Exchange anisotropy in PtMn/Ni$_{80}$Fe$_{20}$ films on MgO(1 1 0)

D.H. Wei$^{a,*}$, C.C. Yu$^b$, H.M. Duh$^c$, Y.D. Yao$^b$, J.H. Chien$^c$, T.S. Chin$^a$

$^a$Department of Materials Science and Engineering, National Tsing Hua University, HsinChu 300, Taiwan, ROC
$^b$Institute of Physics, Academia Sinica, Taipei 115, Taiwan, ROC
$^c$Department of Physics, National Kaohsiung Normal University, Kaohsiung 802, Taiwan, ROC

Abstract

For the first time, we successfully developed exchange anisotropy of PtMn/Ni$_{80}$Fe$_{20}$ (110) bilayers grown on a MgO(110) substrate with or without Pt buffer layer. The results of angular-dependent magneto-optical Kerr effect indicate that the PtMn/Ni$_{80}$Fe$_{20}$(110) films possess unidirectional anisotropy with coercivity and exchange field around 135Oe and 60Oe, respectively. The Pt buffer layer strongly influences the formation of epitaxial PtMn/Ni$_{80}$Fe$_{20}$ bilayers.

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The exchange coupling effect across an antiferromagnetic–ferromagnetic (AF–F) interface has attracted considerable interest as it plays a key role in spin valve sensors [1]. PtMn is one of the most promising candidates for the antiferromagnetic pinning layer due to its superior thermal stability. Owing to a crystalline-induced bidirectional and a step-induced unidirectional exchange anisotropy phenomena in PtMn/Ni$_{80}$Fe$_{20}$(110) bicrystal on MgO(100) [2] and quaticrystal [3] films on sapphire, respectively, the bicrystal layer on MgO(100) a bcc buffer layer was required to induce the (1 1 0) orientation. Direct (1 1 0) textured films on MgO(110) has never been tried before. In a continuous effort to understand the effect of exchange anisotropy and interface effect on the magnetic behaviors, we studied the as-deposited PtMn/Ni$_{80}$Fe$_{20}$(110) bilayers on MgO(110) substrates with or without a 5 nm thick Pt buffer layer prepared by molecular beam epitaxy (MBE). The deposition rate and temperature of the Ni$_{80}$Fe$_{20}$ and PtMn were controlled at about 0.05 Å/s and 200°C, respectively. During deposition, the growth pressure was controlled below 5×10$^{-8}$Torr and no magnetic field was applied. The crystal structure was characterized by in situ reflection high-energy electron diffraction (RHEED) and ex situ X-ray diffraction (XRD). The exchange anisotropy of the PtMn/Ni$_{80}$Fe$_{20}$ films was investigated by angular-dependent magneto-optical Kerr effect (MOKE). Deposition temperature is a key parameter for epitaxial growth. Epitaxial structure at 200°C was not possible without Pt buffer, so a 5nm thick Pt buffer layer was invariably adopted [4].

On MgO(110) substrate, the Pt buffer layer was grown with FCC(110) orientation, and the subsequent Ni$_{80}$Fe$_{20}$ and PtMn layers were mainly grown with FCC and FCT(110) structure as observed by XRD, shown in Fig. 1. Fig. 1 also indicates that PtMn layer was grown as an ordered, tetragonal L1$_0$ structure, with a lattice parameter = 3.66 Å along c-axis. Figs. 2(a) and (b) showed the typical RHEED images of MgO(110) substrates and the Pt(110) buffer layer with the probing e-beam aligned along the MgO[1–10] in-plane direction. The oblique diffraction fringes in Fig. 2(b) indicated that (1 1 1) facets formed on the Pt surface and met an angle 35° to the Pt(110) plane [5].

For the PtMn/Ni$_{80}$Fe$_{20}$ bilayers grown on Pt(110) buffer layers, we also observed the oblique (1 1 1) diffraction fringes on the bilayers (110) surface as shown in Figs. 2(c) and (d) for Ni$_{80}$Fe$_{20}$ and PtMn,
respectively. The investigations of XRD and RHEED patterns showed that the main epitaxial relations are MgO(110)//Pt(110)//Ni 80Fe20(110)//PtMn(110), and MgO[001]//Pt[001]//Ni 80Fe20[001]//PtMn[001].

The azimuthal distributions of the exchange field, He, and coercivity, Hc, of the PtMn/Ni80Fe20 bilayers were plotted in Fig. 3. Based on the Stoner–Wohlfarth model [6], the magnetic energy per unit area of exchange coupled F/AF bilayers can be expressed as

\[
E = K_F t_F \sin^2 \theta_F F + K_{AF} t_{AF} \sin^2 \theta_{AF} - J_E \cos(\theta_F - \theta_{AF}) - H_a M_s t_F \cos(\alpha - \theta_F),
\]

where \(H_{\text{c0}} = 2K_F/M_s\) and \(H_{\text{e0}} = J_E/M_s t_F\) are the anisotropy field and exchange field along the easy axis, respectively.

From the in-plane azimuthal analysis, the distribution of coercive and exchange fields of PtMn/Ni80Fe20 bilayers displayed a two-fold symmetry and an unidirectional anisotropy, respectively, as shown in Fig. 3. The exchange field reaches the maximum value (about 60 Oe) at the easy axis, MgO[110] in-plane direction. This condition usually applies to the simple uniaxial F and AF layers, so our case could consist of the simple model prediction based on Eq. (2). Comparing with previous PtMn/Ni80Fe20 bilayers grown on the step structure [3], the strength of exchange coupling in PtMn/Ni80Fe20(110) single crystal films is only about half that of the magnitude of the step-induced one. This is possibly contributed by the interface roughness effect induced by the (111) facet structure.

References