Effects of an Os Buffer Layer on Structure and Exchange Bias Properties of CoFe/IrMn Fabricated on Si(100) and Si(111)

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The structural and exchange bias properties of CoFe/IrMn prepared on Si (100) and Si (111) with an Os/Cu buffer layer were investigated. Since the Os (0002) surface mesh has the same atomic arrangement as fcc (111) orientation, and the lattice mismatch between Os (0002) and IrMn (111) is as low as 2.6%, the CoFe/IrMn grown on H-Si(100) showed a strong IrMn (111) diffraction peak, while a very weak IrMn (111) peak appeared on H-Si (111). With increasing Os thickness (d_{Os}), the IrMn (200) peak was weakened, while the IrMn (111) became strong on H-Si (100). For the CoFe/IrMn grown on H-Si(111), no obvious structural change appeared. Os plays an important role on tuning the IrMn to result in the exchange bias. On the other hand, CoFe/IrMn showed an exchange field (H_{ex}) on both H-Si(100) and H-Si(111) with the Os buffer layer; however, the magnetization switching process was different due to different the crystalline degree. A sharp magnetization switching process occurs for IrMn(111) on Os/Cu/H-Si(100) with a square hysteresis loop. A 370 and 310 Oe of H_{ex} was found in textured CoFe/IrMn on Os/Cu/H-Si(100) and Os/Cu/H-Si(111), respectively.

***Index Terms*—Buffer layer, osmium, textured film.**

I. INTRODUCTION

RECENTLY, the development of spintronic devices has expanded rapidly. The magnetic films are the essential ingredients of spintronics, whose properties, such as structure, technical magnetization, etc., have great influence on the overall performance of spin devices. A suitable buffer layer is used for an antiferromagnetic (AFM) layer to induce the ferromagnetic/antiferromagnetic (FM/AFM) coupling in magnetic tunnel junction (MTJ) or spin valve (SV) structures [1]. The control of the crystallinity of memory cells is a new issue worth study since a crystal MTJ structure results in higher MR ratios [2]. Many face center cubic (fcc) metals, such as NiFe and NiFeCr, are used to provide strong fcc (111) orientation in magnetic films [3]. Furthermore, the hexagonal close-packed (hcp) structure Ru buffer layers could also enhance the exchange field (H_{ex}) of Mn_3Ir/Co-Fe and avoiding interdiffussion during growth [4] due to its high melting point. Compared with Ru, Osmium (Os) is also the hcp structure and has higher melting point. However, few reports have been found on the growth of the textured magnetic films with Os buffer layers. In this article, we extend our previous work [5] to investigate the growth of textured CoFe/IrMn by using Os buffer layers on both Si (100) and Si (111) substrates. The improvement on IrMn structure and the magnetic properties of CoFe/IrMn was dependent on the thickness of Os layer. Results of this study may suggest that Os can be a new candidate buffer layer for the growth of crystalline magnetic films.

II. EXPERIMENT

A textured structure of CoFe 10/IrMn 30 was grown by magnetron sputtering on Si (100) and Si (111), respectively, with an Os (d_{Os})/Cu 30 buffer layer, where the thickness was in nm, and d_{Os} was varied from 0 to 30 nm. Before depositions, Si wafers were first cleaned to degrease them with acetone and dipped into 10% HF solution for several seconds to form a hydrogen-terminated surface. Then they were loaded into the vacuum chamber immediately. All films were deposited in sequence at about a 5 mTorr pressure of pure Ar gas under an external filed of 200 Oe without breaking the vacuum. No external heating was applied to the substrates during film growth. After deposition, all samples were subjected to magnetic field annealing at 200°C under 3 kOe for 30 min as a training effect. Magneto-Optical Kerr Effect (MOKE) and a vibrating sample magnetometer (VSM) were used to examine the magnetic behavior, while the crystal structure was studied by X-ray diffraction (XRD) with a Cu-K_α source.

