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Dot arrays of $L1_1$ type Co–Pt ordered alloy perpendicular films

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Magnetic properties of dot arrays of $L1_1$ type Co–Pt ordered alloy perpendicular films were studied. $L1_1$-Co–Pt films with a large uniaxial magnetic anisotropy K_u of the order of 10^7 erg/cm^3 were fabricated at a substrate temperature of 360 °C using ultrahigh vacuum sputter film deposition. Dot patterns with dot diameters of 70–200 nm were made using high resolution e-beam lithography and reactive ion etching (RIE). The values of K_u were measured by the GST method using the Anomalous Hall Effect; we observed the averaged signals of 6000 dots. The values of K_u for dot arrays of 10-nm-thick $L1_1$-$Co_{50}Pt_{50}$ films deposited on MgO(111) substrates (single crystal films) and glass disks (polycrystalline films) were nearly the same as those of the original films independent of D, indicating no significant etching damage by the RIE process. Magnetic force microscopy images revealed that all dots were single domains in the present D region. The coercivity H_c of the dot arrays was 25.0 kOe [MgO(111) substrate, $D=70$ nm] and 14.3 kOe (glass disks, $D=80$ nm). The switching field distribution σ/H_c was relatively small, $\sigma/H_c=0.15$, even for dot arrays fabricated on glass disks, indicating the homogeneous formation of a $L1_1$ type ordered structure in the $Co_{50}Pt_{50}$ layers. © *2009 American Institute of Physics*. [DOI: 10.1063/1.3068539]

I. INTRODUCTION

A new recording system using patterned media is one possibility to overcome the trade-off between thermal stability and recording writability. Composite dot structures such as exchange coupled composite,[1] hard/soft stacked,[2] and exchange spring[3] are promising candidates for patterned media applications, and all these media require magnetically hard materials having a large uniaxial anisotropy energy K_u, of the order of 10^7 erg/cm^3, to realize their full potential.

It is likely that $L1_1$ type $Co_{50}Pt_{50}$ ordered films[4–6] are promising candidates for high density recording media because of their high K_u and relatively low fabrication temperature (300–400 °C), but in all previous reports $L1_1$ type $Co_{50}Pt_{50}$ films were fabricated on single crystal substrates using molecular beam epitaxy. We successfully fabricated $L1_1$ type Co–Pt ordered alloy films with the easy axis of magnetization perpendicular to the film plane using ultrahigh vacuum (UHV) sputter film deposition.[7,8] The values of the order parameter S and K_u for $L1_1$ type $Co_{50}Pt_{50}$ films increased as the substrate temperature T_s increased. K_u reached about 3.7×10^7 erg/cm^3 ($S=0.54$) at $T_s=360$ °C for single crystal films deposited on MgO(111) substrates, indicating a potential increase in K_u by enhancing the ordering. The K_u values of polycrystalline films deposited on glass disks were smaller than those of single crystal films on MgO(111) substrates, however, K_u reached 1.9×10^7 erg/cm^3 at $T_s=360$ °C. Moreover, these films had a preferred crystal orientation with the close-packed plane parallel to the film plane, and the easy axis distribution, estimated from the rocking curves of the $L1_1$-(222) diffraction line, was 3.4°, even for the films deposited on glass disks. The experimental results demonstrated the potential of these Co–Pt ordered films for use in data storage applications, due to their very high K_u, comparable to $L1_0$-type $Fe_{50}Pt_{50}$ films, the relatively low fabrication temperature and good controllability of the grain orientation.

In this study, we fabricated dot arrays of $L1_1$ type Co–Pt ordered alloy films. We examine the structural and magnetic properties of these dot arrays and demonstrate their potential for use in data storage applications.

