Adjustable Microwave Properties in FeCoZr/Cu Multilayers

Guozhi Chai, Zhiling Wang, Gaoxue Wang, Wenbo Sui, and Desheng Xue

Key Lab for Magnetism and Magnetic Materials of the Ministry of Education, Lanzhou University, Lanzhou 730000, China

The FeCoZr/Cu multilayers were prepared by radio frequency sputtering. The static and microwave properties of these films were investigated by measuring the hysteresis loops and microwave permeability spectra. According to the static magnetic results, the multilayers were well in-plane uniaxial anisotropic samples with high saturation magnetization 1.7 T. The anisotropic field of these multilayer thin films can be adjusted from 18 Oe to 64 Oe by changing the thickness of Cu interlayer from 8.7 nm to 1.8 nm. As a consequence, the microwave permeability and resonance frequency can also be adjusted from 1.70 GHz to 2.88 GHz. This work might facilitate search for new materials with high permeability at high frequency.

***Index Terms*—FeCo sputtered films, high saturation magnetization, magnetic multilayers, soft magnetic films.**

I. Introduction

A GREAT variety of devices working in different GHz frequency are developed in these years. Then soft magnetic thin films with adjustable resonance frequencies and permeabilities are required for applying in these devices [1]–[3]. With the work of Snoek and Kittel [4]–[6], the resonance frequency and permeability strongly depend on the in-plane uniaxial magnetic anisotropic (IPUMA) field (H_k) and saturation magnetization. The resonance frequencies and permeabilities can be adjusted by changing the IPUMA fields. In our earlier works, it have been found that a method with changing the oblique angle can adjust the IPUMA field of single layer CoNb thin films [7], another method with changing the interlayer thickness can adjust the IPUMA field of CoNb/Ta multilayer [8]. However, for these thin films with Co as the main magnetic phase, the saturation magnetization is about 1.0–1.4 T which restrict the high permeability. The purpose of this paper is to find a material with higher M_s, adjustable resonance frequencies and permeabilities. The $Fe_{1-x}Co_x$ $(0.3 < x < 0.4)$ alloy has the highest saturation flux density of $\mu_0 M_s \geq 2.4$ T [9]. The following study is to investigate the microwave properties of the FeCoZr/Cu multilayer.

II. Experimental Details

The multilayers were prepared by radio frequency (rf) sputtering with background pressure lower than 5×10^{-5} Pa. $Fe_{70}Co_{30}$ target on which Zr chips were placed in a regular manner and Cu target was used to deposit the FeCoZr/Cu multilayers. Magnetic layers were deposited at an oblique angle to attain uniaxial anisotropy [7], [10]. The structures of FeCoZr/Cu multilayers are shown in Fig. 1. All the samples have eight FeCoZr layers. Thickness of each FeCoZr layers is 10 nm and Cu interlayers are changed from 16.9 to 1.8 nm for different samples. The thickness of each layer was determined by controlling the deposit time.

The component of the FeCoZr layer is measured by energy dispersive x-ray spectroscopy (EDS). The thickness of these films was measured by surface profiler meter (Vecco Dektak 8). The static magnetic properties of these thin films were obtained by measuring the hysteresis loops by vibrating sample magnetometer (Lakeshore model 7304). The microwave properties of these thin films were obtained by measuring the microwave permeability spectra with a PNA E8363B vector network analyzer using shorted microstrip transmission-line perturbation method [11].

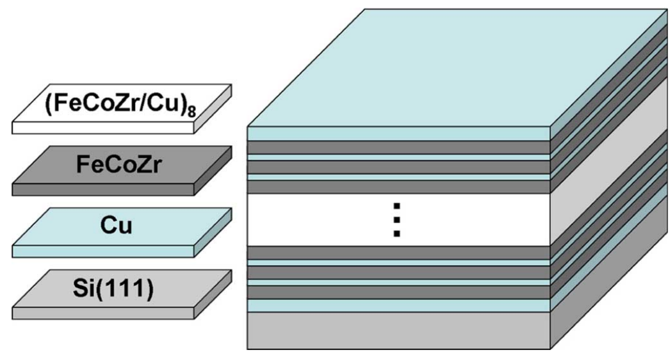

Fig. 1. Structure of FeCoZr/Cu multilayers on a 20 nm Cu buffer layer. The substrates are $10 \times 20 \times 0.42$ mm^3 (111)-oriented Si pieces. Thickness of each FeCoZr layers is 12 nm and Cu interlayers change from 16.9 to 1.8 nm for different samples.

