April 2006

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Yan, M.L.; Xu, Yinfan; and Sellmyer, David J., "Nanostructure and magnetic properties of highly (001) oriented $L1_0$ $(Fe_{49}Pt_{51})_{1-x}Cu_x$ films" (2006). *David Sellmyer Publications*. 1.
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JOURNAL OF APPLIED PHYSICS **99**, 08G903 (2006)

Nanostructure and magnetic properties of highly (001) oriented $L1_0$ $(Fe_{49}Pt_{51})_{1-x}Cu_x$ films

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(Presented on 1 November 2005; published online 18 April 2006)

We report on nonepitaxially grown $L1_0$ Cu-alloyed FePt thin films with strong (001) texture. The FePt films with different Cu contents were deposited directly on Si wafers with a $Fe_{49}Pt_{51}/Cu$ multilayer structure. The Cu content was varied from 0 to 13 at. %. All films were annealed at 600 °C for 5 min. X-ray-diffraction characterization showed that only one set of $L1_0$ diffraction peaks appeared and no elemental Cu diffraction peaks were visible. This result, along with a varying c/a lattice-parameter ratio, suggests that Cu substitutes Fe or Pt in the $L1_0$ lattice and ternary FePtCu alloy films are formed. (001) texture was enhanced with the increase of Cu content. Transmission electron microscope images showed that the grain size of FePtCu was about 10 nm. For FePt film with 11 at. % Cu substitution, coercivity was about 5 kOe, which is suitable for writing in a practical perpendicular-recording film. © *2006 American Institute of Physics*. [DOI: 10.1063/1.2164428]

INTRODUCTION

Areal densities in magnetic recording have been increasing at such a rapid rate that 1 $Tbit/in^2$ densities are now targeted. $L1_0$-phased FePt films have generated much interest for use as a high-density perpendicular magnetic recording medium due to their high magnetocrystalline anisotropy ($K_u \sim 7\times 10^7$ erg/cm^3).[1] Up to now, FePt films have not been used as a practical perpendicular magnetic recording medium because of perpendicular orientation, grain size, and magnetic properties. In addition, these films require a rather high-temperature annealing to transform the FePt films from disordered phase (face-centered cubic) to ordered phase (face-centered tetragonal), if the FePt films are deposited at ambient temperature. In order to solve these problems and obtain suitable properties for perpendicular magnetic recording media, the additions of third elements to FePt have been explored. For example, C, Ag, Cu, Au, and Ni additives have been reported.[2–10] In particular, $L1_0$ FePt films with Cu additive attracted significant attention. Several authors focused on investigations of the ordering transformation temperature.[4–9] Other properties, such as coercivity,[4] stress,[7] and Curie temperature[9] were also reported. We have introduced a technique for fabricating small-grain, well-oriented $L1_0$ FePt-based nanocompsite films without the use of epitaxial growth.[2,3,10–12] In this paper, we report on Cu-alloyed, nonepitaxially grown $L1_0$ FePt thin films with strong (001) texture and effects of Cu content on orientation, lattice parameters, magnetic coherence length, and magnetic properties.

EXPERIMENT

All films in this study were deposited with dc magnetron sputtering by depositing directly onto Si(111) wafers with a 100 nm thermally oxidized SiO_2 layer. The substrate was nominally held at room temperature. A pure Cu target and a Pt target with Fe chips on it were used to prepare samples with the $Si/SiO_2/[FePt/Cu]_n$ multilayer structure. No other buffer layer and seed layer were used. The Cu content was varied from 0 to 13 at. % by changing the initial Cu layer thickness. The sputtering pressure was 4 mTorr. The deposition rates for FePt and Cu were about 0.5 Å/sec. All film thicknesses were 12 nm, which was achieved by adjusting the number of multilayeres n. After the deposition, the samples were annealed by rapid thermal annealing (RTA) at 600 °C for 5 min. The atomic ratio of Fe:Pt was determined to be 49:51 by energy dispersive x-ray spectroscopy (EDX). The crystal structures were characterized by x-ray diffraction (XRD). The magnetic properties were measured with a superconducting quantum interference device (SQUID), in fields up to 7 T. Magnetic coherence length was estimated by magnetic force microscopy (MFM) in thermally demagnetized films. Grain size was estimated by transmission electron microscopy (TEM).

RESULTS AND DISCUSSION

Figure 1 shows XRD patterns for $(Fe_{49}Pt_{51})_{1-x}Cu_x$ ($x=0$, 1, 3, 5, 7, 9, 11, and 13 at. %). All samples were annealed at 600 °C for 5 min. For the sample with $x=0$, i.e, the $Fe_{49}Pt_{51}$ film, the XRD pattern showed mainly the (111) diffraction peak, indicating that the film was (111) textured. As the Cu content increased to 3 at. %, the intensities of $I_{(001)}$ and $I_{(002)}$ peaks increased, and the intensity of $I_{(111)}$ peak decreased. With further increase of Cu content, the trend in $I_{(001)}/I_{(111)}$ increased, and the (111) peak was almost invisible when $x=7$ at. %. Thus the increase of $I_{(001)}/I_{(111)}$ ratio reflected an enhancement of (001) orientation with an increase of the Cu content, at least up to 13 at. %. Figure 1 also shows that the positions of $(00l)$ peaks shift to the higher angle with an increase of Cu content, and no elemental Cu

