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FeNi-based Film Nanostructures For High Frequency Applications: Design and Characterization

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Abstract. FeNi films were deposited by DC magnetron sputtering at different Ar pressures. The structure and magnetic properties of the FeNi films are affected by the Ar pressure. Ferromagnetic resonance (FMR) measurements were done at a frequency of about 8.85 GHz. Both the value of resonance field and resonance line width show strong dependence on the Ar pressure: the lowest value of the resonance field and the narrowest resonance width correspond to the smallest argon pressure. Increase of the Ar pressure causes the films to have a significant perpendicular anisotropy with the easy axis pointing out of the plane. The magnetic properties and FMR were also studied for the $[FeNi(170\ nm)/Ti]_n/FeNi(170\ nm)$ (n = 1, 2, 5) structures prepared at the smallest Ar pressure. The FMR studies showed that the obtained multilayers are very robust: the value of the resonance field and resonance line width of the $[FeNi/Ti]_n/FeNi$ multilayers are very close to the corresponding values for the FeNi films.

Introduction

Modern fabrication technologies result in the appearance of many nanostructured materials which require precise characterization. Among other types of magnetic nanostructures one can mention thin films and multilayers as the materials especially attractive for electronic and biomedical applications [1-2]. FeNi thin films and multilayered structures are materials for high frequency devices, like inductors or the magnetoimpedance-effect (MI)-based magnetic-field sensors [2-4]. A relatively high thickness of the soft magnetic films of the order of microns is required for the high MI values [5]. On the other hand, an increase in the thickness of a permalloy film above the critical value $L_c \sim K_\perp^{-0.5}$, where $K_\perp$ is the perpendicular magnetic anisotropy constant, results in an increase in coercivity [6-7]. In this work we study magnetic properties and microwave absorption of a series of thin permalloy films and $[FeNi(170\ nm)/Ti]_n/FeNi(170\ nm)$ (n = 1, 2, 5) multilayered structures prepared by the dc magnetron sputtering at different values of argon pressure, aiming to obtain the magnetically soft thick ferromagnet.

Experimental

As the first step the FeNi thin films were deposited by the DC magnetron sputtering onto the glass substrates at room temperature using a $Fe_{20}Ni_{80}$ target. A dc "in plane" magnetic field of 250 Oe was applied during the deposition in order to induce an uniaxial magnetic anisotropy. The background pressure was 3×10^{-7} mbar. Three series of samples were prepared at different argon pressures: P1 series at 3.8×10^{-3}, P2 series at 8.3×10^{-3}, and P3 series at 2.4×10^{-2} mbar (Table 1). The thicknesses of the films were in the range of 20 nm to 300 nm. As the second step,

FeNi/Ti/FeNi trilayers were prepared with a thickness of the Ti layer varying from 2 to 20 nm in order to determine an optimum thickness of the Ti spacer, taking into account the coercive force, H_c, value. Finally, the $[FeNi(170\ nm)/Ti]_n/FeNi(170\ nm)$ (n = 2, 5) multilayers were prepared at the P1 pressure, which allowed us to obtain the samples with the best magnetic softness. The hysteresis loops were measured by a vibrating sample magnetometer, VSM, in the film plane in the longitudinal direction, i.e. parallel to the direction of the application of magnetic field during the sample deposition, transverse and perpendicular to the sample plane. The values of H_c, saturation magnetization, M_s, and the constant of perpendicular magnetic anisotropy were determined from the hysteresis loops. The static magnetizations determined by VSM for thin FeNi films were in a reasonable agreement with the common value for the bulk permalloy alloys.

The microwave studies of all types of the samples were done by a cavity-perturbation technique with a conventional homodyne detection with a half-wavelength rectangular cavity. The external magnetic field H was rotated in plane perpendicular to the plane of the sample. For the "in plane" configuration, the resonance field $H_{res} = H_{||}$ and for the "out of plane" configuration, $H_{res} = H_{\perp}$ [8]. The ferromagnetic resonance (FMR) measurements, i.e. resonant absorption of microwave radiation in a magnetic material, were done at room temperature for the resonance frequency, *f*, of about 8.85 GHz. In all cases, only one resonance line was observed. A half power width, ΔH, was determined from the microwave absorption measurement for each sample.