III. RESULTS AND DISCUSSION

The XRD results of Os/Cu/Si (100) and Cu/Os/Cu/Si (100) are presented in Fig. 1(a). Obviously, a Cu (002) peak (near 51°) and an Os (0002) peak (near 41.78°) appeared when Os/Cu was put directly on Si (100). Due to Os being an hcp metal and its (0002) surface has the same atomic arrangement as that of the fcc (111) plane, so all other fcc metals growing

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on top of the Os (0002) plane would grow to form the fcc (111) plane with small enough lattice mismatch. Evidence of this relationship was obtained by putting another Cu layer on the Os, and the clear Cu (111) peak overlapping with the Os (10$\underline{1}$1) peak near 43.5° was observed. However, as shown in Fig. 1(b), the Cu on H-Si (111) neither forms obvious Cu (111) nor Cu (002) with such a thin Cu layer. The CoFe/IrMn on Os/Cu/Si (100) showed a strong peak near 41.5°, including of the IrMn (111) ($2\theta = 41.57°$) and the Os (0002). A small CoFe (111) peak ($2\theta = 44.2°$) was also overlapped with the Os (10$\underline{1}$1) peak. By contrast, the IrMn grown on Cu/Si (100) only showed the IrMn (002) ($2\theta = 47.8°$) instead of IrMn (111) due to the lower lattice mismatch between IrMn and Os. The lattice constants of Cu, Os, IrMn, and CoFe were 3.615, 2.73, 3.76, and 3.547 Å, respectively. Thus, along the film growth direction, the relative distances between two neighboring atoms were 2.556 (Cu), 2.73 (Os), 2.658 (IrMn), and 2.508 (CoFe) Å. The mismatches between each layer were 6.8% (Cu (002)/Os (0002)), −2.64% (Os (0002)/IrMn (111)), and −5.64% (IrMn (111)/CoFe (111)), respectively. All the mismatches were smaller than 7%, below which metal film can be epitaxially grown. Since the lattice mismatches between each layer were sufficiently small, the fcc CoFe/IrMn growing on top of the Os (0002) plane could form the fcc (111) orientation, obtaining higher H_{ex} [3]. That is the main reason to control the film structure. Compared with Os, other hcp materials, such Ti (a = 2.95 Å), Hf (a = 3.196 Å), and Zr (a = 3.232 Å), showed relatively high lattice mismatches in the interface: −9.9% (Ti (0002)/IrMn (111)), −15.99% (Hf (0002)/IrMn (111)), and −17.76% (Zr (0002)/IrMn (111)), respectively. Therefore, the Os does show lower lattice mismatching and is suitable for epitaxial growth of magnetic films. However, the CoFe/IrMn only showed a very weak IrMn (111) peak on Os/Cu/Si (111), while essentially no peaks appeared when films were grown on Cu/Si (111). No Cu (002) formed on H-Si (111) when the Cu thickness was only 30 nm; thus, the lattice mismatch calculation mentioned above was non-tenable in this case. Interestingly, on the Os/Cu/Si (100), the intensity of the Os (10$\underline{1}$1) peak was stronger than that of the Os (0002) peak when t_{Os} was thinner. The intensity of the Os (0002) peak rose more sharply than that of the Os (10$\underline{1}$1) peak as t_{Os} increased, which indicated that the crystalline structure of the Os was changed. Thus, the surface states may be more suitable for IrMn (200) surface growth in the initial growth state of Os growth. At these conditions, the IrMn (200) peak was stronger than the IrMn (111) peak. That the CoFe film on IrMn/Os/Cu did not show an obvious (111) peak may be attributed to the low intensity due to its lower thickness.

