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Spin-Wave Resonance Detection of Nanostructured Magnetic Alloy Inhomogeneities, Using the Example of Co–P and Co–Ni Planar Systems

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Abstract—Inhomogeneous layered magnetic thin films of amorphous and nanocrystalline Co–P and Co–Ni alloys are studied via spin-wave resonance. It is found that the formation of a magnetic potential profile specified over the coating thickness leads to characteristic modifications of the spin-wave resonance spectrum. Another important factor that determines the type of modification is the dominant magnetic parameter (the constant of magnetization or exchange coupling).

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INTRODUCTION

It is well known that microwave electromagnetic radiation can induce standing spin waves in thin ferromagnetic films [1, 2]. If external magnetic field H applied orthogonally to the film plane ($H \perp h$), the resonance condition is

$$H_n = \frac{\omega}{\gamma} + 4\pi M_{\text{eff}} - \frac{2A}{M_{\text{S}}} k^2, \tag{1}$$

where ω is the fixed microwave field frequency, $A = 2JS^2/a$ is the exchange coupling constant, and $k = n\pi/L$ is the wave vector (where n is the mode number and L is the film thickness). The dependence of H_{r} on n^2 can be plotted using the experimental spin-wave resonance (SWR) curve and identifying n according to certain rules that were clearly described in [3, 4].

The possibilities of other types of the dependence of the resonance fields in forming a magnetic potential of a certain type were theoretically predicted by Schlomann [5] and Portis [6]. These dependences were later experimentally confirmed in studying various planar structures [7–10]. In these experimental works, however, the detected spectra had an unpredictable shape even for planar systems of the same chemical composition, testifying to the random distribution of magnetic parameters in these systems.

The aim of this work was to refine a technique for forming structures with a specified distribution of the magnetic spin parameter over the film thickness.

EXPERIMENTAL

The investigated film samples were synthesized via chemical deposition from appropriate metal salt solutions. Number N of the $[Co_XNi_{1-X}]_N$ and $[Co_XP_{1-X}]_N$ film layers ranged from 7 to 9, and the thickness of individual layers was 20–25 nm. To obtain the desired $4\pi M_{\text{eff}}(z)$ and $A(z)$ dependences, the ferromagnetic composition of the film was changed monotonically over the film thickness from one layer to another.

The resonance characteristics were measured at room temperature on a conventional electron spin resonance spectrometer with a pumping frequency of 9.2 GHz. The films were magnetized parallel and perpendicular to the sample surface in fields of up to 20 kOe.

RESULTS AND DISCUSSION

Two series of the Co–P multilayers had different profiles of the dominant magnetic parameter (exchange coupling constant). The samples in the first series consisted of alternating amorphous (90 at % of Co) and crystalline (93 at % of Co) Co–P layers formed via stepwise variation of the phosphorous concentration over the sample thickness (Fig. 1a). The samples in the second series were gradient coatings of the same alloy, but with a phosphorous concentration selected to ensure the quasilinear change in the phosphor content over the coating thickness, from values corresponding to the amorphous alloy to ones typical of crystalline compositions (Fig. 1b). An aperiodic magnon crystal thus formed. The different characters of the variation

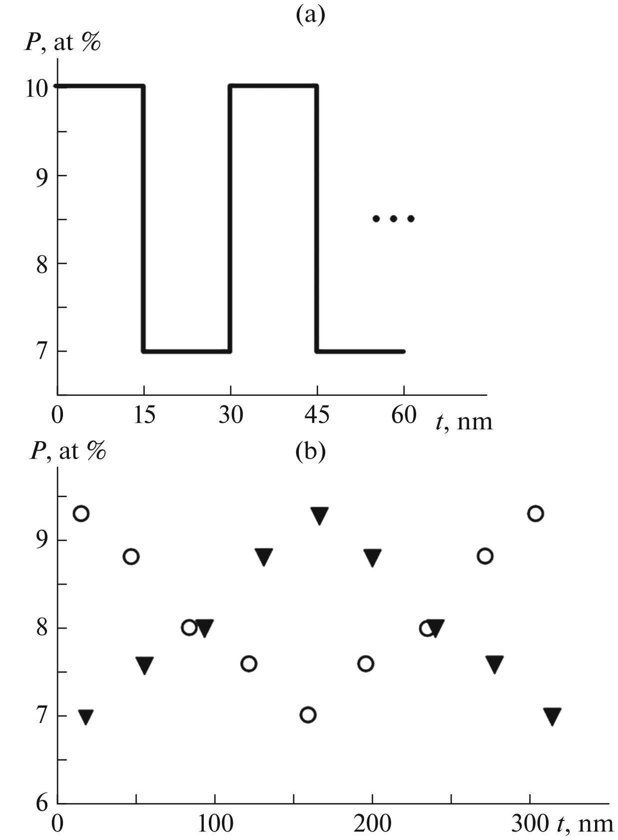

Fig. 1. Exchange coupling constant distribution that results in the formation of (a) the first stop band of the magnon crystal or (b) the dependence of the resonance fields $H_r(n) \sim n^{2/3}$.

