1-17-2008

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Nanostructure and magnetic properties of $L1_0$ FePt:X films

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(Presented on 7 November 2007; received 13 September 2007; accepted 11 October 2007; published online 17 January 2008)

Nonepitaxial FePt:X films (X=Cu, Au, CuAu) with tunable magnetic properties are fabricated and investigated. Emphasis is on controlling and adjusting the magnetic properties of high-density perpendicular recording media through exchange decoupling and anisotropy. The films are initially deposited as multilayers with the structure $[\mathrm{FePt}/X]_n$ and have individual thicknesses from about 0.06 to 1.1 nm. To create an (001)-oriented granular $L1_0$ structure, the films are then annealed at temperatures of 600 °C for 5 min and 550 °C for 10 min. The data indicate that Cu enters the $L1_0$ lattice whereas Au segregates at the grain boundaries and reduces the intergranular exchange coupling. For X=CuAu, we obtain coercivities H_c below 10 kOe, and slopes $\alpha=(dM/dH)_{H_c}$ of about 1. For X=Cu, we find a favorable reduction in Curie temperature and H_c. © *2008 American Institute of Physics*. [DOI: 10.1063/1.2830556]

I. INTRODUCTION

The $L1_0$-ordered phase of FePt is a candidate for perpendicular magnetic recording media with areal densities in excess of 1 Tbit/in.^{2}, due to its large magnetocrystalline anisotropy ($K_u \approx 7\times10^7$ ergs/cm^3) and to its chemical inertness relative to rare-earth options.[1] However, FePt deposited on a substrate at ambient temperature is found in a metastable $A1$ phase which then requires thermal processing to achieve the desired $L1_0$ phase and (001) texture. Once formed, the coercivity or saturation field of fully ordered $L1_0$ FePt can be in the range of 10–20 kOe, normally well beyond the range of standard write heads.[2] Controlling the coercivity, the easy-axis orientation and the grain/cluster size and exchange coupling are important issues that must be addressed before FePt can be viable in recording media.[3]

Previous work has shown that the $L1_0$ FePt grain size can be controlled by alloying FePt with materials such as AlO_x, MgO, C, Ag, and Au or by cluster deposition.[4–9] Materials such as Au and Al_2O_3 also act to segregate and magnetically decouple the FePt grains.[5,9] Control of the magnetic easy axis has been done using epitaxial growth, where the film is deposited on a heated substrate, usually MgO,[10] or nonepitaxial multilayer techniques, where the Fe and Pt, or FePt and a third material, are alternately deposited on an amorphous substrate held at ambient temperature.[11] A method to counter the high coercivity of these films is that of heat-assisted magnetic recording (HAMR),[12] in which a laser locally heats the area to be written to or below the material's Curie temperature T_C, thereby lowering its coercivity. After the write process the bit is allowed to cool and regain its high coercive field, stabilizing the magnetization. A relatively low T_C is beneficial for this process to be effective and practical.[13]

In this paper, we report on FePt:X films, where X=Cu, Au, and CuAu are made using two different preparation methods. The FePt:Au and FePt:CuAu samples are nonepitaxially sputtered whereas the FePt:Cu films are made via deposition of gas-aggregated FePt clusters with alternating layers of Cu. The FePt:CuAu films are motivated by the need to control the coercivity and the intergranular magnetic coupling in FePt films. Au is shown to increase the coercivity H_c while decreasing magnetic coupling. Conversely, Cu has been shown to decrease H_c (Ref. 14) as it effectively reduces magnetocrystalline anisotropy[15] by substituting for Fe in the $L1_0$ lattice.[16,17] Cluster-deposited FePt:Cu films exhibit a decrease in H_c, M_s, and T_C with increased Cu content.

II. EXPERIMENTAL METHODS

The FePt films alloyed with Au and CuAu were magnetron sputtered onto Si substrates at ambient temperature from a $Fe_{49}Pt_{51}$ composite target and 99.99% pure Au and Cu elemental targets. Initial chamber conditions were 4×10^{-7} Torr and Ar pressure during deposition was 4 mTorr. Individual layer thicknesses in the FePt:Au system were 0.5 nm FePt and 0.06–0.24 nm Au. For the two FePt:CuAu films, layer thicknesses were 1.1 nm for FePt, 0.06 nm for Au, and 0.06 or 0.18 nm for Cu. Total film thicknesses were held at 10 nm. Postdeposition annealing of the as-deposited multilayers was necessary to form the $L1_0$ phase. All films were annealed at 600 °C in a rapid-thermal annealing (RTA) oven with 5% H_2 in Ar forming gas.

