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Field dependence of magnetization for a thin ferromagnetic film on rough antiferromagnetic surface

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ABSTRACT

Simple theoretical models are proposed for the analytical and the numerical study of the exchange bias phenomenon in the layered systems with rough AFM/FM interface. It is shown that the qualitative type of the magnetization curves depend crucially on the variation of the roughness degree. We obtain that the magnetization curves are qualitatively of the same type in the cases of perfect and rough FM/AFM interfaces. The method which allow to identify the character of the interface (rough or perfect) is proposed.
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1. Introduction

The exchange bias phenomenon (EBP) consists in a shift of the magnetization curve on the external field $M(H)$ along the field axis. This phenomenon is usually observed in contacting ferromagnetic (FM) and antiferromagnetic (AFM) systems. The study of this phenomenon is a long standing question (see e.g. [1]). Recently EBP is of a great interest because of technical application of the multilayered systems with alternating thin FM and AFM films [2]. In the case of uncompensated AFM interface the appearance of the EBP is due to the local impact of the AFM boundary layer through FM/AFM interface on the FM subsystem. An uncompensated AFM interface generates nonzero average local field $\langle J_0 M^0_{afm} \rangle$,

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where J_0 is the parameter of exchange interaction through the interface and M^0_{afm} is the average magnetization of the AFM boundary layer.

The recent experimental studies [3,4] show that the shifted magnetization loop may has a more complicated form: the dependence can be asymmetric with a horizontal plateau $M = const$. These features are associated to the impact of the AFM on the FM. Since the AFM is presented then the inhomogeneous magnetization distribution (domains or incomplete domain walls) appears inside the FM film.

In the perfect uncompensated interface the most possible is the appearance of the FM domain walls (DW) parallel to the plane of the FM/AFM interface for the great value, of the FM layer thickness l. It was shown (see [5]) that the type of the magnetization curve $M(H)$ depends on the value of the exchange interaction J_0. In particular, when J_0 increases the symmetric hysteresis loop shifts along the field on the value J_0 and then becomes asymmetric. For the fixed J_0, the qualitative type of the magnetization curve does not change with the FM film thickness l. The exchange bias changes on the value $\delta H_{eb} \sim 1/l$ and the width of the hysteresis loop ΔH changes.

However, the experimental works show that the EBP is observed in the systems with a compensated interface $M^0_{afm} \simeq 0$ and in the case of very disordered or rough interfaces as well (see, e.g. [6,7]). To explain this fact in [8] we propose a model with atomic steps on the FM/AFM boundary and domains with alternating M^0_{afm} directions. There is an other model proposed in [9]. In this model the exchange magnetic interaction of the contacting FM and AFM subsystems through the interface is provided only by the point magnetic contacts (MPC) randomly distributed with the small density. The MPC density do not exceed a couple of percent of a total amount of the surface atoms [4,10].

The goal of this paper is to study analytically the magnetization curves $M = M(H)$ in the presence of the MPC for simple models. The main result is that the magnetization dependencies coincide quantitatively with hysteresis loops obtained earlier for a model with the perfect interface. However, our approach allow us to determine the origins of the EBP in such kind of systems. In order to do this we have to obtain dependence of the magnetization on the FM film thickness.

2. Continuous one-dimension model for the interface with magnetic point contacts

A model of the FM/AFM interface with MPC (Fig. 1) is considered. In the framework of this model we assume that MPC create one-dimensional straight chains in the y direction. These chains are distributed periodically along x axis with the period L. The distribution of magnetization in the FM is uniform in the direction z perpendicular to the interface. AFM is assumed to be a hard magnetic material (i.e. its magnetization M^0_{afm} in the MPC is fixed).

The FM/AFM bilayer is in an external magnetic field H. We assume the strong easy-plane anisotropy caused for example by magneto-dipole interaction. The FM magnetic moments are in the easy plane because of the easy-plane anisotropy. The orientation of the magnetic moments in the easy plane is defined by the angle φ. This direction coincides with the direction of the axis of the single-ion magnetic anisotropy β. The interaction of the FM magnetic moments is defined by the parameter of the exchange interaction J. The exchange interaction in the MPC is described by

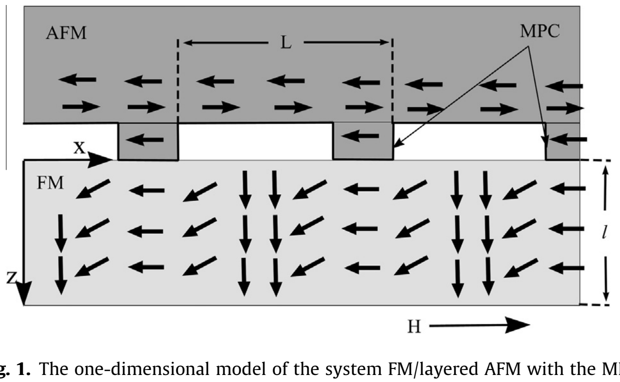

Fig. 1. The one-dimensional model of the system FM/layered AFM with the MPC.

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