ISSN 1062-8738, Bulletin of the Russian Academy of Sciences. Physics, 2014, Vol. 78, No. 4, pp. 328–329. © Allerton Press, Inc., 2014.
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Spin-Wave Resonance in Multilayer FeNiP/Pd Films

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Abstract—Ferromagnetic and spin wave resonances are studied in FeNiP/Pd multilayer films obtained via chemical vapor deposition. The partial exchange interaction constant of polarized Pd films is found to be $A_{Pd} \approx 1 \times 10^{-7}$ erg/cm.

DOI: 10.3103/S1062873814040145

Spin wave resonance is the excitation of standing dipole-exchange spin waves by a homogeneous alternating field in magnetic thin films. The expression for the resonance fields has the form

$$H_r = \omega/\gamma + 4\pi M_{eff} - \eta k^2, \tag{1}$$

where $\eta = 2A/M_0$ is the spin wave rigidity (or dispersion coefficient) of the material in which the spin waves are excited; wave vector $k = n(\pi/d)$ is determined by number n of half-waves that fit into thickness d of the film; M_{eff} is the effective magnetization, which differs from saturation magnetization M_0 by the contribution from elastic stresses; and A is the constant of exchange interaction.

Multilayer ferromagnetic films are now being studied extensively due to the numerous physical phenomena found to occur in these structures. Van Stapele et al. [1] demonstrated, both theoretically and experimentally, that when making spin-wave resonance spectral measurements in multilayer Fe/Ni films, relation (1) proved valid with $\eta = \frac{2A_{eff}}{\langle M \rangle}$. A_{eff} being a modified exchange interaction constant of the composite structure, $d = N(d_1 + d_2)$ standing for the thickness of the multilayer film, and N denoting the number of double layers. The relationship between A_{eff} and the partial exchange interaction constants of individual layers is given by the expression

$$\frac{d}{A_{eff}} = N\left(\frac{d_1}{A_1} + \frac{d_2}{A_2}\right). \tag{2}$$

The spin-wave resonance spectra for multilayer ferromagnetic/nonferromagnetic material films have been recorded in a number of works: for $Ni_{81}Fe_{19}/Zr$ films in [2], for $Ni_{81}Fe_{19}/W_{90}Ti_{10}$ films in [3], for Co/Pt films in [4], for Co/Pd films in [5], and for NiFe/DyCo/NiFe films in [6]. The spectra recorded

Table 1. Effective magnetization M_{eff} and saturation magnetization M_0 of the $[(Fe_{32}Ni_{68})_{98}P_2/Pd] \times N$ and $[(Fe_{20}Ni_{80})_{98}P_2/Pd] \times N$

	M_{eff}, Gs	M_0, Gs
$[Fe_{32}Ni_{68}(150)/Pd(10$ Å$)] \times 15$	518	709
$[Fe_{32}Ni_{68}(30)/Pd(10$ Å$)] \times 25$	696	780
$[Fe_{20}Ni_{80}(120)/Pd(10$ Å$)] \times 20$	874	690
$[Fe_{20}Ni_{80}(70)/Pd(10$ Å$)] \times 20$	616	440
$[Fe_{20}Ni_{80}(50)/Pd(10$ Å$)] \times 25$	576	424

Table 2. Values of effective and partial exchange interaction constants A_{eff} and A_{Pd}, respectively, for the $[(Fe_{32}Ni_{68})_{98}P_2/Pd] \times N$ films containing 2 at % P in our FeNi alloy

	$A_{eff} \times 10^{-6}$, erg/cm	$A_{Pd} \times 10^{-6}$, erg/cm
[FeNi(150 Å)/Pd(10 Å)] × 15	0.475	0.11
[FeNi(120 Å)/Pd(10 Å)] × 10	0.424	0. 09
[FeNi(90 Å)/Pd(10 Å)] × 20	0.57	0.04
[FeNi(60 Å)/Pd(10 Å)] × 20	0.4	0.14
[FeNi(30 Å)/Pd(10 Å)] × 25	0.16	0.05

