Influence of growth orientation on the exchange bias in epitaxial CoMn/Ni$_{80}$Fe$_{20}$ films

J.C.A. Huang*, H.C. Chiu

Physics Department, National Cheng-Kung University, Ta-Hsueh Road, # 1, Tainan 701, Taiwan

Abstract

Exchange coupling effect has been studied in the as-deposited (1 1 1), twinned (1 1 0) and (2 1 1) oriented CoMn/Ni$_{80}$Fe$_{20}$ films grown on Mo or Pt seeding layer by molecular beam epitaxy. Uniaxial magnetic anisotropy was observed in all cases mainly due to the epitaxial strain between the Ni$_{80}$Fe$_{20}$ and seeding layers. We observed that the exchange bias field (coercivity) is relatively large (small) for the (1 1 1) oriented CoMn/Ni$_{80}$Fe$_{20}$ film compared to those of the twinned (1 1 0) and (2 1 1) samples. The orientational dependence of the exchange coupling effect in the as-deposited CoMn/Ni$_{80}$Fe$_{20}$ film is very similar to that of the FeMn/Ni$_{80}$Fe$_{20}$, where uncompensate plane seems not required for significant exchange bias effect, in marked contrast to the case of PtMn/Ni$_{80}$Fe$_{20}$. © 2000 Elsevier Science B.V. All rights reserved.

Keywords: Exchange coupling; Magnetic anisotropy; Growth orientation; Molecular beam epitaxy

1. Introduction

The exchange coupling across an antiferromagnetic/magnetic (AF/F) interface has been intensively studied as it plays a primary role in the exchange biased spin-valve structure [1–5]. Due to the smallness of the blocking temperature, CoMn is a less studied AF material compared to, for example, FeMn, NiMn and PtMn. It is known that the AF phase of FeMn does not require ordered structure. In contrast, the AF phase of NiMn and PtMn is the chemically ordered L1$_0$-type structure with preferred spin alignment along the specific crystal direction which generally required high-temperature annealing to get sufficient exchange biasing (EB) effect.

In an effort to understand EB effect in AF/F films, we find that (1 0 0) orientation (so-called un-compensate plane) or twinned (1 1 0) crystal is indeed beneficial for EB effect in PtMn/Ni$_{80}$Fe$_{20}$ system, in contrast to (1 1 1) compensate plane of PtMn/Ni$_{80}$Fe$_{20}$ which shows negligible EB effect [6]. On the other hand, the (1 1 1) oriented FeMn/Ni$_{80}$Fe$_{20}$ films [7] exhibit larger EB effect than the other orientations, in marked contrast to the case of PtMn/Ni$_{80}$Fe$_{20}$. For comparison, we study here the EB effect of the as-deposited (1 1 1), (1 1 0) and (2 1 1) CoMn/Ni$_{80}$Fe$_{20}$ epitaxial films.

2. Sample preparation and structure characterizations

The crystal growth was carried out by a molecular beam epitaxy system (Vacuum Product made, model MBE-930). Details of the chamber in which crystal growth took place were provided elsewhere [8,9]. The base pressure of the MBE system is about $2 \times 10^{-10}$ Torr. During deposition of the CoMn or Ni$_{80}$Fe$_{20}$ layer, the growth pressure was controlled below $5 \times 10^{-9}$ Torr and the deposition rates at $0.1$–$0.2 \, \text{Å/s}$. The FCC (1 1 1), (1 1 0) and (2 1 1) oriented CoMn/Ni$_{80}$Fe$_{20}$ films were simultaneously grown on epitaxial-grade Al$_2$O$_3$ (11-20), Al$_2$O$_3$ (1-102) and Al$_2$O$_3$ (1-100) substrates, respectively. Mo (or Pt) was served as the seeding layer before initial deposition of the Ni$_{80}$Fe$_{20}$ and CoMn layer. The Mo (Pt) seeding layer was deposited at optimal growth temperature of...
Fig. 1. RHEED images of (a), (b) 200 Å Mo(1 1 1) seeding layer grown on Al₂O₃(11-20), (c), (d) the subsequent Ni₈₀Fe₂₀ layer, and (e), (f) CoMn layer. The RHEED beam was directed parallel to the Mo[1-10] azimuth for (a), (c) and (e), and along the Mo[0 0 1] azimuth for (b), (d) and (f).