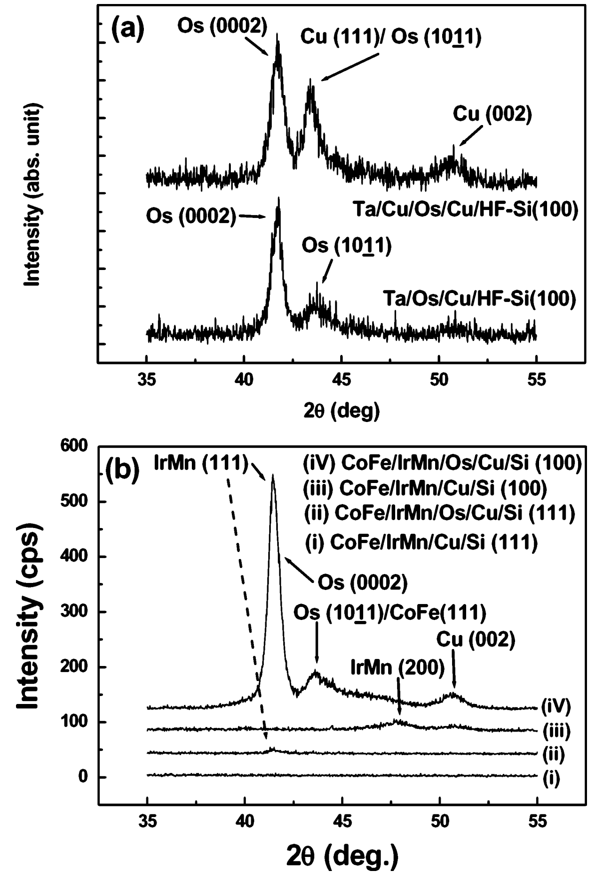

Fig. 1. (a) XRD patterns of the evidence that the Os (0002) can provide a suitable surface mesh to grow fcc (111) orientation. (b) XRD pattern of CoFe/IrMn grown on Cu/H-Si (100) and Cu/H-Si (111) with and without Os buffer layer.

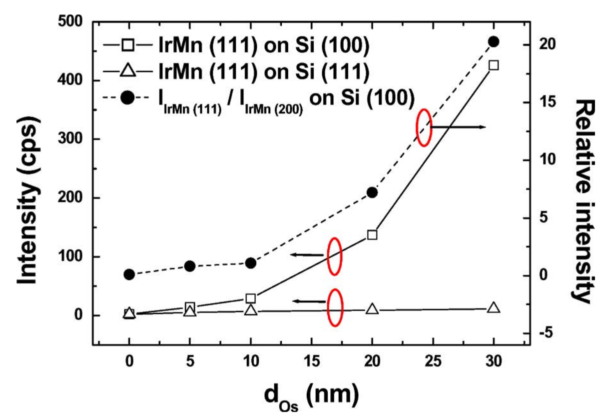

Fig. 2. The $I_{IrMn}(111)$ on Si (100) and Si (111) and the relative intensity of $I_{IrMn}(111)/I_{IrMn}$ (200) were a function of (d_{Os}).

As seen from Fig. 2, the intensity of the IrMn (111) ($I_{IrMn(111)}$) on both substrates was a function of the d_{Os}. Only a weak IrMn (111) peak could be found when the d_{Os} were larger than 20 nm on H-Si (111). This indicated that the film was weakly-oriented in the normal direction. The IrMn (200) peak appeared on H-Si (100) when the d_{Os} were not thick enough, and the $I_{IrMn(111)}$ on H-Si (100) increased as the d_{Os} increased. This indicates that the growth of IrMn film can be controlled. The increment of the $I_{IrMn(111)}$ as d_{Os} increased was sharper, while the $I_{IrMn(200)}$ was kept constant. The relative peak intensity on H-Si (100), defined as $I_{IrMn(111)}/I_{IrMn(002)}$, is also shown in Fig. 2. The $I_{IrMn(111)}$ and $I_{IrMn(200)}$ were nearly the same when d_{Os} were less than 10 nm, and then the $I_{IrMn(111)}$ was raised sharply. According to these results, the increasing d_{Os} restrained the growth of the IrMn (200) and made the surface change into a suitable surface mesh to grow IrMn (111) on H-Si (100). Thus, Os plays an important role on IrMn structure tuning.