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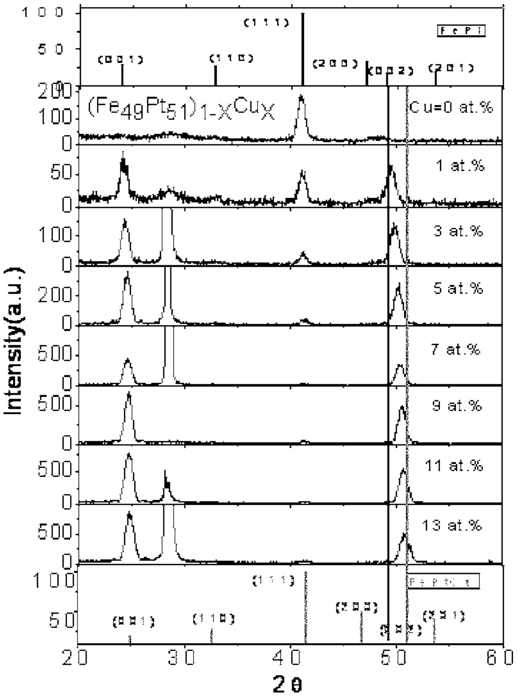

FIG. 1. XRD patterns of $(Fe_{49}Pt_{51})_{1-x}Cu_x$ films with different Cu content. All films were annealed at 600 °C for 5 min. The total film thickness is 12 nm.

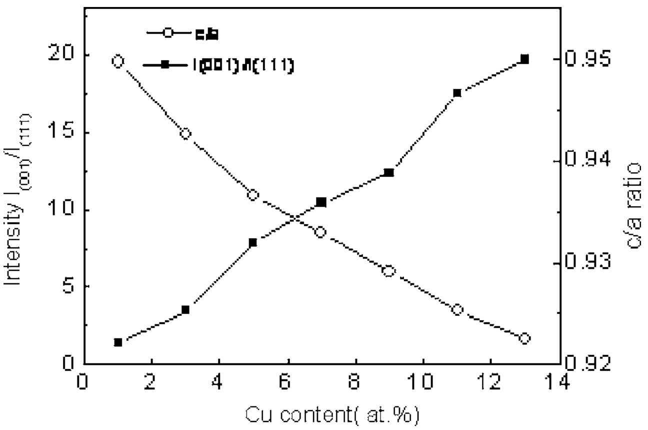

FIG. 3. Effects of Cu content on orientation and c/a ratio of $(Fe_{49}Pt_{51})_{1-x}Cu_x$ films. All films were annealed at 600 °C for 5 min. The total film thickness is 12 nm.

diffraction peaks are visible in the XRD patterns, even up to 13 at. %. This result indicates that Cu substitutes for Fe or Pt in the $L1_0$ FePt lattice to form an alloy with FePt. The same result has been reported by Platt *et al.*[5] and Maeda *et al.*[4] Platt *et al.* reported that Cu had limited solubility in Fe, but it formed stable alloy with Pt in the bulk.[5] Kai *et al.* reported that Cu atom was located in the Fe site in FePt ordered alloy through first-principles band calculations and ultraviolet photoelectron spectroscopy experiment.[13] From our experiments it was not possible to determine whether the Cu substituted for Fe or Pt in the $L1_0$ FePt structure. Further understanding of Cu atomic positions in the ordered $L1_0$ FePt alloy is needed.

From the positions of the (001), (002), and (111) XRD peaks, the average values for *a*- and *c*-lattice parameters were calculated for FePt films with Cu content. Figure 2 shows *a*- and *c*-lattice parameters and the c/a ratio for FePt films with Cu additive. For the bulk $L1_0$ FePt, *a*- and *c*-lattice parameters were reported as 3.852 and 3.713 Å, respectively.[14] The c/a ratio for the bulk FePt was 0.964. As shown in Fig. 2, when the Cu content is 1 at. %, the *a*-lattice parameter remained almost constant (3.586 Å) and the *c*-lattice parameter decreased to 3.675 Å, which gives the c/a ratio as 0.952. With the increase of Cu content, *c* shows a further decrease and *a* remains almost unchanged. When the Cu content was increased to 13 at. %, the *c* decreased to 3.589 Å, which gave the reduced c/a to approximately 0.922. This decreasing trend of c/a ratio in FePt films with Cu additive is similar to the reported results in the literature.[5,9]

Figure 3 shows the (001) texture development of FePt films by examining the trend of $I_{(001)}/I_{(111)}$ peak ratio as a function of Cu content. x=at. %, the ratio of $I_{(001)}/I_{(111)}$ was close to 1. As Cu content increases to 13 at. %, the ratio of $I_{(001)}/I_{(111)}$ increases to around 20. Figure 3 also shows that the c/a ratio decreases with the increase of Cu content. Clearly, Cu alloyed with FePt improves the (001) texture of $L1_0$ FePt.