The FePt clusters were formed with a sputtering-based gas-aggregation source.[18] The chamber Ar flow pressure was 0.5 Torr. The nominal thickness of the FePt layer is 1 nm with cluster size of about 5 nm in diameter. This implies a partial occupancy of the clusters in FePt layers. The thickness of Cu was adjusted to obtain volume fractions of 5%, 10%, 20%, and 30%. The as-made FePt:Cu cluster films were annealed in a RTA oven at 550 °C for 10 min under an Ar gas flow.

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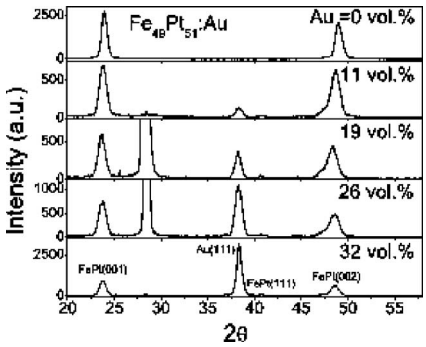

FIG. 1. XRD spectra of FePt:Au films as a function of Au content.

X-ray diffraction was performed using a Bruker-AXS D8 Discover system using Cu $K\alpha$ radiation (λ_{av} =1.54184 Å). The magnetic properties were measured in a superconducting quantum interference device (SQUID) in fields up to 7 T, and the magnetic coherence lengths were estimated by magnetic force microscopy (MFM).

III. RESULTS AND DISCUSSION

Figure 1 shows the XRD data highlighting the $L1_0$ (001) superlattice and (002) fundamental diffraction peaks indicating an alignment of the c axis perpendicular to the film. The (111) peak for both Au and FePt becomes more prominent as the volume percentage of Au increases. The appearance of the Au peak indicates the presence of elemental Au in the sample which is consistent with works done by Yuan *et al.*[19] and Barmak *et al.*[20] showing that Au segregates to the grain boundaries in FePt films. The FePt (111) peak is indicative of the degradation of (001) texturing. A measure of the (001) rocking curve supports loss of (001) texture as the full width at half maximum (FWHM) increases from 3.25° to 4.25° with increasing Au.

Figure 2 shows an increase in H_c and a decrease in magnetization M_s with increase in Au content. The decrease in M_s is caused by dilution effects, although the change in slope at 19 vol % is not clear. The increase in H_c with Au content is likely due to exchange decoupling of FePt grains by the intergranular Au.[4] MFM was used to measure approximate magnetic coherence lengths as a function of vol % Au which is shown in Fig. 3. Figure 3 also shows the trend of the parameter α, which is the slope of the hysteresis curve $(4\pi dM/dH)$ taken at H_c. The decreases of both coherence

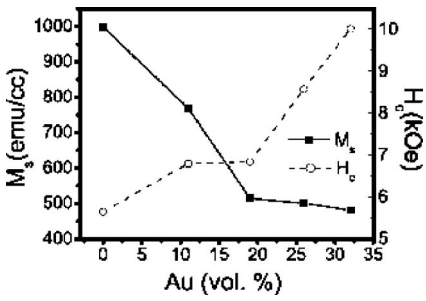

FIG. 2. H_c and M_s of FePt:Au films as a function of Au content.

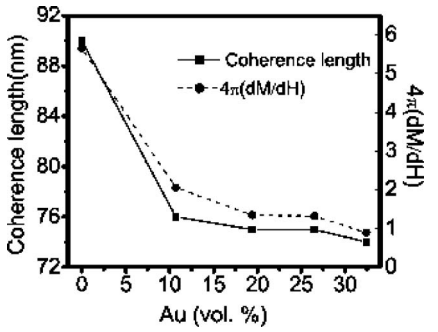

FIG. 3. Coherence length and slope α for FePt:Au films ($\alpha=4\pi dM/dH$ at H_c).

lengths from 90 to 74 nm and α from 5.7 to 0.89 with increasing Au content again are consistent with decreasing exchange coupling of FePt grains.

