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New highly oriented soft magnetic underlayer structures for perpendicular recording

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Highly oriented soft underlayers with face-centered-cubic (fcc) phase Co, Co alloy, and composite NiFe/Co film structures have been epitaxially grown on single crystal Si wafers by sputter deposition. The epitaxial orientation relationships have been determined by x-ray diffraction and transmission electron microscopy. It was found that the soft underlayer magnetic properties can be modified in a wide range by fine tuning the Co alloy composition or the Co alloy thickness in a NiFe/Co structure. Ti films were sputter deposited on top of the NiFe and Co layers and epitaxial growth in both Ti(0001)/Co(111) and Ti(0001)/NiFe(111) was observed. Through this highly oriented Ti intermediate layer, a Co alloy perpendicular media layer with greatly improved hexagonal-close-packed (0001) orientation can be integrated with the highly (111) textured fcc soft magnetic underlayers. [S0021-8979(00)45808-1]

INTRODUCTION

It is believed that a soft magnetic underlayer is a very important part in the perpendicular media structure[1,2] and the control of its crystalline orientation and microstructure is desirable as this directly influences the anisotropy, coercivity, and recording performance of the media. Previously we have discussed highly oriented NiFe (permalloy) films epitaxially grown on Ag and Cu underlayer templates, which were grown on HF etched Si substrates by sputter deposition.[3] In this study, using similar template techniques, highly oriented face-centered-cubic (fcc) Co and Co based alloy thin films with soft magnetic properties have been successfully prepared on HF etched Si substrates. From transmission electron microscopy (TEM) and x-ray pole figure ϕ scan measurements, it has been found that the fcc phase of Co grows and the epitaxial relationships were determined. Also, epitaxial growth of permalloy films on Ag underlayers have been achieved without a Cu intermediate layer. It was also found that NiFe films can be epitaxially grown on the fcc Co films. Since the NiFe growth is epitaxial, an epitaxial highly oriented fcc Co alloy film can be grown on these underlayer structures. Experiments show that by inserting the thin fcc Co or Co alloy intermediate layer between NiFe and Ag, the magnetic properties of the soft magnetic films can be modified. This should provide the process flexibility for controlling the troublesome soft underlayer domain wall motion induced media noise.[1]

The hexagonal-close-packed (hcp) phase is desired for the magnetically hard Co alloy media on top of the soft underlayer structure. In order to obtain an hcp phase Co alloy, it is necessary to insert a Ti intermediate layer between the hcp Co alloy and the soft fcc underlayer. Our earlier work showed that the (0001) texture of Ti films is important in inducing growth of a highly (0001) textured Co alloy media.[4] In this work, the epitaxial growth of (0001) textured Ti films has been observed on NiFe and Co films with (111) orientation. Since when Co is deposited directly on the fcc layer, a fcc Co grows, the introduction of a hcp Ti(0001) textured film on the fcc phase allows the hcp Co(0001) textured film to grow. The use of the Ag/Si template induces all of these layers to grow epitaxially and to be highly oriented.

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EXPERIMENT

The detailed experimental growth techniques have been described in our previous work.[3,4] The epitaxial structure of the films was studied by x-ray $\theta/2\theta$ diffraction, pole figure ϕ scans and TEM. The magnetic properties of the films were measured using a vibrating sampling magnetometer, torque magnetometer, and a BH loop tracer.

RESULTS AND DISCUSSIONS

All samples were deposited on HF-etched Si substrates with Ag underlayers. Figure 1(a) shows the x-ray diffraction pattern of a typical sample with the structure of Co (30 nm)/Ag (50 nm)/Si(111). In θ–2θ x-ray diffraction patterns, only the fcc textures corresponding to the epitaxial relationships between each of the layers were observed. Figure 1(b) shows a plane view TEM diffraction pattern of the (111) zone axes of the Co and Ag layers. Epitaxial growth is clearly indicated and the epitaxial relationship of

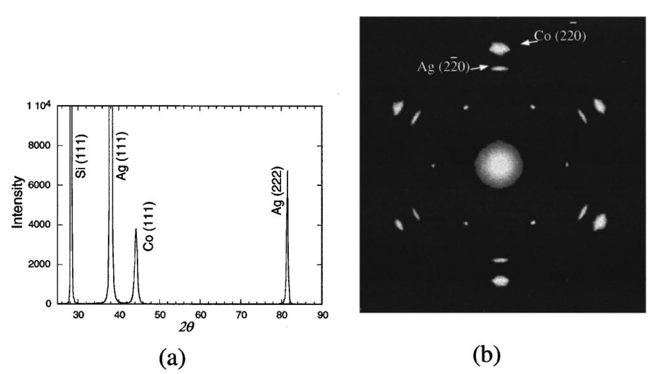

FIG. 1. (a) X-ray diffraction pattern of Co/Ag films deposited on Si(111). (b) A TEM diffraction pattern of the (111) zone axes of the Co, Ag layers for a Co/Ag/HF etched Si(111) sample.

