Temperature dependences of the exchange bias in Dy-Co/FeNi bilayers

A.S. Rusalina, A.V. Svalov

anastasia.rusalina@urfu.ru

Institute of Natural Sciences and Mathematics, Ural Federal University, 620002 Ekaterinburg, Russia

Abstract. The work is devoted to the study of the magnetic properties of exchange-coupled Dy-Co/FeNi films in a wide temperature range. The temperature dependence of the spontaneous magnetization of the ferrimagnetic layer is the reason for the change in the order of magnetization reversal of the layers with a change in temperature. The efficiency of interlayer exchange interaction varies slightly with temperature.

Keywords: multilayer films, ferrimagnetism, magnetic compensation, interlayer exchange interaction, exchange bias

Control of the magnetic moment orientation in thin-film spintronic elements is one of the key aspects of the operation of such devices. In particular, in spin valves, the ferromagnetic layer is coupled by exchange interaction with an adjacent antiferromagnetic layer, a synthetic multilayer antiferromagnet, or a layer with a high coercive force. The ways of optimizing the functional properties of these layers, taking into account the features of specific devices and the conditions of their application, continue [1-3]. Among the promising materials, films of alloys of heavy rare earth elements with iron and cobalt are considered, in particular, amorphous ferrimagnetic films Dy-Co [4,5]. In this paper, a study of the magnetic properties of exchange-coupled film structures Dy-Co/FeNi in a wide temperature range, including the compensation temperature of the ferrimagnetic layer Dy-Co, is carried out.

$Dy_{20}Co_{80}$, $Fe_{20}Ni_{80}$ single layer films and exchange-coupled bilayers Dy-Co(20 nm)/FeNi(40 nm) were obtained by magnetron sputtering in an argon atmosphere. Deposition on glass substrates occurred in the presence of a constant magnetic field of 250 Oe oriented in the plane of the substrate. All samples were protected from oxidation by a buffer and capping Ta layer of 5 nm thick. Magnetic properties were studied using an MPMS-7XL measuring complex in the temperature range from 5 K to 300 K.

The characteristic minimum in the temperature dependence of magnetization $M(T)$ and the maximum in the dependence of coercive force $H_c(T)$ indicate the ferrimagnetic nature of the $Dy_{20}Co_{80}$ film. The magnetic compensation temperature T_{comp} was approximately 220 K. The Dy-Co, FeNi films and Dy-Co/FeNi bilayers had induced uniaxial magnetic anisotropy in the plane of the sample, the easy axis of magnetization (EA) of which coincides with the direction of the magnetic field present during sputtering.

Figure 1 shows the hysteresis loops measured for the Dy-Co/FeNi film along the EA at different temperatures. The features of the film magnetization reversal are determined by the balance of the Zeeman energy, magnetic anisotropy and interlayer exchange coupling, which orients parallel the magnetic moments of the FeNi layer and the magnetic sublattice Co of the Dy-Co layer. At T = 5 K, the Dy moment dominates in the total magnetic moment of the Dy-Co layer; therefore, in the absence of an external magnetic field, the magnetic moments of the Dy-Co and FeNi layers are ordered antiparallel.

In this case, the behavior of the Dy-Co/FeNi film is in many ways similar to the behavior of an "exchange" or "spin spring." One of these features is a shifted hysteresis-free minor loop of the soft magnetic layer's magnetization reversal (insert in Fig. 1,a). A strong external field aligns the magnetic moments of the layers parallel to each other, which is accompanied by the emergence and compression of an interlayer magnetic inhomogeneity such as a domain boundary. A decrease in the field is accompanied by a reversal of the magnetic moment of the FeNi layer and the disappearance of the interlayer magnetic boundary (Fig. 1,a). The boundary energy σ_w can be estimated using the well-known expression:

$$\sigma_w = 4(AK_u)^{1/2}, \qquad (1)$$

where A is the exchange interaction constant, K_u is the magnetic anisotropy constant. Substituting the corresponding A and K_u values for FeNi and Dy-Co films into this expression, we obtain σ_w = 0.2 erg/cm^2 if the boundary is formed in the FeNi layer, and σ_w = 2.1 erg/cm^2 if the boundary is formed in the Dy-Co layer. Comparison of these two σ_w values suggests that the boundary is formed in the FeNi layer.