III. Results and Discussion

The component of the FeCoZr magnetic layers carried out by EDS is $Fe_{64}Co_{28}Zr_8$. The saturation magnetizations of these samples are all about 1.7 T. We found that these FeCoZr/Cu multilayers were well defined IPUMA form. Fig. 2 show the in-plane hard axis hysteresis loops of FeCoZr/Cu multilayers as a function of Cu interlayer thickness. As expected, the H_k show a decrease behavior as the thickness of Cu interlayer continuously increasing. For instance, H_k for FeCoZr/Cu multilayer with Cu layer 1.8 nm is 64.1 Oe, whereas H_k is 17.9 Oe for Cu layer 8.7 nm. The behavior of H_k is similar with our previous results in CoNb/Ta multilayers.

Frequency dependences of the real (μ') and imaginary (μ'') components of the relative permeability of the FeCoZr/Cu multilayers are shown in Fig. 3 as a function of Cu interlayer thickness. As we expected, the resonance frequency f_r enlarged into a higher value with the H_k increasing, and moreover, the value

Manuscript received February 18, 2011; accepted May 15, 2011. Date of current version September 23, 2011. Corresponding author: D. Xue (e-mail: xueds@lzu.edu.cn).

Color versions of one or more of the figures in this paper are available online at http://ieeexplore.ieee.org.

Digital Object Identifier 10.1109/TMAG.2011.2157468

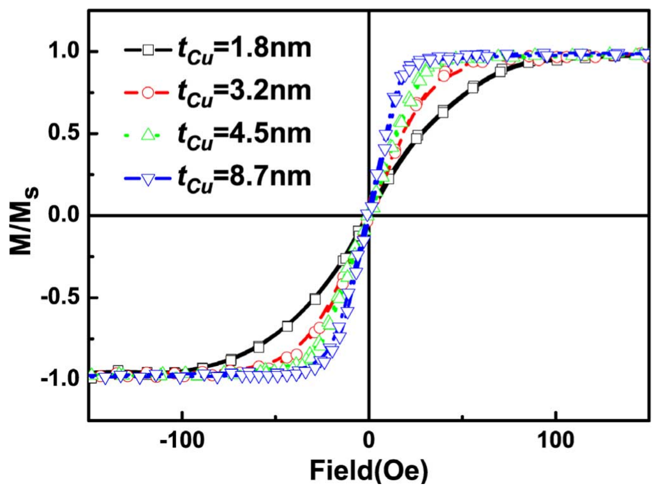

Fig. 2. In-plane hysteresis loops along the hard axis of FeCoZr/Cu multilayers as a function of Cu interlayer thickness change from 16.9 to 1.8 nm.