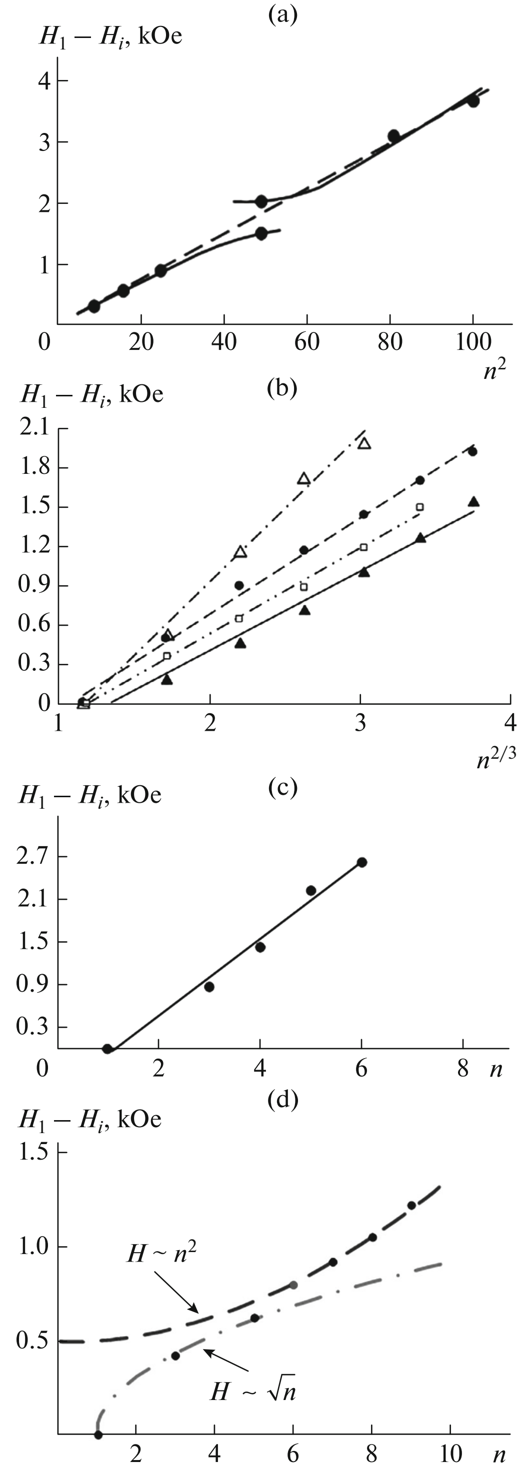

Fig. 2. Dependences of resonance fields on mode number for (a, b) Co–P and (c, d) Co–Ni planar systems.

in the average value of the dominant magnetic parameter over the film thickness for the two considered cases led to different modifications of the SWR spectra. The first quasi-Brillouin zone formed with a stepwise thickness profile of the phosphorous concentration (Fig. 2a), as is indicated by a doublet detected at the seventh peak. The quasilinear change in the phosphorous concentration over the Co–P gradient film thickness produced the dependence of the resonance fields on mode number $H_r(n) \sim n^{2/3}$ (Fig. 2b).

The SWR spectra of the Co–Ni multilayers were modified by changing the magnetization over the thickness in order to form a parabolic profile of the magnetic parameter [6, 11]. The first type of modification was obtained by increasing the magnetization in each layer from the substrate to the center from the lower to the higher value (Fig. 3a). The spectral dependence of the fields on the mode number is in this case described as $H_r(n) \sim n$ $(0 < k < k_{\text{critical}})$ (Fig. 2c). The second type of modification was obtained by reducing the magnetization in each layer from the substrate to the center from the higher to the lower value (Fig. 3b), thus modifying the positions of the resonance field in the SWR spectrum: $H_r(n) \sim \sqrt{n}$ in the range of $0 < k < k_{\text{critical}}$ and $H_r(n) \sim n^2$ $(k > k_{\text{critical}})$ (Fig. 2d).

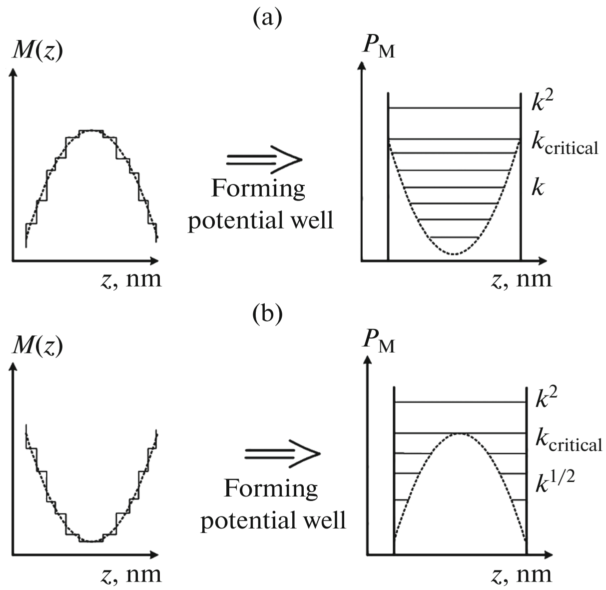

Fig. 3. Functional dependence of magnetization M over the layered coating thickness and the profile of magnetic potential P_M for the Co–Ni planar coatings

CONCLUSIONS

The experimental SWR spectra of the chosen planar systems testify to the formation of modified spectra of exchange standing spin waves, which indicate the formation of the first Brillouin zone of the magnon crystal [12] and different magnetic potential profiles specified by the technological parameters.

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