II. EXPERIMENTAL PROCEDURE

Films were deposited using an UHV dc and rf magnetron sputtering system (ANELVA, E8001). The substrate temperature was 360 °C, which is the temperature where the values of S and K_u nearly saturate.[7,8] The base pressure prior to film deposition was less than 7×10^{-7} Pa. Films were deposited on MgO(111) substrates and 2.5 in. glass disks. The thickness of the $Co_{50}Pt_{50}$ layer was 10 nm. Pt(20 nm) and Ru(20 nm) were used as underlayers for films on MgO(111) substrates and glass disks, respectively. The difference in the seed layer material resulted in no significant difference in K_u values.[7,8]

Dot patterns were formed using high resolution e-beam lithography and reactive ion etching. The magnetization curves of the dot arrays were examined by anomalous Hall effect (AHE) measurements.[9] We observed the averaged AHE signals of 6000 dots. The values of K_u ($=K_{u1}+K_{u2}$) for films and dot arrays were measured by the GST method[10] using the AHE with a maximum applied field of 7 T.

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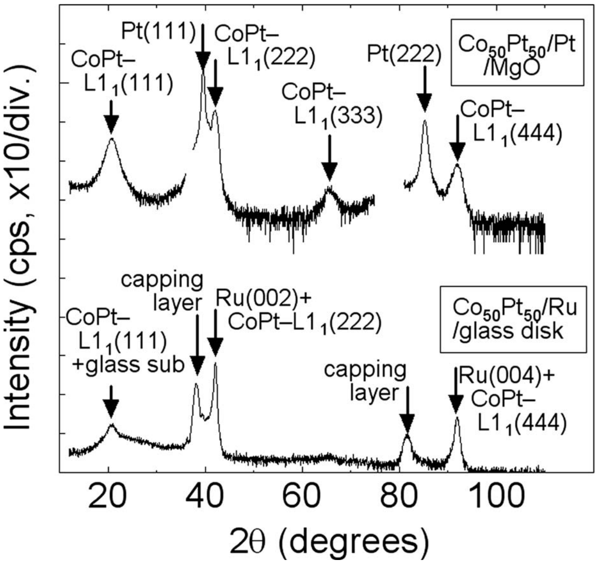

FIG. 1. XRD patterns of $L1_1$-$Co_{50}Pt_{50}$ films (10 nm) deposited on MgO(111) and glass disk.

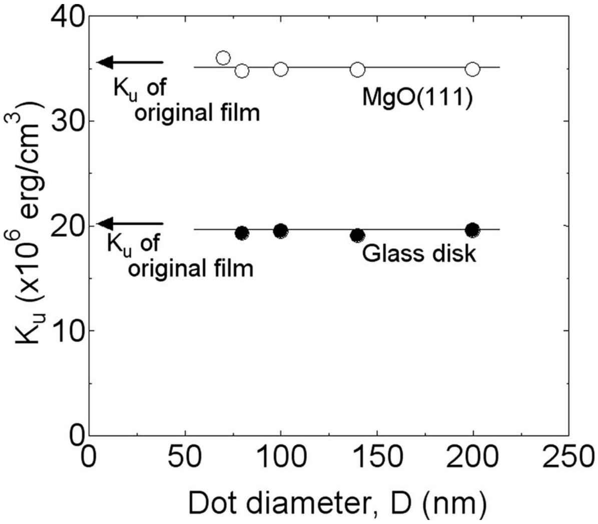

FIG. 3. Values of K_u of $L1_1$-$Co_{50}Pt_{50}$ (10 nm) dot arrays as a function of the dot diameter D. In the figure the K_u values of the original films are also indicated.

III. RESULTS AND DISCUSSION

Figure 1 shows the x-ray diffraction (XRD) patterns for $Co_{50}Pt_{50}$ films deposited on MgO(111) single crystal substrates and glass disks, respectively. Both films have a preferred crystal orientation with the close-packed plane parallel to the film plane. Diffraction lines of $Co_{50}Pt_{50}$-$L1_1$(111) planes were observed in both XRD patterns, indicating the formation of a $L1_1$ type ordered structure, although the diffraction intensity for the polycrystalline film deposited on a glass disk was weak. XRD analysis revealed that Co–Pt films deposited on MgO substrates were single crystal. The easy axis distribution, estimated from the rocking curves of the $L1_1$-(222) diffraction line, was about 2° and 3.4° for the films deposited on MgO(111) single crystal substrates and glass disks, respectively. The value of K_u for the film deposited on a MgO(111) substrate was 3.5×10^7 erg/cm^3, although the order parameter, S, calculated using the diffraction intensities for the $L1_1$-(222) and $L1_1$-(111) planes,[11] was about 0.47. The value of K_u for the film deposited on a glass disk was 2.0×10^7 erg/cm^3, which was nearly half that of the films deposited on MgO(111) single crystal substrates. The saturation magnetization M_s for these films was about 940 emu/cm^3.