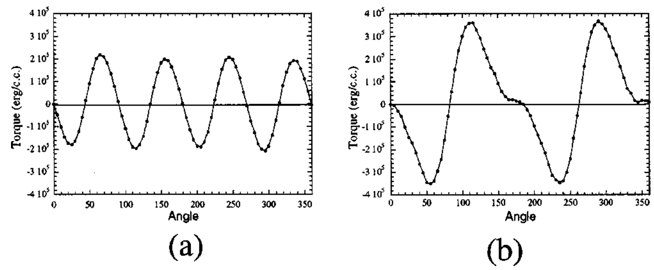

FIG. 2. Measured in-plane torque curves for (a) (100) oriented Co film; (b) (110) oriented Co film.

TABLE I. Measured magnetic properties of NiFe and some Co alloys.

Alloy composition	Maximum coercivity (Oe)	Ms (emu/cm^3)
NiFe (21 wt % Fe)	1.0	855
Co	9.8	1410
$Co_{92}Pt_8$	118.4	1330
$Co_{80}Cr_{20}$	154.2	573
$Co_{76}Cr_{20}Pt_4$	170.0	560
$Co_{68}Cr_{20}Pt_{12}$	355.6	510

$Co(111)[\bar{2}\bar{2}0]\|Ag(111)[\bar{2}\bar{2}0]$ is evident. This epitaxial relationship was also confirmed by x-ray pole figure ϕ scan measurements.

Earlier, the same techniques were employed to characterize the epitaxial growth of Co films grown on Si(110) and Si(100) substrates.[5] The epitaxial relationships were determined to be cube on cube, that is

$$Co(100)[001]\|Ag(100)[001]\|Si(100)[001],$$

$$Co(110)[001]\|Ag(110)[001]\|Si(110)[001].$$

In-plane torque measurements showed significant differences in the torque curves for fcc Co films grown with (111), (100), and (110) orientations. For our (111) textured thin films isotropic behavior was observed. No torque data values, distinguishable from the background noise, were observed. On the other hand, the (100) and (110) oriented Co films showed significant, and different, in-plane torque values. Figures 2(a) and 2(b) shows the measured torque curves for (100) and (110) oriented Co films, respectively. In our recent work, the anisotropy constants K_1 and K_2 of Co films grown on (100) and (110) Si substrates were discussed.[5]

Co films with (111) orientation showed soft magnetic properties. Figure 3 shows the hysteresis loops of a (111) textured Co film grown on a Ag/Si(111) template. The coercivity along a field induced easy axis is about 10 Oe.

In addition, Co alloy films such as CoCr, CoPt, and CoCrPt were also epitaxially grown on the Ag/Si template.

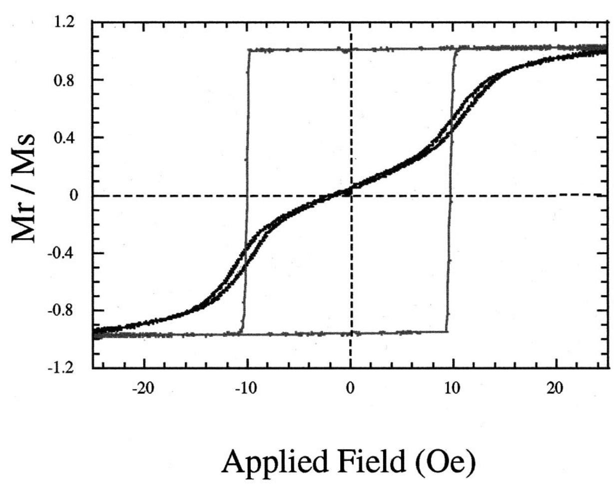

FIG. 3. Hysteresis loops of a sample with the structure of Co (30 nm)/Ag (50 nm)/Si(111), along the easy and hard axes, respectively.

The epitaxial relationships were found to be the same as those of pure Co films. However, the coercivities were found to be very sensitive to the composition of the Co alloys. Listed in Table I are the measured magnetic properties of some of the fcc alloy films. It is observed that the addition of Cr or Pt to the Co significantly increased the energy barriers to wall motion (HcMs product) of the soft fcc films.

