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Excellent Magnetic Properties of $Co_{53}Fe_{22}Hf_{10}O_{15}$ Thin Films

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Nanocrystalline CoFeHfO thin films have been fabricated by *RF* sputtering method. It is shown that the CoFe-HfO thin films possess not only high electrical resistivity but also large saturation magnetization and anisotropy field. Among the composition investigated, $Co_{53}Fe_{22}Hf_{10}O_{15}$ thin film is observed to exhibit good soft magnetic properties: coercivity (H_c) of 0.18 Oe; anisotropy fild (H_k) of 49.92 Oe; saturation magnetization ($4\pi M_s$) of 15.5 kG. The frequency response of permeability of the film is excellent. The excellent magnetic properties of this film in addition of an extremely high electrical resistivity (r) of 185 μcm make it ideal for uses in high-frequency applications of micromagnetic devices. It is the formation of a peculiar microstructure that resulted in the superior properties of this film.

Keywords : CoFeHfO thin film, soft magnetic thin film, anisotropy field

1. Introduction

During the last decades, searches for suitable magnetically soft, low coercivity, high saturation magnetization and anisotropy and resistivity materials, have been carried out to fulfill the requirements of writing heads and high-frequency inductors.

The growing interest in micromagnetic intergrated devices such as inductors and transformers for power delivery and signal conditioning, has renewed interest in highly resistive granular magnetic films [1, 2]. Among these materials, soft magnetic films based on Co-Fe permalloy and ion-rich Fe-Zr, Fe-Ti, Fe-Ta have been investigated [3-5]. However, desirable soft magnetic properties are typically obtained only after postdeposition heat treatment, for nanocrystallinezation, of the deposited films at relativity high temperature of 300°-600°C such a high temperature post heat treatment is an added complication in the processing of devices which contain other components and materials, some sensitive to the high-temperature post heat treatment [3]. In the present work, we have successfully achieved the desirable to avoid the high-temperature post heat treatment.

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2. Experiment

Co-Fe-Hf-O thin films were fabricated on Si wafer by *RF* reactive sputtering under $Ar+O_2$ atmosphere, at the $O_2/(Ar+O_2)$ gas flow ratio is 2 to 10%. Magnetic filed of 100 *Oe* is applied during sample preparation to induce an in-plane uniaxial anisotropy. Other condition in this study were as flows: base vacuum of less than 2×10^{-7} Torr; working pressure of 2×10^{-3} Torr; *AC* sputtering power of 300 W; the time sputtering is controlled from 1 min to 5 min to obtain thickness of the film is about 300 nm.

The exactly composition of Co-Fe-Hf-O films was measured by auger electron spectra (AES). The electrical resistivity was measured with a conventional four-point probe. The magnetic properties were measured with a DMS vibrating sample magnetometer (VSM) and a SHB-109 BH loop tracer. The effective permeability of the thin films was measured in the range of 1 to 3000 MHz by network analyzer HP4191A. The crystal structure was observed by x-ray diffraction (XRD) and high resolution transmission electron microscopy (HRTEM).

3. Results and Discusion

Fig. 1 shows the result of $Co_{70}Fe_{30}Hf_{10}O_6$ thin film that was prepared with 300 W power, 6% partial of oxygen

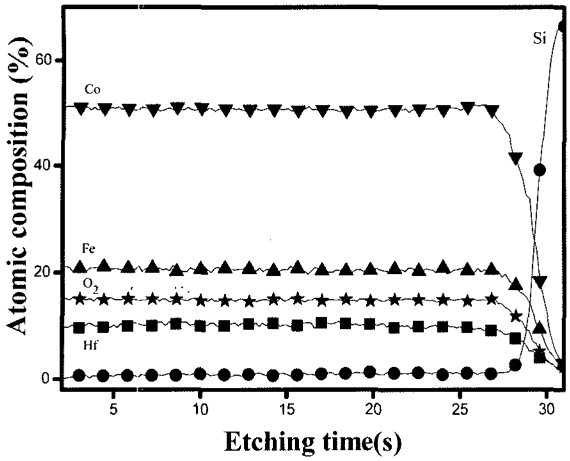

Fig. 1. AES-depth profile of CoFeHfO thin film as deposited with 6% oxygen.

during 3 minutes. This result shows that, the composition is almost constant along to thickness of thin film and indicated that our sputtering technique is good method to make thin film. The exact composition is $Co_{53}Fe_{22}Hf_{10}O_{15}$.