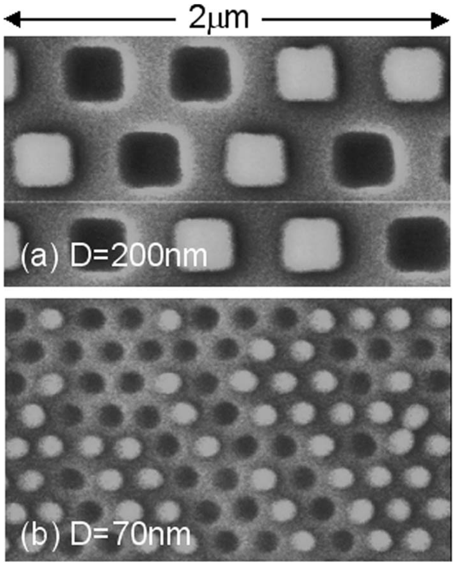

FIG. 2. MFM images of $L1_1$-$Co_{50}Pt_{50}$ (10 nm) dot arrays with the dot diameters D of 200 and 70 nm after demagnetization along the film normal direction.

Magnetic force microscopy (MFM) images of dot arrays with dot diameters D of 200 and 70 nm are shown in Figs. 2(a) and 2(b). The images were observed after demagnetization along the film normal direction. The demagnetizing process was carried out by applying alternating dc magnetic fields with decreasing amplitude. All dots showed a single domain state even after demagnetization along the film normal direction, indicating that the single domain state is stable even for the dot arrays with $D=200$ nm.

Figure 3 shows the values of K_u for the dot arrays as a function of D. We estimated the K_u values for the dot arrays taking account of the shape anisotropy of the dot, assuming that M_s is unaffected by etching damage. In the figure, the K_u values of the original films are also indicated for comparison. The K_u values in each series of dot arrays were nearly the same as those of the original films, independent of D. This result indicates there was no significant etching damage from the RIE process, and, homogeneous formation of $L1_1$ type ordered structure in the $Co_{50}Pt_{50}$ layers.

Figure 4 shows AHE hysteresis loops and AHE remanence curves for dot arrays fabricated on MgO(111) substrate ($D=70$ nm) and glass disks ($D=80$ nm). The remanence AHE curves were identical to the AHE hysteresis loops in both dot arrays, indicating that the magnetization reversal process in these dots was irreversible. However the AHE curves were not rectangular because the AHE signal was averaged over 6000 dots. The coercivity H_c was 25.0 [MgO(111) substrate] and 14.3 kOe (glass disks).

The slope of the AHE curves from negative saturation to positive saturation was caused by dot-to-dot variations in the

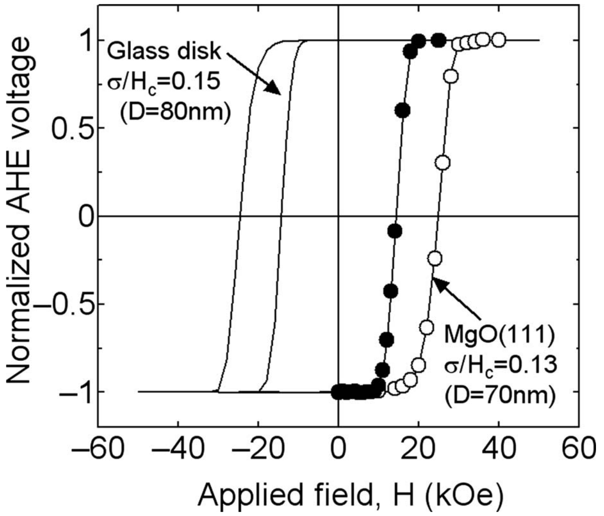

FIG. 4. AHE hysteresis loops and remanence AHE curves of $L1_1$-$Co_{50}Pt_{50}$ (10 nm) dot arrays on glass and MgO substrates.

