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Stability of perpendicular anisotropy in NiFe/Au/Co/Au multilayers☆

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Abstract

The influence of annealing on a giant magnetoresistance, magnetization reversal, and microstructure of magnetron sputtered spin valve $[NiFe/Au/Co/Au]_{10}$ multilayers (MLs) consisting of ferromagnetic layers with alternating in-plane (NiFe) and out-of-plane (Co) magnetic anisotropy has been investigated. It is shown that properties of the MLs are relatively stable against annealing up to 263 ° C and are primarily influenced by mixing at Au/Co interfaces. The MLs with thicker Co layers are more stable.

Keywords: Magnetic films and multilayers; X-ray diffraction; Magnetic measurements; Electronic transport

1. Introduction

Magnetic layered structures with alternating in-plane and out-of-plane anisotropy in neighboring magnetic layers, separated by nonmagnetic spacer, were shown to possess properties interesting from an application point of view [1–5]. In particular, it was demonstrated that $[NiFe/Au/Co/Au]_N$ multilayers display giant magnetoresistance (GMR) [1] and that their magnetic and magnetoresistive properties can be modified in a broad range by adjusting layers thicknesses [1] and/or using composite magnetic layers [2]. It was also shown that they are resistant to low temperature annealings [3] and display satisfactory temperature stability [4]. The aim of this study is to explain the observed changes of magnetic properties of $[NiFe/Au/Co/Au]_{10}$ MLs under the influence of high temperature annealings and to determine Co thickness range assuring the high thermal stability.

2. Experimental

The $[Ni_{80}Fe_{20}(2\,nm)/Au(1.9\,nm)/Co(t_{Co})/Au(1.9\,nm)]_{10}$ MLs with $t_{Co} = 0.6 - 1.2$ nm were deposited in Ar atmosphere using UHV magnetron sputtering. The films were deposited directly onto Si(1 0 0) substrates with native oxide. The sputtering rates were 0.06, 0.05, and 0.045 nm/s, for Au, NiFe and Co, respectively. The microstructure was investigated using low and high angle X-ray diffraction (LAXRD and HAXRD) with Cu Kα radiation. The magnetization reversal processes were studied at room temperature with a vibrating sample magnetometer (VSM). Current in-plane magnetoresistance was measured at RT in a four-point configuration. Magnetic fields up to 1600 kA/m (2 T), applied in-plane and perpendicularly, were used. The MR(H) dependence was calculated relative to the resistance at 1600 kA/m and the maximum value determined from MR(H) is called magnetoresistance (MR) amplitude throughout the text. The samples were cumulatively annealed in gas flow thermostat in dry N_2 in temperatures (T_A) up to 300 °C. Each annealing lasted 1 h.

3. Results and discussion

As was already shown [3] the MR amplitude in NiFe/Au/Co/Au MLs is not changed by annealings at $T_A \leq 250\,°C$. Annealings at higher temperatures ($T_A = 300\,°C$) lead to a strong degradation of the MR effect (Fig. 1). Exemplary $M(H)$ dependencies indicate that annealings at $T_A \leq 263°$ C modify the magnetization reversal processes of Co layers (Fig. 1) but do not result in the change of the anisotropy direction from out-of-plane (the anisotropy changes are discussed later). For magnetic field applied perpendicularly annealings result in the changes of nucleation (H_N) and domain annihilation (H_A) fields [3]. The values of this fields are significantly lower, however, than the shape anisotropy saturation field of NiFe layers ($H_S^{NiFe} = M_S^{NiFe}$) and thus Co layers influence directly the MR(H) only in limited field range: $|H| < H_N$, $H_A \ll H_S^{NiFe}$ [6]. That is the reason why MR amplitude does not change significantly for $T_A \leq 263\,°C$ (Fig. 2).

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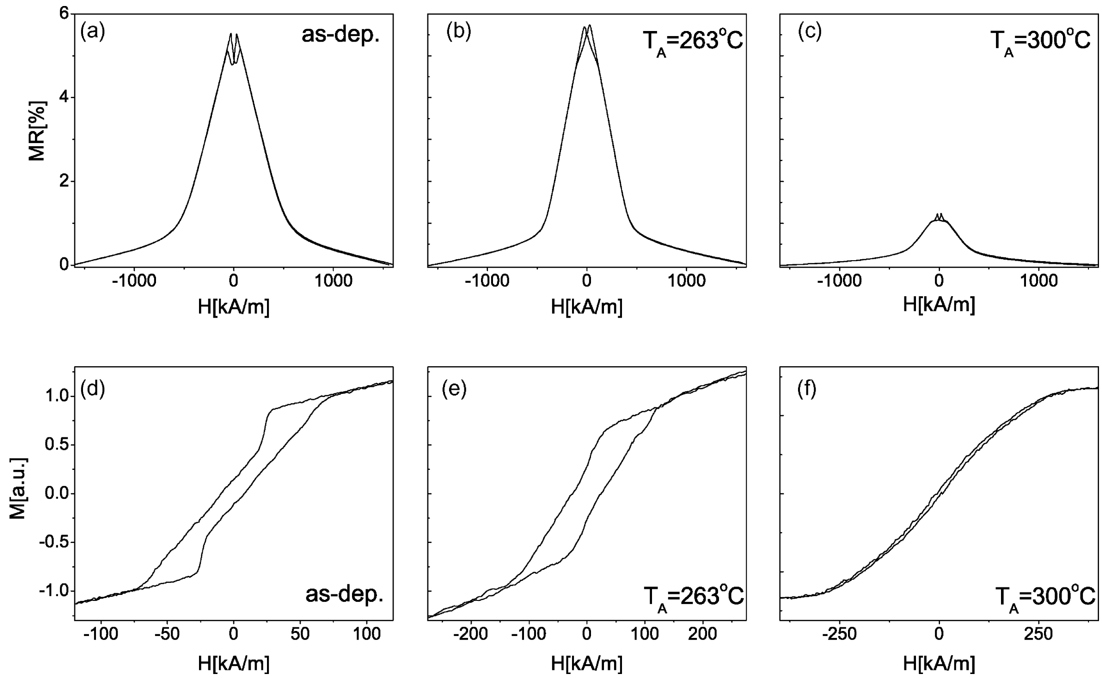

