MAGNETIC AND RESONANCE PROPERTIES OF EXCHANGE SPRING MULTILAYERS $[(CoP)_{soft}/NiP/(CoP)_{hard}]_n$

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Exchange spring magnets based on interlayer exchange coupling between hard and soft magnetic layers [1] are a new class of nanoscale materials which are suitable for solving a number of spintronics problems [2,3]. When the interlayer coupling is controllable, e.g. by introducing of a nonmagnetic layer [4], there is a good reason to expect new manifestations in magnetic behavior, which can be of practical importance.

Our previous study [5,6] has revealed that an increase in the number of blocks (*n*) for multilayer structures $[(CoP)_{soft}/NiP/(CoP)_{hard}]_n$ enhances the effect of the magnetically soft layer on the magnetization of the film structure. The insertion of a nonmagnetic NiP spacer causes extraordinary magnetization and coercivity oscillations. The nonmagnetic layer affects the exchange coupling between the ferromagnetic layers. The exchange spring type behaviour was found to be more pronounced with the number of structural blocks increasing. The aim of present study was to investigate changing the magnetic state in multilayer film structures consisting of alternate magnetically soft and hard layers and separated by a nonmagnetic spacer, when the number of blocks (*n*) increases in this structure.

$[(CoP)_{soft}/NiP/(CoP)_{hard}]_n$ films were made using a chemical deposition method [5]. The $(CoP)_{hard}$ layer was in the hexagonal polycrystalline state whereas the $(CoP)_{soft}$ layer was amorphous. The magnetic anisotropy of hexagonal cobalt is two orders of magnitude greater than the anisotropy of amorphous cobalt. The intermediate NiP layer was amorphous and nonmagnetic. We synthesized the $(CoP)_{soft}$, $(CoP)_{soft}$/NiP films and multilayer structures with the number of blocks $n = 1, 5, 10$. Both magnetic layers had thickness of $t = 5$ nm and the nonmagnetic layer thickness was $t_{NiP} = 2$ nm. Since ferromagnetic resonance technique is sensitive to changes in internal fields of various natures, we used it for studying our materials. The electron magnetic resonance spectra were measured on a "Bruker ELEXSYS E580" EPR-spectrometer operating at frequency 9.4 GHz. In our experiment, the magnetic field was parallel to the film plane. Then the spectra obtained were processed by fitting the experimental integral absorption curve to the sum of Lorentzian lines [6].

The FMR-spectrum of a trilayer film structure (*n*=1) consists of two microwave absorption lines located in the region between the resonance fields corresponding to the (CoP_{soft}) film and the bilayer film (CoP_{soft}/NiP). When the number of blocks (*n*) is increased, a third peak of microwave absorption arises. With increasing in the number of blocks, the shape of the FMR-spectrum changes as well as the resonance field of third peak markedly changes too [6]. In the case of film structures with a large number of blocks, the appearance of the third absorption peak does not fit into the simple two-sublattice model.

The magnetic hysteresis loops study [5] exhibited that the features of magnetization can be explained provided that a long-range interlayer interaction exists. Consideration of the negative biquadratic interlayer coupling can cause skewed structure but the system still remains as two-sublattice model.

If one subsystem is divided into two, a situation similar to the Yafet–Kittel-type of magnetic ordering [7] for ferrites may be observed, when a skewed magnetic structure is formed, i.e. antiferromagnetic interaction has to be realized between the layers following the nearest magnetic layer. Consequently, there is a ferromagnetic interaction between the magnetically soft and magnetically hard layers, while