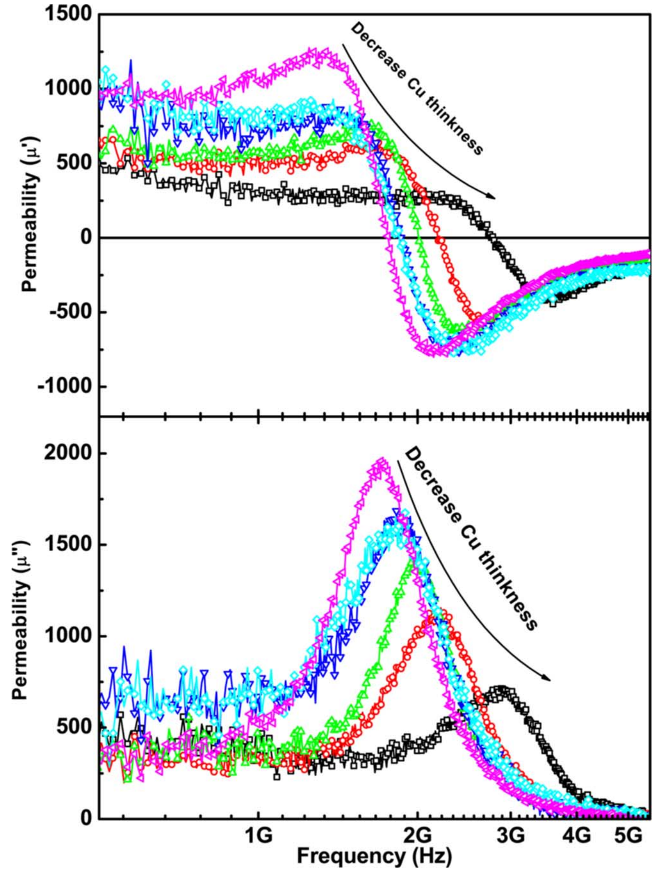

Fig. 3. Microwave permeability spectra of FeCoZr/Cu multilayers as a function of Cu interlayer thickness.

μ' still keep at a high level. For example, for FeCoZr/Cu multilayers with Cu layer 8.7 nm with small H_k, the μ' is larger than 960 up to 1.5 GHz as shown in Fig. 3, and f_r is around 1.7 GHz which cause significant magnetic loss and a sharp decrease of μ' and increase of μ''. Correspondingly, for FeCoZr/Cu multilayers with Cu layer 1.8 nm with high H_k, f_r can obtain a value as high as 2.88 GHz but μ' still with a moderate value $\sim$268 up to 2.5 GHz.

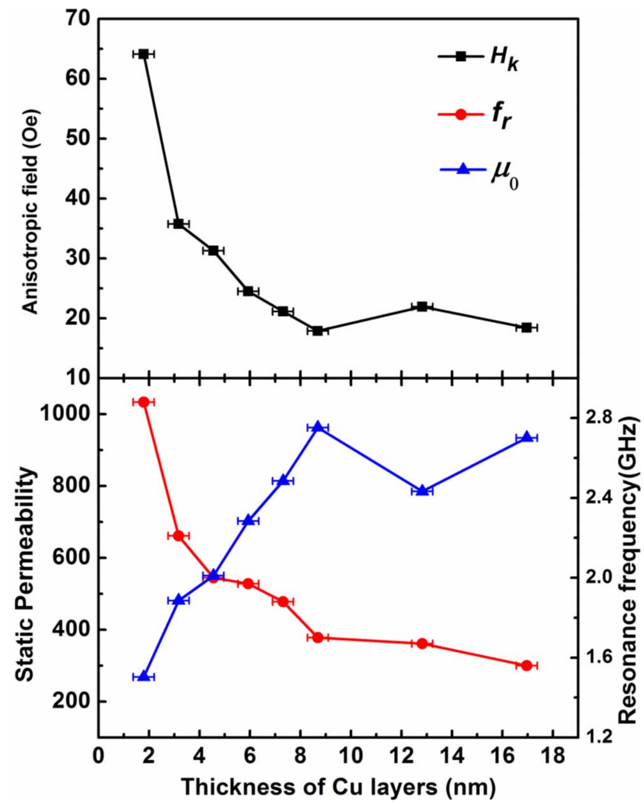

Fig. 4. Dependences of anisotropic fields, static permeabilities and resonance frequencies of FeCoZr/Cu multilayers as functions of the thickness of Cu interlayers.

Fig. 4 shows the dependences of anisotropic fields, permeabilities and resonance frequencies of FeCoZr/Cu multilayers as functions the thickness of Cu interlayers. The anisotropic fields show an adjustable dependence with the Cu interlayer thickness as we supposed. The largest anisotropic field 64.1 Oe was found for the sample with Cu thickness as 1.8 nm. With the thickness of Cu decreased, the anisotropic field getting larger. For Cu layers thicker than 8 nm, H_k of these samples are all about 18 Oe. As a consequence, the resonance frequency is 2.88 GHz for Cu layer as 1.8 nm, and reduces to 1.70 GHz, 1.67 GHz and 1.56 GHz for Cu thickness as 8.7, 12.8 and 16.9 nm. At the same time, the permeability increase from 268 to 962 for thickness of Cu layer change from 1.8 nm to 16.9 nm. We can obtain from Fig. 4 that the high frequency performance of FeCoZr/Cu multilayers can be controlled by adjusting the thicknesses of the Cu interlayers.