Table 1. Selected properties of the single-layer films and multilayered structures prepared at different values of argon pressure: P1 = 3.8×10^{-3} ($4\pi M_s$ = 9.9 kG); P2 = 8.4×10^{-3} ($4\pi M_s$ = 9.5 kG); and P3 = 2.4×10^{-2} mbar ($4\pi M_s$ = 7.8 kG), where M_s is saturation magnetization measured by VSM.

Sample	Structure/Pressure	H_c [Oe]	$H_{\|\|}$ [kOe]	$H_{\perp}$ [kOe]	$4\pi M_{eff}$ [kG]	ΔH [Oe]
N1	FeNi (25 nm); P1	0.9	0.84	12.6	9.6	50
N2	FeNi (65 nm); P1	1.0	0.83	12.9	9.9	50
N3	FeNi (122 nm); P1	1.1	0.83	12.8	9.9	80
N4	FeNi (238 nm); P1	6.0	0.83	12.8	9.9	80
N5	FeNi (258 nm); P1	15	0.79	12.8	9.9	70
N6	FeNi (25 nm); P2	4.5	1.10	10.8	7.5	100
N7	FeNi (65 nm); P2	10	1.13	9.2	6.3	200
N8	FeNi (75 nm); P2	34	1.14	10.0	6.4	230
N9	FeNi (88 nm); P2	45	1.03	10.5	7.5	220
N10	FeNi (300 nm); P2	35	1.03	10.2	7.2	280
N11	FeNi (23 nm); P3	11	1.50	7.9	4.8	260
N12	FeNi (42 nm); P3	17	1.46	8.0	5.0	290
N13	FeNi (73 nm); P3	45	1.45	8.0	5.0	320
N14	FeNi (96 nm); P3	40	1.38	8.3	5.1	330
N15	FeNi (260 nm); P3	45	1.30	8.4	5.4	480
S1	FeNi (170 nm); P1	0.7	0.86	12.7	9.7	80
S2	FeNi(170 nm)/Ti(20 nm)/FeNi(170 nm); P1	1.1	0.84	12.6	9.6	80
S3	FeNi(170 nm)/Ti(12 nm)/FeNi(170 nm); P1	0.5	-	-	-	-
S4	FeNi(170 nm)/Ti(10 nm)/FeNi(170 nm); P1	0.4	-	-	-	-
S5	FeNi(170 nm)/Ti(6 nm)/FeNi(170 nm); P1	0.2	0.84	12.9	9.9	120
S6	FeNi(170 nm)/Ti(4 nm)/FeNi(170 nm); P1	0.2	-	-	-	-
S7	FeNi(170 nm)/Ti(3 nm)/FeNi(170 nm); P1	0.2	-	-	-	-
S8	FeNi(170 nm)/Ti(2 nm)/FeNi(170 nm); P1	11.0	0.84	12.5	9.6	150
S9	$[FeNi(170\ nm)/Ti(6\ nm)]_2/FeNi(170\ nm)$; P1	0.1	0.82	12.7	9.8	120
S10	$[FeNi(170\ nm)/Ti(6\ nm)]_5/FeNi(170\ nm)$; P1	0.1	0.82	12.5	9.6	140