Figure 4 shows the coercivity H_c variation of $L1_0$ FePt films with Cu content. As seen in this figure, coercivity H_c

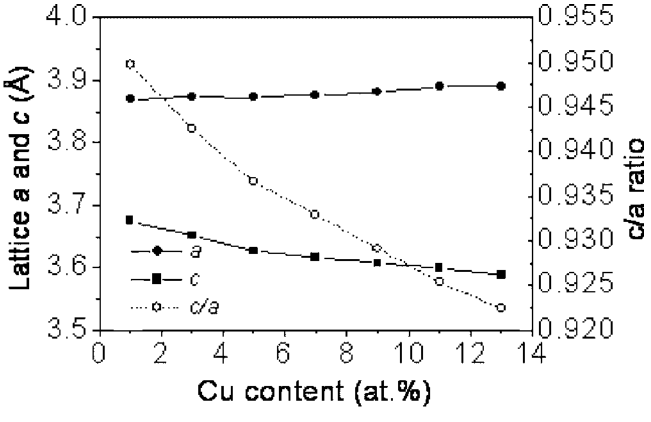

FIG. 2. *a*- and *c*-lattice parameters and c/a ratio of $(Fe_{49}Pt_{51})_{1-x}Cu_x$ films. All films were annealed at 600 °C for 5 min. The total film thickness is 12 nm.

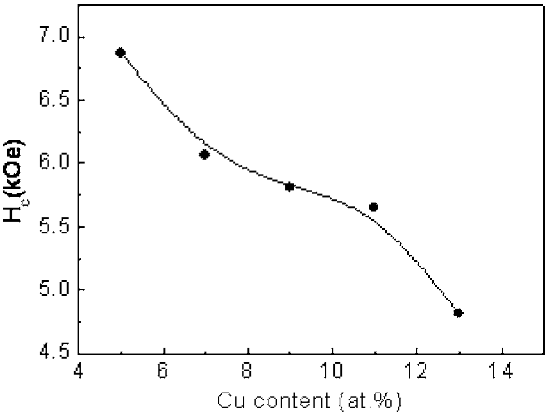

FIG. 4. Coercivity H_c of $L1_0$ FePt films with Cu content. All films were annealed at 600 °C for 5 min. The total film thickness is 12 nm.

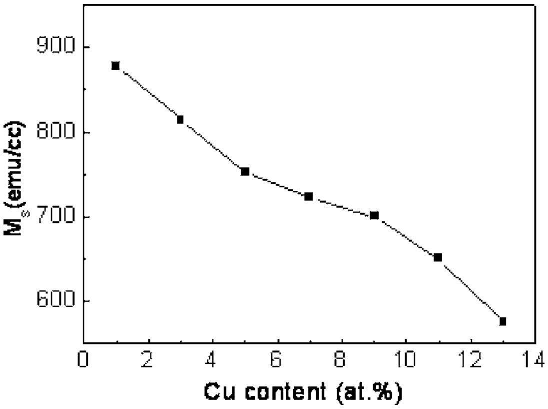

FIG. 5. Saturation magnetization M_s of $L1_0$ FePt films with Cu content. All films were annealed at 600 °C for 5 min. The total film thickness is 12 nm.

decreases with the increase of Cu content. One possible explanation for this behavior is that magnetic anisotropy of $L1_0$ FePt films decreased[15] because of Cu alloying with FePt. The effect of Cu amount on saturation magnetization M_s also was shown in Fig. 5. The data showed the decreasing trend of M_s in the $L1_0$ FePt films. This result was reasonable and consistent with simple dilution effects.

TEM and MFM were used to analyze the sample of $(Fe_{59}Pt_{51})_{1-x}Cu_x$ with Cu 11 at. %. The sample thickness was 12 nm and annealed at 600 °C for 5 min. The TEM image showed that the grain size of this sample was about 10 nm. MFM images have been used to analyze the magnetic coherence length as we reported previously.[16] The sample was in the thermally demagnetized state. The magnetic coherence length obtained from MFM images was about 80 nm. The magnetic measurement showed that the loop had a squareness ratio of about 0.89 with a coercivity about 5.5 kOe, which is suitable for writing in a practical perpendicular recording medium.

SUMMARY AND CONCLUSION

Nonepitaxially grown $L1_0$ FePtCu thin films with strong (001) texture were obtained. The effects of Cu alloying on orientation, lattice parameters, coherence length, M_s, and H_c were investigated for $L1_0$ FePt films. XRD data provided evidence of Cu alloying with FePt by substituting Fe or Pt in the $L1_0$ lattice to form ternary FePtCu films. Magnetic measurements, TEM, and MFM characterizations showed that detailed properties of $L1_0$ FePtCu films were of interest for further development as perpendicular magnetic recording media.

ACKNOWLEDGMENTS

The authors would like to thank Dr. Xingzhong Li and Dr. Langping Yue for assistance and analysis of TEM and MFM images. This research was supported by DOE, NSF-MRSEC, INSIC, W. M. Keck Foundation, and CMRA.

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