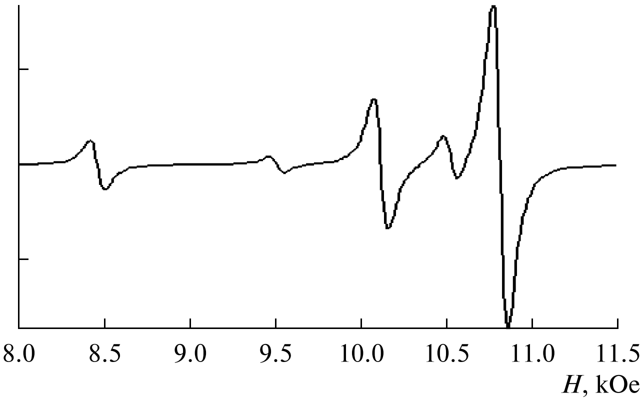

Fig. 1. Spin-wave resonance spectrum of a [FeNi(40 Å)/Pd(10 Å)] · 25 film containing 2 at % P in FeNi alloy with the external field normal to the film plane.

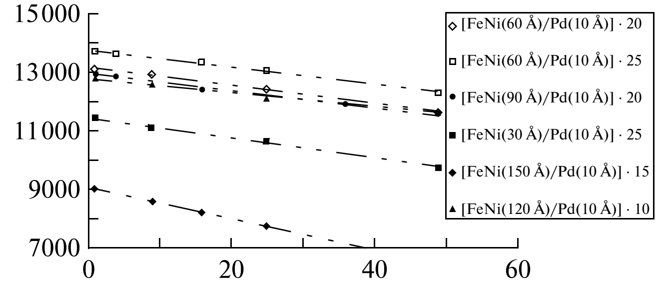

Fig. 2. Resonance field strength H_r as a function of the squared serial number n^2 of the mode of the spin-wave resonance spectra observed in the orthogonal experimental geometry for $[(Fe_{32}Ni_{68})_{98}P_2/Pd] \cdot N$ multilayer films containing 2 at % P.

in these films indicated the excitation of standing dipole-exchange spin waves caused by exchange spin waves passing through the layers of the nonferromagnetic material. This testified to the existence of a magnetic moment in the intermediate layers; i.e., to the polarization of these layers in the multilayer structure, their thickness being limited. When recording spin-wave resonance spectra, expression (2) allows us to determine the partial exchange interaction constant for a spin wave propagating through the polarized metal layers.

In this work, multilayer FeNiP/Pd films were studied via ferromagnetic and spin-wave resonance. Our aim was to find the partial exchange interaction constant of our polarized Pd films.

Multilayer FeNiP/Pd films and standard reference single-layer FeNiP films different in composition were obtained via chemical vapor deposition on a glass sheet. The phosphorus concentration in the prepared alloys was 2 and 10 at %. The total thickness of the $Fe_{1-x}Ni_x$/Pd(10 Å) was 2000 Å. Our investigations were conducted by means of ferromagnetic and spin-wave resonance spectroscopy at a frequency of f = 9.2 Hz at room temperature in magnetic fields of up to 20 kOe. The saturation magnetization was measured with a vibration magnetometer at room temperature and magnetic field strengths of up to 12 kOe.

Table 1 lists the values of M_{eff} for the resulting films. Values of M_0 measured with the magnetometer are also listed here. The differences between M_{eff} and M_0 were due to elastic stresses in the investigated structures and the concentration dependence of the magnetostriction constant ($M_{eff} = M_0 + 3\lambda\sigma/M_0$, where λ is the magnetostriction constant of the material being studied and σ is the magnitude of local stresses). The results given in the table point to compressive elastic stresses in our multilayer structures: $\sigma < 0$.

The spin-wave resonance spectrum of Fig. 1 was recorded with the film normal to the direction of the external magnetic field. Figure 2 illustrates strength H_r of the resonance field as a function of the squared serial number of the mode (n_2) in the spin-wave resonance spectra. The above dependences allowed us to determine the values of A_{eff} for multilayer structures, and to calculate the partial exchange interaction constants of the polarized Pd layers using values of the partial exchange interaction constants of our standard single-layer reference films. The results are listed in Table 2.

The presented A_{Pd} values agree with those determined from the spin-wave resonance spectra of multilayer Co/Pd structures in [5].

ACKNOWLEDGMENTS

This work was performed by order of the RF Ministry of Education and Science.

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Translated by S. Kittell