Epitaxial growth of NiFe films on the Ag/Si(111) templates has also been achieved using the same epitaxial growth techniques. Moreover, it was observed, here, that the epitaxial growth of the NiFe film on the Ag/Si(111) template can still develop even if a thin Co or Co alloy intermediate layer is introduced. Figures 4(a) and 4(b) are the TEM diffraction patterns of the (111) zone axes of the NiFe, Co, and Ag layers from samples with structures of NiFe (30 nm)/Ag (50 nm)/HF-etched Si(111) and NiFe (30 nm)/Co(5 nm)/Ag (50 nm)/HF-etched Si(111), respectively. Epitaxial growth is clearly indicated in both cases. From the TEM data and from x-ray pole figure ϕ scan measurements, the orientational relationships were also determined to be cube on cube, that is

$$NiFe(111)[\bar{2}\bar{2}0]\|Ag(111)[\bar{2}\bar{2}0]\|Si(111)[\bar{2}\bar{2}0];$$

$$NiFe(111)[\bar{2}\bar{2}0]\|Co(111)[\bar{2}\bar{2}0]\|Ag(111)[\bar{2}\bar{2}0]\|Si(111)[\bar{2}\bar{2}0].$$

It is observed that the coercivity of the permalloy films can be modified by inserting the Co or Co alloy intermediate layer. Figure 5 shows the coercivities of a 30-nm-thick NiFe film grown on $CoCr_{20}$/Ag (50 nm)/Si(111), with various CoCr thickness. By increasing the thickness of CoCr intermediate layer, the coercivity of the soft underlayer structure increased significantly. CoCr alloy was chosen here for its low M_s value, so that the behavior of NiFe could be observed better from the hysteresis loops. Clearly this dual layer structure for the soft underlayer provides considerable flexibility toward controlling the coercivity of the layer and potentially the soft underlayer induced media noise.

In order to achieve a high uniaxial anisotropy, the hcp phase is desired for the Co-alloy media. Unfortunately, it is very difficult to obtain a pure hcp phase of Co alloy when deposited directly on permalloy or fcc Co soft underlayers. Typically, in traditional polycrystalline films, a Ti or TiCr intermediate layer has been necessary to induce perpendicular orientation into the hcp phase.[1] In our earlier work, we showed that (0001) textured Ti underlayers could be used to significantly improve the (0001) texture of Co-alloy films via epitaxial growth on our Ag/Si templates.[4] Here, we found that Ti films with (0001) orientation grow epitaxially on the (111) textured NiFe and Co soft underlayers. This property

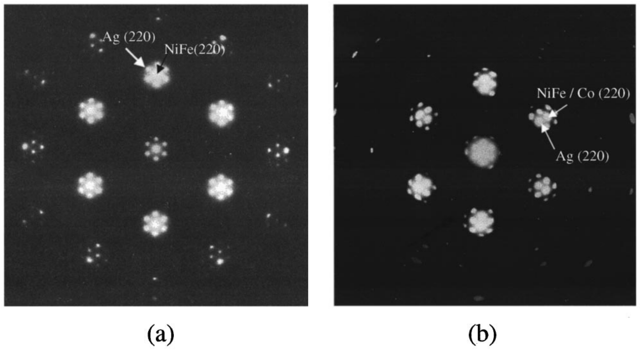

FIG. 4. A TEM diffraction pattern of the (111) zone axes from samples with structures of (a) NiFe (30 nm)/Ag (50 nm)/HF-etched Si(111) and NiFe (30 nm)/Co (5 nm)/Ag (50 nm) / HF-etched Si(111), respectively.

allows the desired, strongly textured, (0001) Co alloys and the (111) textured soft underlayers to be integrated together.