Fig. 2 shows XRD patterns of $Co_{53}Fe_{22}Hf_{10}O_{15}$ film, the diffraction strong peaks is distributed around 2θ of (44°-46°), corresponding to the diffraction from CoFe (110). It is the main crystalline in our thin films and plays important role in making excellent magnetic properties of thin films. So we concentrated to fabricate this crystal. The other broad and low peak at 2θ of (41°-43°), (65°-67°) due to the diffraction from monoclinic, CoO (200), CoFe (200), respectively. These crystals are not good for magnetic properties, so we try to decrease amount of CoO by controlled O_2 gas flow [6] and CoFe (200) by controlled thickness of film [4].

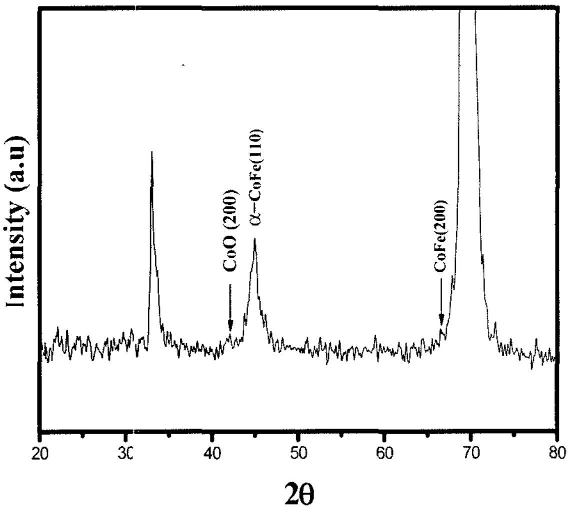

Fig. 2. XRD diffraction patterns of $Co_{53}Fe_{22}Hf_{10}O_{15}$ reactive sputter-deposited thin films.

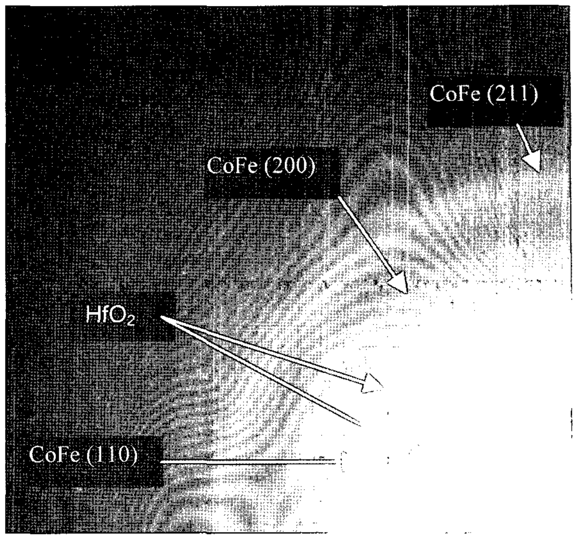

Fig. 3. SAD patterns of $Co_{53}Fe_{22}Hf_{10}O_{15}$ thin film.

To confirm these phases, SAD of thin film was determined. Fig. 3 shows a halo ring is observed at the first diffraction ring suggesting the presence of remaining amorphous and granular phases in the films, which can be indexed using the α-Co(Fe) (110), α-CoFe (110), amorphous oxide phases a-HfO phases. The intensity of this ring is so high indicated that amount of these phases is high also. The second diffraction ring could be due to a distribution of CoFe (200) in the film. The third diffraction ring can be indexed using a combination of the α-Co(Fe) (211), α-CoFe (211). The second and third ring is weak indicated that amount of CoFe (200) and CoFe (211) are very low. The outer diffraction rings correspond to reflections from monoclinic Co phases.

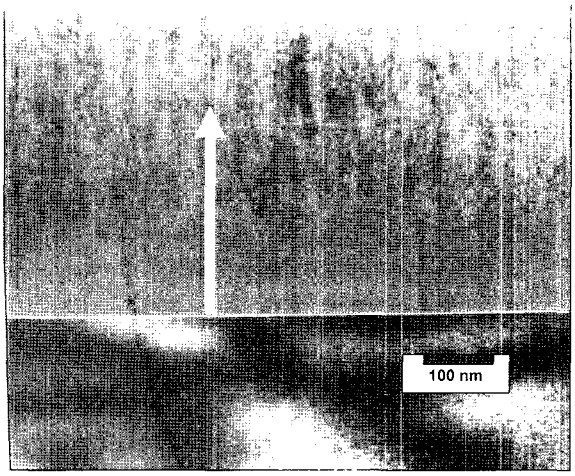

Fig. 4. HRTEM view of film with 6% O_2. Arrows point to the direction of nanocrystalline CoFe-rich layers (black) and amorphous HfO-rich layers (white), respectively.