As the only difference of these multilayers is the spacing of the magnetic layers, the change of the magnetic properties might derive from the interlayer interactions as described in our previous work [8]. The interlayer interactions decrease while the thickness of Cu layer increasing. As a sequence the IPUMA fields increase with the increasing interactions between FeCoZr layers.

IV. Conclusion

In summary, this work provides FeCoZr/Cu multilayers with high saturation magnetization as 1.7 T and adjustable microwave properties. The multilayers with adjustable IPUMA field from 64.1 to 17.9 Oe can be conveniently obtained by changing the thicknesses of the Cu interlayers from 1.8 nm to 8.7 nm. As a consequence, the adjustable range of permeability and resonance frequency are 268 to 962 and 2.88 to 1.56 GHz.

ACKNOWLEDGMENT

This work was supported in part by the NSFC under Grants 10774062 and 11034004, the National Science Fund for Distinguished Young Scholars under Grant 50925103, the Keygrant Project of Chinese Ministry of Education under Grant 309027, the Scholarship Award for Excellent Doctoral Student granted by Ministry of Education, and the Fundamental Research Funds for the Central Universities under Grant lzujbky-2010-219.

REFERENCES

[1] Y. Zhao, X. Zhang, and J. Xiao, "Submicrometer laminated Fe/SiO2 soft magnetic composites—An effective route to materials for high-frequency applications," *Adv. Mater.*, vol. 17, pp. 915–918, 2005.
[2] D. S. Gardner, G. Schrom, P. Hazucha, F. Paillet, T. Karnik, S. Borkar, R. Hallstein, T. Dambrauskas, C. Hill, C. Linde, W. Worwag, R. Baresel, and S. Muthukumar, "Integrated on-chip inductors using magnetic material (invited)," *J. Appl. Phys.*, vol. 103, p. 07E927, 2008.
[3] N. N. Phuoc, F. Xu, and C. K. Ong, "Ultrawideband microwave noise filter: Hybrid antiferromagnet/ferromagnet exchange-coupled multilayers," *Appl. Phys. Lett.*, vol. 94, p. 092505, 2009.
[4] J. Snoek, "Dispersion and absorption in magnetic ferrites at frequencies above one Mc/s," *Physica*, vol. 14, pp. 207–217, 1948.
[5] C. Kittel, "On the theory of ferromagnetic resonance absorption," *Phys. Rev.*, vol. 73, pp. 155–161, Jan. 1948.
[6] D. Xue, F. Li, X. Fan, and F. Wen, "Bianisotropy picture of higher permeability at higher frequencies," *Chin. Phys. Lett.*, vol. 25, pp. 4120–4123, 2008.
[7] X. Fan, D. Xue, M. Lin, Z. Zhang, D. Guo, C. Jiang, and J. Wei, "In situ fabrication of $Co_{90}Nb_{10}$ soft magnetic thin films with adjustable resonance frequency from 1.3 to 4.9 GHz," *Appl. Phys. Lett.*, vol. 92, p. 222505, 2008.
[8] G. Chai, Y. Yang, J. Zhu, M. Lin, W. Sui, D. Guo, X. Li, and D. Xue, "Adjust the resonance frequency of $(Co_{90}Nb_{10}/Ta)_n$ multilayers from 1.4 to 6.5 GHz by controlling the thickness of Ta interlayers," *Appl. Phys. Lett.*, vol. 96, p. 012505, 2010.
[9] S. Wang, N. Sun, M. Yamaguchi, and S. Yabukami, "Sandwich films: Properties of a new soft magnetic material," *Nature*, vol. 407, pp. 150–151, 2000.
[10] W. D. Li, O. Kitakami, and Y. Shimada, "Study on the in-plane uniaxial anisotropy of high permeability granular films," *J. Appl. Phys.*, vol. 83, pp. 6661–6663, 1998.
[11] V. Bekker, K. Seemann, and H. Leiste, "A new strip line broad-band measurement evaluation for determining the complex permeability of thin ferromagnetic films," *J. Magn. Magn. Mater.*, vol. 270, pp. 327–332, 2004.