Two samples of FePt:CuAu were deposited both with $Fe_{49}Pt_{51}$ and vol % of Au around 5, but with the vol % of Cu equal to 5 or 13. The shift in x-ray peaks for these samples is consistent with Cu substituting into the FePt lattice.[16] Using the Scherrer equation on in-plane XRD data gives lateral grain sizes of ~7 nm. Figure 4 shows the out-of-plane hysteresis loop for the sample with 13 vol % Cu. As the Cu content increased, M_s was found to decrease, which is consistent with dilution effects. The value of α remains constant at ~1.1 indicating grains that are fairly well exchange decoupled in both of the samples. This is likely due to the intergranular Au. The additional of 8 vol% Cu lowers H_c from 11.8 to 9.53 kOe. Clearly, by adding Cu and Au to FePt films we are able to decrease the intergranular exchange coupling and to control H_c.

From XRD data for the cluster-deposited FePt:Cu films (not shown), we see that even at 30 vol %, after annealing at 550 °C for 10 min, there are no signs of Cu peaks. This, along with the downward trend of H_c with Cu content, shown in Fig. 5, indicates that Cu is being incorporated into the $L1_0$ lattice. Substitution of Cu for Fe would explain the decrease in H_c. Figure 6 shows the Curie temperature as function of the Cu vol %. The decrease of T_C is in agreement with trends found by Berry *et al.*[21] for sputtered thin films of FePt:Cu. We have performed mean-field calculations of T_C for systems of this type, investigating both a random solid solution of the Cu atoms in the Fe planes or an ordered

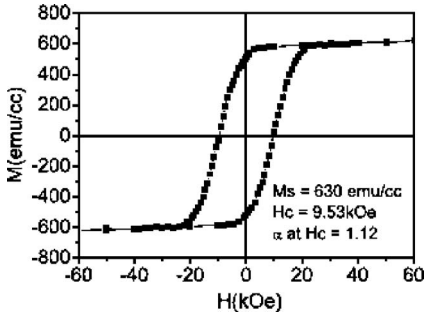

FIG. 4. SQUID hysteresis loop for $Fe_{49}Pt_{51}$ with 10 vol. % Au and 13 vol. % Cu.

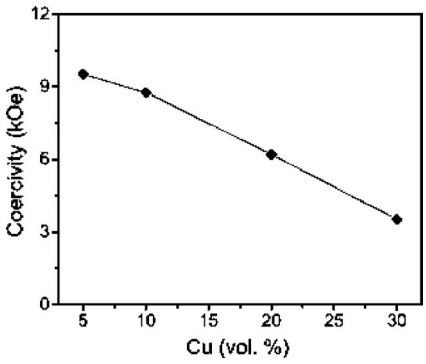

FIG. 5. Coercivity as a function of Cu content for cluster-deposited FePt:Cu.

Fe–Cu arrangement as in $FeCuPt_2$. The results, to be reported elsewhere, suggest that the experimental system may exhibit a degree of order in the Fe and Cu sites.

In summary, we have shown that the $L1_0$ FePt system can be modified by alloying with Au, Cu, or CuAu, resulting in a degree of control over anisotropy, coercivity, exchange coupling, and Curie temperature.

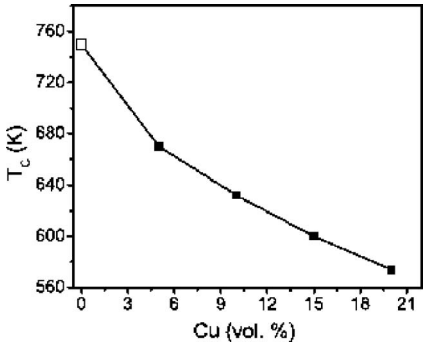

FIG. 6. Measured Curie temperature as a function of vol.% Cu. Open square data point from Ref. 12.

ACKNOWLEDGMENTS

We are grateful for financial support to NSF-MRSEC (DMR 0213808), INSIC, and NCMN.

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