Figures 6(a) and 6(b) are the TEM diffraction patterns for the Ti (30 nm)/NiFe (30 nm)/Ag (50 nm)/Si(111) and the Ti (30 nm)/Co (30 nm)/Ag (50 nm)/Si(111) samples, respectively. It shows the (111) zone axis of Ag, NiFe, and Co to be parallel to the (0002) zone axis of the hcp Ti with the (220) reflections from the fcc phase being parallel to the $(11\bar{2}0)$ reflections of the hcp phases. This result is also in agreement with the pole figure measurements. The diffracted spots from the Ag, NiFe, Co, and Ti are all sharp, indicating very good epitaxial growth. The orientational relationships were determined to be

$$\mathrm{Ti}(0001)[11\bar{2}0]\|\mathrm{NiFe}(111)[2\bar{2}0]\|\mathrm{Ag}(111)[2\bar{2}0]\|\mathrm{Si}(111)[2\bar{2}0];$$

$$\mathrm{Ti}(0001)[11\bar{2}0]\|\mathrm{Co}(111)[2\bar{2}0]\|\mathrm{Ag}(111)[2\bar{2}0]\|\mathrm{Si}(111)[2\bar{2}0].$$

Rocking curve measurements were also employed to investigate the dispersion of the textures. The measured $\Delta\theta_{50}$ of the NiFe, Co (111), and Ti (0001)/Ag (111) are all less than 1°, indicating highly oriented film structures. The (0001) texture of Co alloy grown on Ti has a $\Delta\theta_{50}$ of about 2.5°.

Finally, samples with structures of hcp Co-alloy/Ti/(fcc-Co-alloy or NiFe)/Ag/Si(111) were prepared. These media

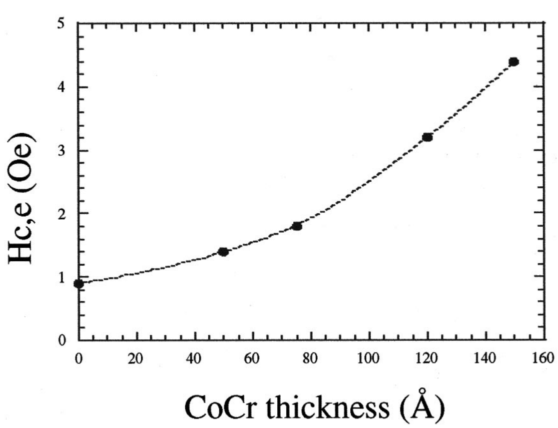

FIG. 5. Measured easy axis coercivities of samples with the structure: NiFe (30 nm)/CoCr/Ag (50 nm) Si(111), with various $Co_{80}Cr_{20}$ layer thicknesses.

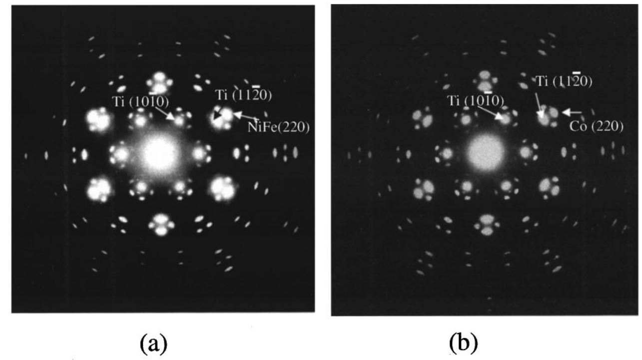

FIG. 6. TEM diffraction patterns for samples (a) Ti (30 nm)/NiFe(30 nm)/Ag (50 nm)/Si(111) and (b) Ti (30 nm)/Co (30 nm)/Ag(50 nm)/Si(111).

structures showed satisfactory magnetic properties even when the Ti intermediate layers were very thin. For example, a sample with the structure of $Co_{68}Cr_{20}Pt_{12}$(50 nm)/Ti(5 nm)/$Co_{68}Cr_{20}Pt_{12}$(10 nm)/Ag(50 nm)/Si(111) showed an overall coercivity of 2120 Oe. By estimating the magnetization change that is contributed to the total film, as the soft film rotates, the coercivity of the hcp $Co_{68}Cr_{20}Pt_{12}$ layer can be estimated to be around 3200 Oe. Further study to separate the interaction of these two layers to observe the magnetic behavior is in process.

SUMMARY

In this study, highly oriented fcc NiFe, Co, and Co-alloy thin films were epitaxially grown on single crystal Si substrates. The epitaxial relationships were determined by x-ray diffraction, x-ray pole figure ϕ scans, and TEM. On top of the (111) textured NiFe and Co films, Ti was found grown epitaxially with a (0001) orientation. This orientation is desired to induce highly (0001) textured hcp Co-alloy perpendicular recording media. The magnetic properties of the soft underlayers were found to be sensitive to the layer structure. This sensitivity should provide a pathway for controlling the domain wall motion induced media noise. The epitaxial relationships determined in this work should also be useful in providing instructive information to those working on polycrystalline media structures, where grain to grain epitaxy is desired.

ACKNOWLEDGMENTS

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