Magnetic properties of FePt thin films with multilayered structure

S Matsumoto, T Shima
Division of Engineering, Graduate School of Tohoku Gakuin University, 1-13-1, Chuo, Tagajo 985-8537, Japan
E-mail: shima@tjcc.tohoku-gakuin.ac.jp

Abstract. The structure and magnetic properties of FePt films with multilayered structure have been investigated. Intermediate layer of Cu or Fe/Au was inserted between top and bottom FePt layers. From X-ray diffraction patterns, the (002) fundamental peak and (001) and (003) super lattice peaks of the \( L_1_0 \) phase have been clearly observed for all the samples. The peak from FePt (200) has begun to observe for FePt/Cu/FePt films at the thickness of more than 3 nm. With increasing the intermediate layer thickness \( t \), coercivity measured in the direction perpendicular to the film plane was increased. However, an uniaxial magnetocrystalline anisotropy \( K_u \) was decreased for FePt/Cu/FePt films, while \( K_u \) maintains a large value of \( 4 \times 10^7 \) (erg/cm\(^3\)) for FePt/Fe/Au/FePt films. It was confirmed that the top FePt layer was grown epitaxially on the intermediate layer of Fe/Au without deterioration of the large \( K_u \).

1. Introduction
Magnets of nanometer size are of great technological and scientific interest, because nano-scale patterned or particulate magnets may guide to the applications in various magnetic devices such as ultra high density magnetic recording media, magnetic field generator in monolithic microwave integrated circuits and spin electronics devises. For these applications, nanomagnets with a large uniaxial anisotropy is required. Recently, a lot of studies have been made on \( L_1_0 \) ordered [CuAu (I) type] FePt thin films[1]-[11] and nano particles[12],[13] by conventional thin film preparation route and chemical synthesis, since they possess high uniaxial magnetocrystalline anisotropy \( (K_u=7.0 \times 10^7 \text{ erg/cm}^3) \)[14] and high corrosion resistance. For practical use, it is essential to realize highly oriented FePt thin films grown epitaxially on multilayered structure. However, the orientation control and the magnetization behaviour of FePt thin film with multilayer arrangement have not yet been fully elucidated. In this study, in order to see the effect of intermediate layer of Cu or Fe/Au on the film structure and the magnetic properties for FePt films, FePt / (Cu, Fe/Au) /FePt thin films have been investigated.

2. Experimental procedure
All the samples were prepared using an ultrahigh vacuum magnetron sputtering system with separate targets of Fe, Pt, Cr, Cu and Au. The base pressure was under \( 5.0 \times 10^{-6} \text{ Pa} \) and high-purity argon of 0.680 Pa was flown during sputtering. A Cr seed layer of 1nm was deposited on a MgO(100) single crystalline substrate. An epitaxial Au(001) buffer layer of 40 nm was deposited at room temperature, and then annealed at 300°C for 1 hour. Consecutively the bottom FePt layer of 20 nm
was deposited at 300˚C. An intermediate layer of Cu or Fe/Au layer was deposited at room temperature. The thickness of Cu and Au intermediate layer was varied from 0 to 10 nm. A thin Fe layer of 0.5-nm-thick also plays a role to maintain the (100) orientation of Au layer. Then top FePt layer of 10 nm was deposited at 300˚C. Finally, the samples were annealed at 600˚C to promote the L1₀ ordering of FePt layer. The magnetic properties were measured by a superconducting quantum interference device (SQUID) magnetometer. The structural characterization was performed by X-ray diffraction with Cu Kα radiation.

3. Results and discussion

3.1. FePt/Cu/FePt films

X-ray diffraction (XRD) patterns for FePt (20 nm) /Cu (tCu nm) / FePt (10 nm) films with various Cu intermediate layer thicknesses (tCu) are shown in Figure 1. tCu is varied for 0 nm (a), 1 nm (b), 3 nm (c), 4 nm (d), 5 nm (e), and 10 nm (f). The film with tCu = 0 nm is identical to be FePt single layer. In addition to fundamental (002) peak, (001) and (003) superlattice peaks of the L1₀-FePt phase have been clearly observed for all the samples. The unlabeled peaks are due to the MgO substrate. With increasing tCu, however, the peak from FePt (200) began to observe for the films with tCu ≥ 3 nm. It is thought that the crystal orientation of the top FePt layer tends to lie in the in-plane direction with increasing tCu. Furthermore, the peak from Au (200) has been shifted to higher angle with increasing tCu, indicating that the Cu layer was diffused into Au buffer layer after the annealing of the L1₀ ordering in FePt layer.

Magnetization curves for FePt/Cu/FePt films with various tCu are shown in Figure 2. All the measurements were performed at room temperature. The solid and broken lines denote the curves measured in the field perpendicular direction to the film and in the in-plane direction, respectively. The magnetic easy axis is perpendicular to the film plane for all the samples, since the [001] axis of the tetragonal L1₀ ordered structure is perpendicular to the film plane as demonstrated in Figure 1. Relatively large uniaxial magnetic anisotropy with perpendicular orientation and low coercivity (Hc) of 0.93 kOe were obtained for the film with tCu = 0 nm (FePt single layer). Since the magnetization process of FePt film is classified as the nucleation-type and in this case, it was mainly governed by the domain wall displacement with scarce existence of “pinning” site. The magnetization measured in the in-plane direction was hard to be saturated under the maximum applied field of 70 kOe in the SQUID. This result is well consistent with the previous results [6], [7]. With increasing tCu, remarkable

![Figure 1. XRD patterns for FePt/Cu/FePt films with various Cu intermediate layer thicknesses (tCu). tCu = 0 nm: FePt single layer (a), 1 nm (b), 3 nm (c), 4 nm (d), 5 nm (e), and 10 nm (f).](image-url)
The expansion of the hysteresis of the magnetization curve in the in-plane direction began to observe for $t_{Cu} \geq 3$ nm, indicating that the magnetic easy axis of the top FePt layer was inclined toward the in-plane direction as suggested in Figure 1.