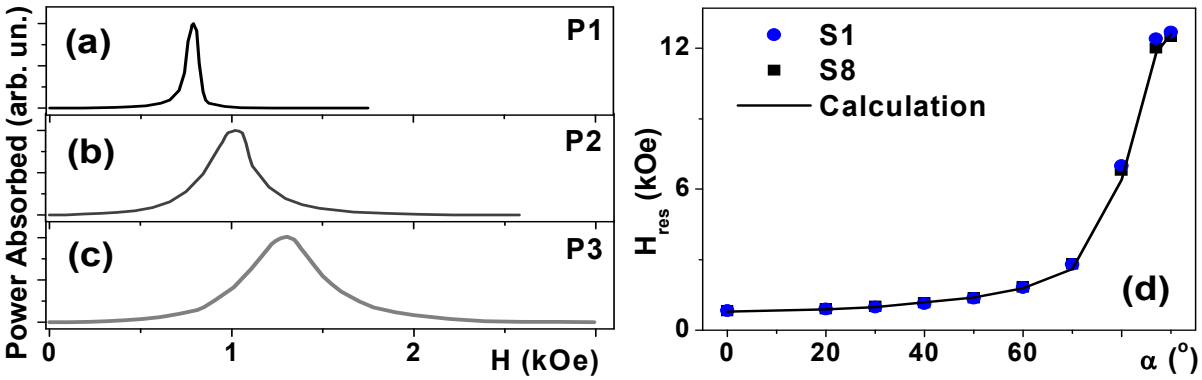

Fig. 1. FMR at f ≈ 8.85 GHz as a function of the field applied in the plane of about 300 nm thick thin films prepared at different Ar pressures (a-c). Angular dependence of the resonance field in the S1 and S8 films. The full line was obtained using the method described in Ref. [9] with the parameter values given in Table 1.

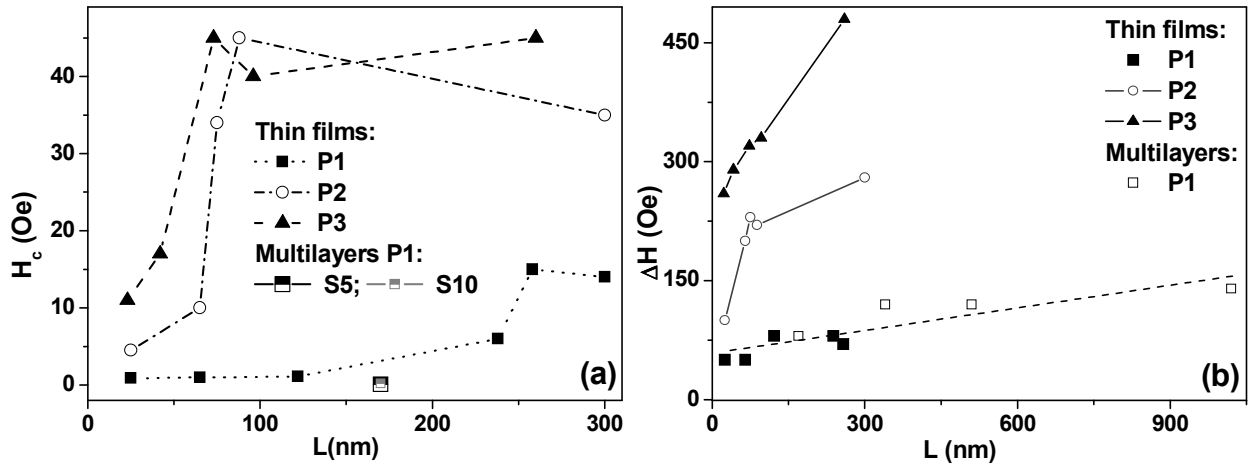

Fig. 2. The dependence of the coercivity of thin FeNi films (selected data for S5 and S10 multilayers are also shown) prepared at different Ar pressures (a). The dependence of FMR line width of FeNi films and [FeNi(170 nm)/Ti(6 nm)]$_n$/ FeNi(170 nm) (n= 1, 2,5) nanostructures on total thickness of magnetic components.

Results and Discussion

It was found that the magnetic properties and microwave absorption of the FeNi films are affected by the Ar pressure in chamber. Fig. 1 shows the FMR spectra of the thin films and multilayers prepared at different Ar pressures. Both the value of the resonance field and resonance line width show a strong dependence on the argon pressure: the lowest value of the resonance field and the narrowest resonance width of about 70 Oe correspond to P1 pressure. The values of the effective magnetization $4\pi M_{eff}$ were calculated in accordance with the familiar formulas:

$$\left(\frac{\omega}{\gamma}\right)^2 = H_{II}(H_{II} + 4\pi M_{eff}) \quad (1a)$$

$$\left(\frac{\omega}{\gamma}\right) = H_{\perp} - 4\pi M_{eff} \quad (1b)$$

where $\omega = 2\pi f$, γ is the gyromagnetic ratio and g = 2.12. Equations (1a, 1b) can be used to determine $4\pi M_{eff}$ and thereby obtain the angular dependence of the FMR field (Fig.1). The values of the effective magnetization $4\pi M_{eff}$ calculated in accordance with familiar formula using the values