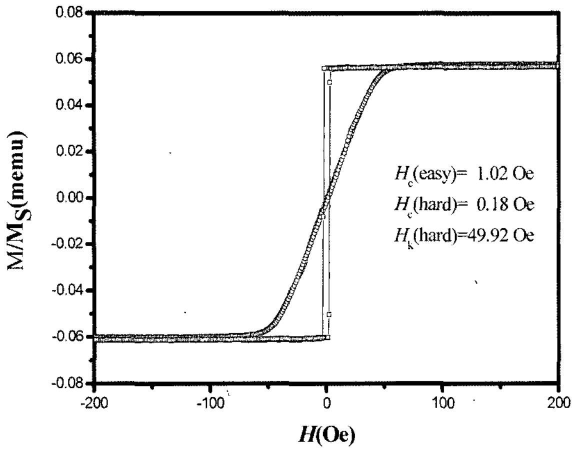

Fig. 5. Magnetization curves of nanocrystalline $Co_{53}Fe_{22}Hf_{10}O_{15}$ *thin film as deposited with 300 nm and 6% Oxygen.*

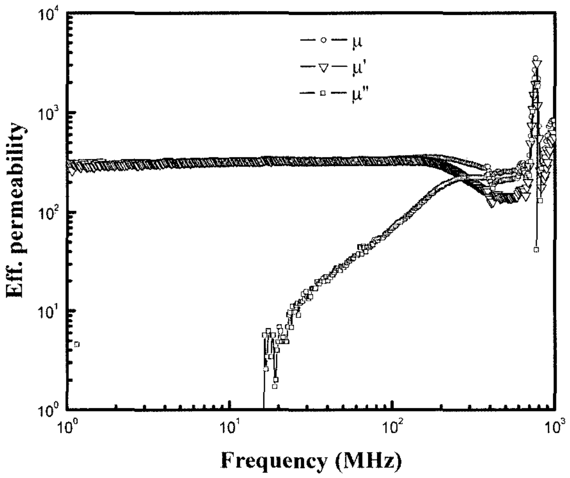

Fig. 6. Frequency dependence of effective permeability of $Co_{53}Fe_{22}Hf_{10}O_{15}$ *film measured along easy axis.*

Fig. 4 shows the TEM image of $Co_{53}Fe_{22}Hf_{10}O_{15}$ thin film with microstructure consists of Co(Fe) nanograins randomly arranged within an amorphous HfO matrix. It has a peculiar microstructure (arrow pointing) which consist of nanocrystaline Co(Fe) –rich laminates of ~2 nm thickness indicated by black color separated one by one by amorphous HfO-rich laminates of ~0.5 nm thickness indicated by white color. This structure can be considering column structure, thereby providing a preferentially uniaxial anisotropy.

Fig. 5 shows typical normalized magnetization curves of nanocrytaline $Co_{53}Fe_{22}Hf_{10}O_{15}$ film. The film exhibits excellent magnetic Properties, with H_c of 0.18 Oe, anisotropy fild, H_k of 49.92 Oe and saturation magnetization of 15.5 kG. The large H_k of this film may be connected with the anisotropic form of nanocrystaline in the film. The large saturation magnetization is relation of a lot of amount crystalline CoFe (110).

Fig. 6 illustrates the effective permeability (μ_{eff}) spectra in the 0 to 2 GHz band. The effective permeability of thin film is about 300, which is maintained up to 650 MHz.

The behavior of μ' (in this case corresponding with μ_{eff}) agrees with the Stoner and Wolfarth theory, which explains the permeability at low frequency the value $\mu' = M_s/H_k$. The excellent μ-f characteristics are due to the high ferromagnetic resonance frequency, f_{FMR} originated from the factors of thin film as mentioned above. It can be said that the high resistivity soft magnetic films with excellent characteristics perform well in the very high frequency range.

4. Conclusion

In summary of this report, the optimal sputtering conditions have been obtained with *300 nm* at *6%* O_2. The optimized film composition is $Co_{53}Fe_{22}Hf_{10}O_{15}$ exhibit very low H_c 0.18 Oe and high resistyvity 185 μcm compared with 5 Oe and *60* μcm observed by Jeon *et al.* [4], it also have higher H_k and saturation magnetization compared with Crawford *et al.* It indicated that $Co_{53}Fe_{22}Hf_{10}O_{15}$ film exhibit excellence magnetic properties and it is very promising for high frequency applications (GHz) was proved in Fig. 6.

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