switching field. A simple calculation revealed that the interdot magnetostatic field was about 100 Oe in the present samples. Even in the saturation remanence state, therefore, it is likely that the slope of the loop was mainly caused by the switching field distribution (SFD) of the dots.

We estimated the applied fields where the magnetization reached $-M_s/2$ and $M_s/2$, respectively, and defined the difference between the two fields as ΔH_c and SFD as $\Delta H_c/H_c$. A simple calculation revealed that $\Delta H_c/H_c$ was 1.35 times larger than σ/H_c, where σ is the standard deviation of the SFD, assuming a Gaussian distribution function.

Figure 5 shows the values of H_c and $\Delta H_c/H_c$ of $L1_1$-$Co_{50}Pt_{50}$ dot arrays deposited on MgO(111) substrates as a function of the dot diameter D. H_c increased gradually from about 22.5 to 25.0 kOe as D decreased from 200 to 70 nm.

$\Delta H_c/H_c$ increased gradually from about 0.14 (σ/H_c =0.10) to 0.17 (σ/H_c=0.13), as D decreased from 200 to 70 nm. The values of $\Delta H_c/H_c$ of the dot arrays on glass substrates were slightly larger than those on MgO(111) substrate, and was about 0.21 (σ/H_c=0.15) for the D=80 nm dot arrays shown in Fig. 4. However, it should be noted that these values of $\Delta H_c/H_c$ were smaller than those of a *hcp*-$Co_{75}Pt_{25}$ dot arrays fabricated with the same RIE process,[12] and the difference was mainly caused by the degree of the easy axis distribution. This result indicates the homogeneous formation of a $L1_1$ type ordered structure in the $Co_{50}Pt_{50}$ layers.

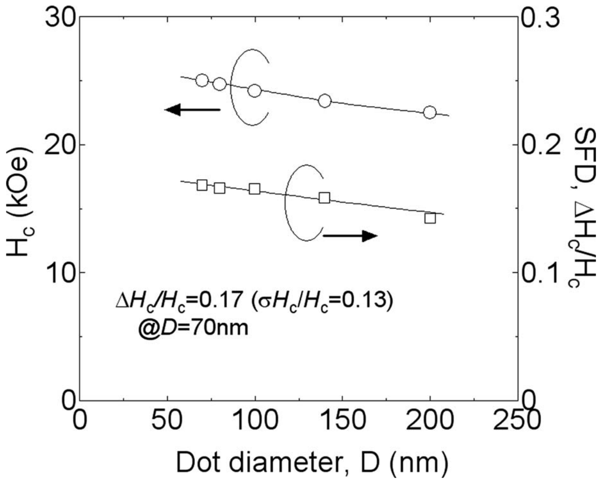

FIG. 5. Values of H_c and $\Delta H_c/H_c$ of $L1_1$-$Co_{50}Pt_{50}$ (10 nm) dot arrays deposited on MgO(111) substrates as a function of the dot diameter D.

IV. CONCLUSION

The magnetic properties of dot arrays of $L1_1$ type $Co_{50}Pt_{50}$ ordered alloy perpendicular films were studied. No significant etching damage by the RIE process on K_u was observed. Moreover, the SFD was relatively small, indicating homogeneous formation of a $L1_1$ type ordered structure in the $Co_{50}Pt_{50}$ layers. These results demonstrate the potential of $L1_1$-type Co–Pt ordered films for use in data storage applications, because of their very high K_u, comparable to $L1_0$-type $Fe_{50}Pt_{50}$ films, relatively low M_s, the relatively low fabrication temperature, and good controllability of the grain orientation.

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