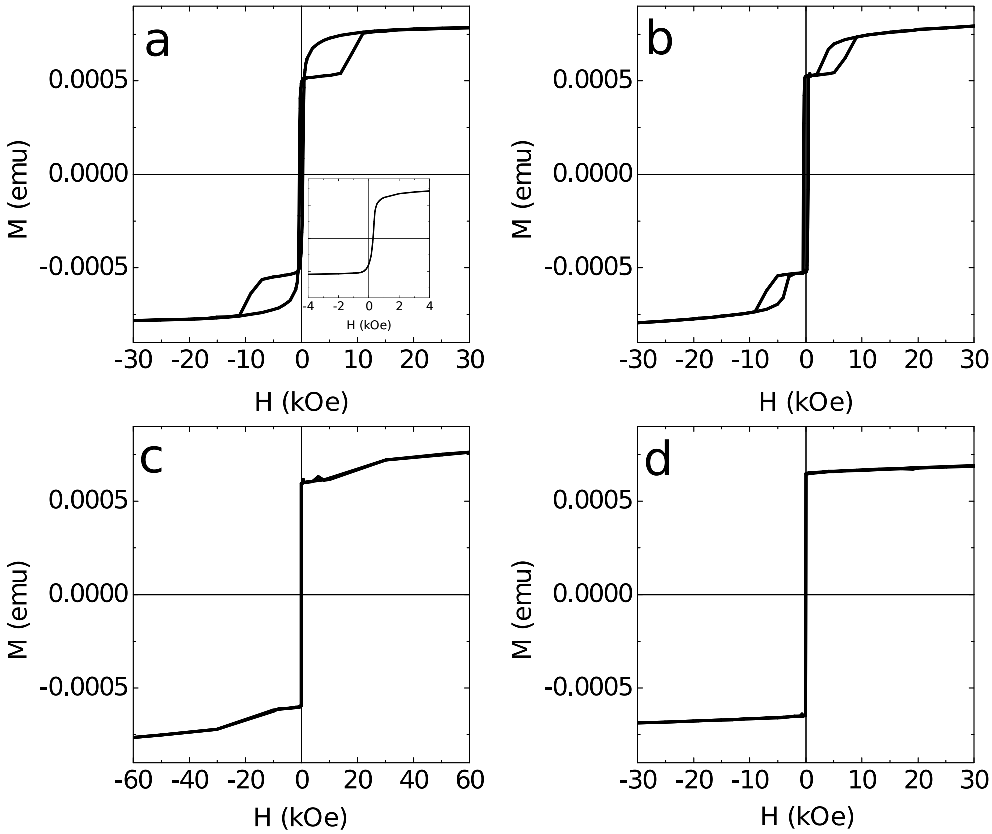

Fig. 1. Hysteresis loops for Dy-Co/FeNi films measured at different temperatures.

An increase in the sample temperature is accompanied by a decrease in the Dy-Co layer moment and its energy in the external field. This leads to a change in the sequence of layer magnetization reversal: when the field decreases, the Dy-Co layer is remagnetized first, and the magnetic moments of the layers are aligned antiparallel (Fig. 1,b,c). An increase in temperature also leads to the disappearance of hysteresis on the Dy-Co layer loop (Fig. 1,c). Most likely, this is due to a decrease in K_u of the Dy-Co layer and a partial displacement of the interlayer magnetic boundary into this layer.

Figure 2 shows the temperature dependence of the exchange bias field H_{eb} defined as the coordinate of the center of the shifted hysteresis loop. The sharp jump in the value of H_{eb} at $T = 50$ K is due to the fact that the sequence of magnetization reversal of the layers has changed. The subsequent increase in H_{eb} is associated with a decrease in the magnetic moment of the Dy-Co layer when approaching T_{comp}. The efficiency of the interlayer exchange interaction is characterized by the value of the constant j, which can be estimated using the well-known expression:

$$H_{eb} = j/M_b t_b, \quad (2)$$

where M_b and t_b are the magnetization and thickness of the layer, which is characterized by a displaced loop. The results of j calculations are shown in Fig. 2,b. Assuming that the interlayer coupling in Dy-Co/FeNi films is mainly determined by the exchange interaction of the moments of the FeNi layer and the Co sublattice of the Dy-Co layer, one could expect temperature independence of j. The observed spread of j values most likely reflects the fact that the value of H_{eb} is determined by the features of the formation of the interlayer magnetic boundary, and they change with a change in temperature.

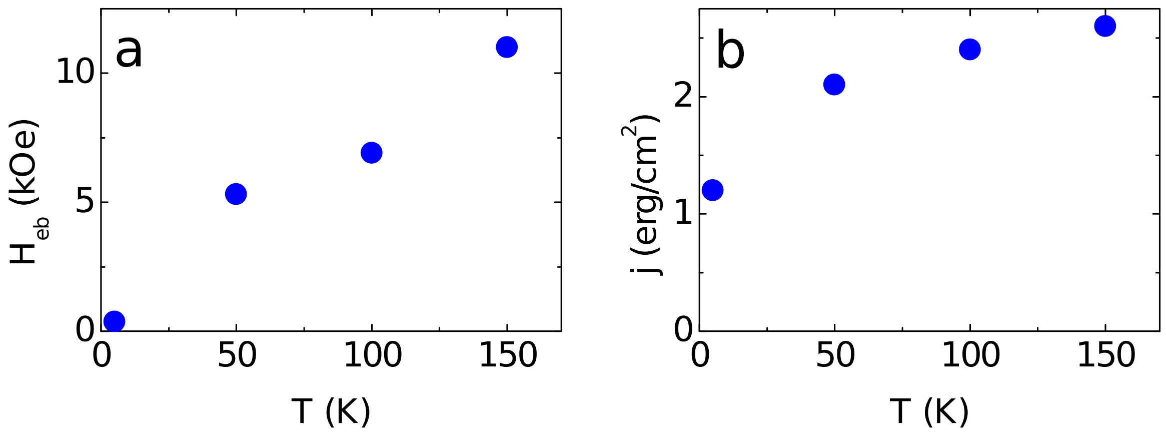

Fig. 2. Temperature dependences of the exchange bias field (a) and the constants of surface interlayer interaction (b) in the Dy-Co/FeNi film.

At $T > T_{comp}$, the magnetic moments of the Dy-Co and FeNi layers are ordered ferromagnetically; in a magnetic field, the Dy-Co/FeNi film behaves as a single whole (Fig. 1,d).

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