of the parallel ($\alpha = 0^o$) and perpendicular ($\alpha = 90^o$) resonance fields are close to the $4\pi M_{eff} \approx 9.9$ kG which is just about the value of the saturation magnetization obtained from VSM. For the high Ar pressure the observed effective magnetization values of $4\pi M_{eff} \approx 5.5$ kOe can be understood, if one takes into account the perpendicular magnetic anisotropy field obtained from the VSM measurements. For all Ar pressures, at the critical thickness of the film L_c, the transition into the "transcritical" state [6-7] and the increase of the coercivity occurred (Fig. 2a). Indeed, an increase of the Ar pressure during the deposition results in growth of the films with the significant perpendicular anisotropy and, therefore, the transition into the "transcritical" state takes place at lower thicknesses.

The angular dependences of the resonance fields were measured in all cases. It was established (see selected examples of the experimental data and a fit in Fig. 1 (d)) that the magnetization of the samples was uniform with the strain induced anisotropy field having a symmetry axis along the normal to the film. It is worth mentioning that even for the S8 multilayer with the highest H_c values a very good agreement between the calculated and experimental angular dependences was obtained. The values of the resonance fields and the resonance line widths of the $[FeNi/Ti]_n/FeNi$ multilayers are very close to the corresponding values for the FeNi films prepared at the pressure P1 and significantly smaller in comparison with the H_{res} and ΔH values for the samples prepared at a higher Ar pressure. The results obtained here should help optimize the parameters necessary for the meaningful use of the FeNi-based magnetic nanostructures in the high frequency technological applications.

Summary

Permalloy films were prepared at different Ar pressures: P1 series at 3.8×10^{-3}, P2 series at 8.3×10^{-3}, and P3 series at 2.4×10^{-2} mbar. As the second step FeNi(170 nm)/Ti/FeNi(170 nm) trilayers were prepared. It was found that FeNi/Ti(6 nm)/FeNi trilayers show the smallest coercivity. Finally, $[FeNi(170nm)/Ti(6\ nm)]_n/FeNi(170\ nm)$ (n = 2, 5) multilayers were prepared at P1 argon pressure. FMR studies showed that obtained multilayers are very robust: the value of the resonance field and resonance line width of the $[FeNi/Ti]_n/FeNi$ multilayers are very close to corresponding values for FeNi films prepared in pressure P1.

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References

[1] H.A. Ferreira, D.L. Graham, P.P. Freitas, J.M.S. Cabral, J. Appl. Phys. 93 (2002), p. 7281.

[2] G.V. Kurlyandskaya, J. Magn. Magn. Mater. 321 (2009), p. 662.

[3] L.V. Panina and K. Mohri, Sens. Act. 81 (2000), p. 71.

[4] M. Vazquez, J.P. Sinnecker, G.V. Kurlyandskaya: Mater. Sci. Forum 302-303 (1999) p. 209.

[5] A.S. Antonov, S.N. Gadetskii, A.B. Granovskii, A.L. Dyachkov, V.P. Paramonov, N.S. Perov, A.F. Prokoshin, N.A. Usov, Fiz. Met. Metalloved. 83 (1997), p. 61.

[6] Y. Sugita, H. Fujiwara, and T. Sato, Appl Phys. Lett., Vol. 10, (1967) p. 229.

[7] A.V. Svalov, G.V. Kurlyandskaya, H. Hammer, P.A. Savin, O.I. Tutynina, Tech. Phys. 49 (2004), p. 868.

[8] S.M. Bhagat, Metals Handbook, Materials Characterization, Ferromagnetic Resonance (American Society for Metals, Metal Park, OH, 1986) p. 276.

[9] S.I. Patil, D. Tan, S.E. Lofland, S.M. Bhagat, I. Takeuchi, O. Famodu, J.C. Read, K.-S. Chang, C. Craciunescu, M. Wuttig, Appl. Phys. Lett. 81 (2002), p. 1279.