As revealed in Fig. 2, $I_{IrMn(111)}$ on both Si (100) and Si (111) had roughly the same intensity when d_{Os} was thinner, while both of the two cases showed roughly similar magnetic properties. However, the hysteresis loops of both cases showed different squareness (S), which is defined as Mr/Ms, and implied different magnetization reversal processes. As the d_{Os} increased, IrMn (111) structure became much better on Si (100), thus, making the better CoFe (111) structure and the magnetization switching of CoFe was more coherent, showing that the S was very closely approaching 1, than that on Si (111). Fig. 3(a) shows the M-H loop of CoFe/IrMn/Os 30/Cu on Si (100) and Si (111), respectively. The non-square hysteresis loop of the CoFe on Si (111) indicated that the number of domain is larger than that of the square one due to the more disorder magnetic moments aligning, thus needing more domain nucleation and domain-wall motions to reverse the whole magnetization. On the other hand, a roughly 180 Oe of H_{ex} of CoFe/IrMn was obtained on both Si (100) and Si (111) with the 30 nm Os buffer layer, while the $I_{IrMn(111)}$ showed very different values on both substrates. One of the factors affecting the initial value of H_{ex} may come from the external field during film growing. An annealing treatment was performed as a training effect to eliminate this probable factor. Fig. 3(b) shows these two M-H loops after 200°C annealing. It is clearly found that the H_{ex} on Si (100) $(H_{ex(100)})$ and Si (111) $(H_{ex(111)})$ were 370 and 310 Oe, respectively. A 60 Oe increment of the H_{ex} on H-Si(100) indicates that the larger H_{ex} came from the better crystalline structure. Certainly, annealing improves the crystallinity of both samples. However, the initial state also determined the degree of improvement in the crystalline structure because the superior crystalline sample may have grain growth occurring first, without grain nucleation process. On the other hand, the superior crystalline structure sample at the as-deposited state would have much better crystallinity than the inferior one. Thus, the interface of the CoFe/IrMn on Si (100) could conform to the ideal interface model, as stated by Meiklejohn and Bean, than that on Si (111). According to the assumptions of the model, the magnetic moments were aligned more parallel, thus giving a larger H_{ex}. That is strong evidence of the improvement of the film structure due to using an Os buffer layer.

IV. Conclusion

The effects of an Os buffer layer on the crystal structure and exchange bias properties of textured CoFe/IrMn grown on Si (100) and Si (111) have been studied. The Os (0002) plane was very suitable for growing fcc (111) metal due to the similar atomic arrangement. With an Os buffer layer, CoFe/IrMn grew more epitaxially on H-Si (100) than on H-Si (111). Besides, the Os buffer layer played an important role on tuning the IrMn crystalline structure. As d_{Os} increased, IrMn (200) was restrained and made the surface change into a suitable surface mesh on which to grow the IrMn (111) on H-Si (100), while such a structural transition did not appear in the case of H-Si (111). Even though CoFe/IrMn on both Si (100) and Si (111) with 30 nm Os showed nearly the same H_{ex}, the better CoFe/IrMn fcc (111) structure on Os/Cu/H-Si(100) resulted in a more coherent magnetization reversal process, thus, a hysteresis loop with large S (~ 1) was obtained. After annealing treatment, a 60 Oe of improvement on H_{ex} was found when CoFe/IrMn was grown on H-Si (100). According to the results of this study, Os was more suitable for use in providing fcc (111) orientation on Si (100).

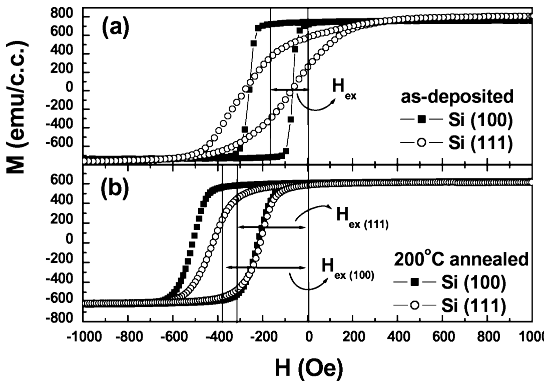

Fig. 3 M-H loop of (a) as deposited and (b) 200°C annealed of CoFe/IrMn/Os30/Cu on both H-Si (100) and H-Si (111) substrates with Os buffer layer.

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