition of FePt-Cu alloy was controlled with applied potential and concentration of $CuSO_4$ to achieve near-equiatomic composition of (FeCu)Pt and Cu composition of 20-30 at%.

III. RESULTS AND DISCUSSION

To investigate the phase transformation of the multilayer and single layer FePt films, crystal structure of 20 nm-thick films was characterized after annealing at 450 ºC for 1 h by x-ray diffraction (XRD). Upon annealing, single layer film showed no peaks of $L1_0$ structure, whereas multilayer films showed (111), (200), and (001) peaks of $L1_0$ structure. To further investigate the phase transformation, degree of $L1_0$ ordering of the annealed films was evaluated from the lattice constant of c-axis from XRD patterns. The c-lattice constants of multilayer and single layer films were evaluated to be 3.62 and 3.74 Å, respectively upon annealing at 450 ºC, which suggested the enhancement of $L1_0$ ordering in multilayer structure to shrink the c-lattice constant. In addition, the out-of-plane coercivity of multilayer film after annealing at 450 ºC was 6.6 kOe, whereas single layer film showed 1.0 kOe. Furthermore, coercivity increased up to 9.0 and 12.3 kOe for multilayer and single layer upon annealing at 650 ºC, suggesting that the phase transformation and magnetic hardening was strongly facilitated in the multilayer structures. Based on these

Takayuki Homma
E-mail: t.homma@waseda.ne.jp
Tel: +81-3-5286-3209

results, fabrication of FePt nanodot arrays with multilayer structure was attempted by depositing FePt into nanopore patterned substrate with 15 nm diameter and 35 nm pitch, and uniform nanodot arrays without deterioration were successfully formed after post annealing process. Furthermore, phase transformation of nanodot arrays was successfully achieved to form FePt nanodot arrays with $L1_0$ structure; a TEM image shows uniform fringes in the perpendicular direction from the substrate without grain boundaries (Fig. 1), suggesting a formation of a single crystal.

Subsequently, enhancement of $L1_0$ ordering was attempted by addition of Cu to form FePt-Cu alloy. Upon annealing at 450 ºC, XRD patterns of FePt-Cu showed peaks of $L1_0$ structure, and (001) peak shifted to higher 2θ angle compared to FePt alloy, which provides evidence of FePt-Cu alloying. In addition, magnetic hardening was observed with FePt-Cu films upon annealing at 450 ºC, whereas the binary alloy showed no magnetic hardening under annealing at 450 ºC. Furthermore, coercivity of FePt-Cu films increased up to 6.0 kOe by controlling the c/a lattice ratio with optimization of the alloy composition. In addition, fabrication of FePt-Cu nanodot arrays with single crystal of $L1_0$ structure was successfully demonstrated due to the facilitation of $L1_0$ ordering by addition of Cu. These results demonstrate successful fabrication of uniform $L1_0$-FePt nanodot arrays with Tbit/in^2 level density, by applying a multilayer structure or addition of Cu to enhance the $L1_0$ ordering.

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Table 1 Electrodeposition conditions

Chemicals	Concentration / mM
$(NH_4)_2C_6H_6O_7$	150
$Fe_2(SO_4)_3$	50
NH_2CH_2COOH	150
$NaNO_2$	100
$(NH_4)_2SO_4$	100
$Pt(NO_2)_2(NH_3)_2$	15
Bath temperature	75 °C
pH	8
Reference electrode	Ag / AgCl
Counter electrode	Pt mesh

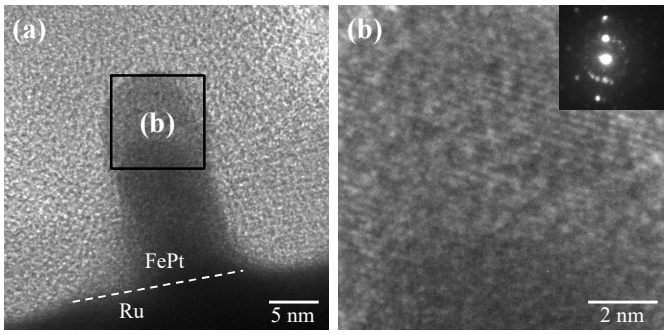

Fig. 1 Cross-sectional TEM image of FePt nanodot arrays with 15 nm diameter and 35 nm pitch. (a) low magnification and (b) high magnification image. Inset shows selective area electron diffraction of nanodot.