### 3.2. FePt/Fe/Au/FePt films

XRD patterns for FePt (20 nm) /Fe (0.5 nm) /Au ($t_{Au}$ nm) /FePt (10 nm) films with various Au intermediate layer thicknesses ($t_{Au}$) are shown in Figure 3. $t_{Au}$ is varied for 0 nm (a), 1 nm (b), 3 nm (c), 5 nm (d), and 10 nm (e). Both fundamental and superlattice peaks of the $L1_0$-FePt phase have been clearly observed for all the samples. While on the contrary to the results with Cu intermediate layer,
the peak from FePt (200) could not observe. It is confirmed that c-axis of both bottom and top FePt layers was successfully aligned perpendicular to the film plane for the films with Fe/Au intermediate layer.

Magnetization curves for FePt/Fe/Au/FePt films with various $t_{Au}$ are shown in Figure 4. The magnetic easy axis is perpendicular to the film plane for all the samples. With increasing $t_{Au}$, $H_c$ was increased. A remarkable step of magnetization curve was observed in the third quadrant of the magnetization curve at $t_{Au} = 10$nm. This is thought to arise from the different thickness of bottom and

![Magnetization curves for FePt/Fe/Au/FePt films with various $t_{Au}$](image)

**Figure 4.** Magnetization curves for FePt/Fe/Au/FePt films with various $t_{Au}$. $t_{Au} = 0$ nm (a), 1 nm (b), 3 nm (c), 5 nm (d) and 10 nm (e).

![Effect of interlayer thicknesses ($t_{Cu}$, $t_{Au}$) on $H_N$, $H_c$ and $K_u$ for FePt/(Cu, Fe/Au)/FePt thin films](image)

**Figure 5.** Effect of interlayer thicknesses ($t_{Cu}$, $t_{Au}$) on $H_N$, $H_c$ and $K_u$ for FePt/(Cu, Fe/Au)/FePt thin films.
top FePt layer, since the nucleation field \(H_N\), at which the magnetization begins to drop with decreasing the field after saturation of each layer is different and occurred individually. In Figure 5, the magnetic properties as a function of intermediate layer thickness are summarized. In order to consider the magnetization process, \(H_N\) is estimated. The tendency of \(H_N\) is almost similar to that of \(H_c\) at \(t \leq 3\) nm. With further increasing \(t\), both \(H_N\) and \(H_c\) for the films with Cu intermediate layer became smaller than that with Au layer. The uniaxial magnetic anisotropy \(K_u\) determined from the area enclosed between the magnetization curves in applied fields parallel and perpendicular to the film plane is also shown in Figure 5(c). With increasing \(t_{Cu}\), \(K_u\) decreased to \(3 \times 10^7\) (erg/cm\(^3\)). However, regardless of the intermediate layer thickness, large value of \(K_u \approx 4 \times 10^7\) (erg/cm\(^3\)) was obtained for the films with Fe/Au intermediate layer. It was confirmed that top FePt layer was successfully grown epitaxially on Fe/Au intermediate layer.

**Summary**
The structure and magnetic properties of FePt films with multilayered structure have been investigated. Intermediate layer of Cu or Fe/Au was inserted between top and bottom FePt layers. It was revealed that the FePt layer was successfully grown epitaxially on the intermediate layer of Fe/Au without deterioration of the large perpendicular magnetic anisotropy. However, in order to understand the exchange coupling behavior between top and bottom FePt layer around the critical thickness of \(t_{Au} = 3\) nm, further detailed investigation such as magnetic domain observation should be needed.

**Acknowledgments**
This work was performed at the Hi-tech Research Center of Tohoku Gakuin University.

**Reference**
[1] B M Lairson, M R Viosokay, R Sinclair, and B M Clemens, 1993 *Appl. Phys. Lett.* 62, 639
[2] B M Lairson and B M Clemens, 1993 *Appl. Phys. Lett.* 63, 1438
[3] A Cebollada, D Weller, J Sticht, G R Harp, R F C Farrow, R F Marks, R Savoy, and J C Scott, 1994 *Phys. Rev. B* 50, 3419
[4] M R Visokay and R Sinclair, 1995 *Appl. Phys. Lett.* 66, 1692
[5] J -U Tiele, L Folks, M F Toney, and D K Weller, 1998 *J. Appl. Phys.* 84, 5686
[6] T Shima, T Moriguchi, S Mitani and K Takanashi, 2002 *Appl. Phys. Lett.* 80 288
[7] T Shima, K Takanashi, Y K Takahashi and K Hono 2002 *Appl. Phys. Lett.* 81 1050
[8] T Maeda, T Kai, A Kikitsu, T Nagase and J Akiyama 2002 *Appl. Phys. Lett.* 80 2147
[9] T Seki, T Shima, K Takanashi, Y Takahashi, E Matsubara, and K Hono, 2003 *Appl. Phys. Lett.* 82 2461
[10] T Shima, K Takanashi, Y K Takahashi and K Hono 2004 *Appl. Phys. Lett.* 85 13
[11] T Shima, K Takanashi, Y K Takahashi and K Hono 2005 *Appl. Phys. Lett.* 88 063117
[12] S Sun, C B Murray, D Weller, L Folks, and A Moser, 2000 *Science* 287, 1989
[13] S Yamamoto, Y Morimoto, T Ono, and M Takano 2005 *Appl. Phys. Lett.* 87, 032503
[14] O A Ovanov, L V Solina, and V A Demshina 1973 *Phys. Met. Metallogr.* 35 81