On Al₂O₃ (1-20) substrate Mo was grown as BCC Mo (1 1 0) plane. The subsequent Ni₈₀Fe₂₀ and CoMn layers were grown as high-quality (1 1 1) oriented films, as evidenced by the in situ reflection-high-energy electron diffraction (RHEED) and X-ray diffraction (XRD) shown for example in Figs. 1 and 2, respectively. On Al₂O₃ (1-102) and Al₂O₃(1-100) substrate Mo was grown as BCC (1 0 0) and (2 1 1) plane, respectively, and the following Ni₈₀Fe₂₀ and CoMn layers were grown as twinned (1 1 0) and (2 1 1) oriented films, respectively. Similar crystal structure and quality was obtained for Ni₈₀Fe₂₀ and CoMn layers grown on Pt seeding layers on sapphire substrates.

900°C (500°C), and followed by Ni₈₀Fe₂₀ of 60 Å at 200°C. For comparison, the subsequent CoMn layer (100 Å) were deposited at ~150°C (about 60°C above the blocking temperature of CoMn layer) and room temperature.

On Al₂O₃ (11-20) substrate Mo was grown as BCC Mo (1 1 0) plane. The subsequent Ni₈₀Fe₂₀ and CoMn layers were grown as high-quality (1 1 1) oriented films, as evidenced by the in situ reflection-high-energy electron diffraction (RHEED) and X-ray diffraction (XRD) shown for example in Figs. 1 and 2, respectively. On Al₂O₃ (1-102) and Al₂O₃(1-100) substrate Mo was grown as BCC (1 0 0) and (2 1 1) plane, respectively, and the following Ni₈₀Fe₂₀ and CoMn layers were grown as twinned (1 1 0) and (2 1 1) oriented films, respectively. Similar crystal structure and quality was obtained for Ni₈₀Fe₂₀ and CoMn layers grown on Pt seeding layers on sapphire substrates.

Fig. 2. X-ray diffraction scanned from CoMn(100 Å)/Ni₈₀Fe₂₀(60 Å)/Mo(200 Å) films grown on Al₂O₃(11-20) substrate. The (1 1 1) peaks of and CoMn and Ni₈₀Fe₂₀ are overlapped for rather close lattice spacings.
3. Magnetic property

The blocking temperature (~ 90°C) of the CoMn layer was determined as the temperature where EB field approaches zero, as measured by the SQUID magnetometer. No exchange coupling effect was observed for CoMn grown at room temperature while samples with CoMn layer grown at about 150°C depends strongly on the crystal orientation as discussed below.

The magnetic anisotropy and EB effect of the CoMn/Ni_{80}Fe_{20} films were measured by longitudinal magneto-optical Kerr effect (LMOKE). Figs. 3(a)–(c) show the angular dependence M–H loops of the (1 1 1), (1 1 0) and (2 1 1) CoMn/Ni_{80}Fe_{20} films grown on Mo seeding layer, respectively. In each case uniaxial magnetic anisotropy was observed which could be mainly induced by the strain between Ni_{80}Fe_{20} and Mo layers during epitaxy. In addition, for the (1 1 1), (1 1 0) and (2 1 1) CoMn/Ni_{80}Fe_{20} films grown on Mo seeding layer the exchange bias fields (H_{eb}) are of about 48, 2 and 2 Oe, respectively; and the corresponding coercive fields (H_{c}) are 40, 4 and 30 Oe, respectively. For the CoMn/Ni_{80}Fe_{20} (2 1 1) case, H_{c} is large probably due to the shape of the anisotropy [8] in the twinned Ni_{80}Fe_{20} (2 1 1) layer. Similar orientation-dependent behaviors of H_{eb} and H_{c} were observed in CoMn/Ni_{80}Fe_{20} films grown on Pt seeding layer, as illustrated in Figs. 4(a)–(c).
In all cases, there is a common trend that the $H_{ab}$ ($H_c$) are relatively large (small) in the (1 1 1) oriented CoMn/Ni$_{80}$Fe$_{20}$ film compared to those of the twinned (1 1 0) and (2 1 1) samples. The results suggest that the orientational dependence of the exchange coupling effect in the as-deposited CoMn/Ni$_{80}$Fe$_{20}$ film is very similar to that of the FeMn/Ni$_{80}$Fe$_{20}$, where uncompensate plane seems not required for significant exchange bias effect, in remarkable contrast to the PtMn/Ni$_{80}$Fe$_{20}$ system.

Acknowledgements

We are grateful for the financial support by the ROC NSC under grant Nos. 87-2112-M-006-014 and 88-2112-M-006-009.

References