Fig. 1. Magnetoresistance (upper panels) and magnetization reversal curves of $[Ni_{80}Fe_{20}(2\,nm)/Au(1.9\,nm)/Co(0.6\,nm)/Au(1.9\,nm)]_{10}$ ML at different stages of the thermal treatment. The dependencies were measured with magnetic field applied perpendicularly to the surface of the sample. Note the different scales on the *x*-axes.

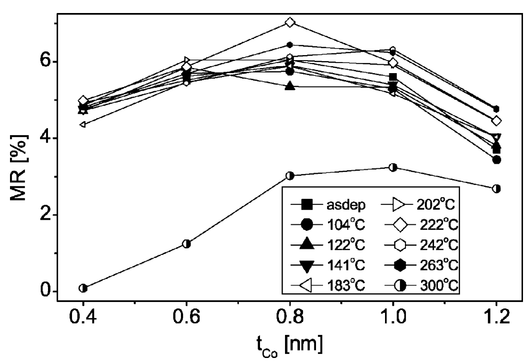

Fig. 2. MR amplitude of $[Ni_{80}Fe_{20}(2\,nm)/Au(1.9\,nm)/Co(t_{Co})/Au(1.9\,nm)]_{10}$ MLs at different stages of the thermal treatment.

In our opinion the small increase of MR amplitude for $222 \leq T_A \leq 263\,^\circ$C is caused by two distinct processes. Firstly, the decrease of H_N [compare Fig. 1(a and b)] increases the range of linear change of resistance towards lower fields thus increasing magnetoresistance (see model curve in Ref. [5]). Secondly, the annihilation of defects by thermal processes leads to the reduction of spin-independent scattering and thus increases MR amplitude. It should be emphasized that absence of strong ferromagnetic coupling between NiFe and Co layers (independent reversal [Fig. 1(d and e)]) and the preservation of easy-plane (NiFe) and easy-axis (Co) anisotropies are the main reasons for GMR stability against annealings at $T_A \leq 263\,^\circ$ C.

In our MLs, contrary to the systems deposited with molecular beam epitaxy [7], annealing in $T_A \leq 263\,^\circ$ C leads to an increase of uniaxial anisotropy of Co layers. As the perpendicular anisotropy raises the in-plane saturation field of investigated MLs monotonically increases with T_A [Fig. 3(a)]. Their effective magnetic anisotropy can be described by the following expression (compare [8]):

$$K_{\mathrm{eff}} = \frac{2K_{1\mathrm{s}}}{\mathrm{t_{Co}}} + K_{1\mathrm{v}} \tag{1}$$

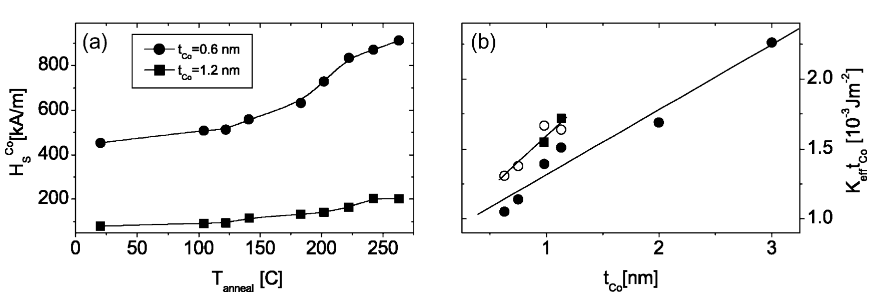

Fig. 3. (a) The in-plane saturation field of Co layers, determined from $M(H)$ dependencies, in $[Ni_{80}Fe_{20}(2\,nm)/Au(1.9\,nm)/Co(t_{Co})/Au(1.9\,nm)]_{10}$ MLs as a function of T_A. (b) The product of the effective perpendicular anisotropy and Co layers thickness vs. Co layer thickness [determined for MLs as in (a)] for as-deposited samples (full dots) and after annealing at $263\,^\circ$ C (empty dots). The perpendicular surface anisotropy constant is $4.24 \times 10^{-4}\,\mathrm{J\,m^{-2}}$ and the volume anisotropy is $466 \times 10^3\,\mathrm{J\,m^{-3}}$ for as-deposited MLs (for annealed MLs the values are $4.23 \times 10^{-4}\,\mathrm{J\,m^{-2}}$ and $748 \times 10^3\,\mathrm{J\,m^{-3}}$, respectively). The lines are linear fits. Squares in (b) relate to $T_A = 300\,^\circ$C.