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Magnetic domain imaging of exchange bias system NiO/Cu/NiFe by Kerr microscopy

Y.M. Chang^a, Minn-Tsong Lin^{a,*}, W. Pan^a, C.H. Ho^a, Y.D. Yao^b, O. de Haas^c,
R. Schäfer^c, C.M. Schneider^c

^a Department of Physics, National Taiwan University, 1 Sec. 4 Roosevelt Road, Taipei 106, Taiwan

^b Institute of Physics, Academia Sinica, 115 Taipei, Taiwan

^c Institute of Solid State and Materials Research, Dresden, Germany

Abstract

Two types of magnetic domain structures were observed by Kerr microscopy for the NiO/Cu/NiFe system with different Cu thicknesses. At Cu = 8 Å, a frozen-in magnetic structure coinciding with the domain wall at room temperature was observed at variation of external field. At Cu = 2 Å, the domain images expand with frustrated domain wall instead. © 2002 Elsevier Science B.V. All rights reserved.

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Exchange bias, or exchange anisotropy phenomenon manifests itself in shifting the center of a hysteresis loop from zero with field H_c in the ferromagnet/antiferromagnet (FM/AFM) bilayer system below Néel temperature T_N of the AFM material. Due to the potential for technological applications, such as magnetic sensors and nonvolatile memory, this subject has been emphasized in recent years. However, the complete mechanism for exchange bias phenomenon is not yet well understood, and the results of theoretical calculations are still in a divergence [1–4]. To extend the understandings on this unidirectional anisotropy behavior, a detail of the interplay between AFM and FM material becomes essential. In the meanwhile, an oscillatory aspect on the coupling strength was lately reported in the antiferromagnet/normal metal/ferromagnet (AFM/NM/FM) system NiO/Cu/NiFe and was interpreted in a similar picture of RKKY-like mechanism [5]. In the field of application, the interlayer exchange bias phenomenon will certainly play important roles analogous to the oscillatory coupling strength in the ferromagnet/normal metal/ferromagnet (FM/NM/FM) system [6], since the

thickness of the metal spacer provides an additional parameter to adjust the exchange bias coupling. The magnetic domain image in the FM layer of the AFM/NM/FM is the consequence of the interplay between exchange bias and interlayer magnetic coupling [5], and thus provides information for both elements. Concerning what has been mentioned above, Kerr microscopy is exploited here to study the influence of the AFM ordering through the conductive spacer on the magnetic domain structure in FM layer by monitoring the magnetization distribution, nucleation, and domain wall movement.

In this work, the NiO/Cu/NiFe trilayers were prepared on the substrate Si (110) in a high-vacuum system with 3×10^{-7} Torr base pressure while RF and DC magnetron sputtering with 2 mTorr Ar working pressure were used for nonconductive (100 Å NiO) and conductive (Cu and 100 Å NiFe) layers, respectively. The 100 Å thickness of the NiO layer was intentionally prepared so as to give the optimum measurement condition of 200 K Néel temperature. A Kerr microscope with the video camera was used for the real-time domain imaging to the ferromagnet NiFe, and all images were taken by the longitudinal Kerr effect.

*Corresponding author.

E-mail address: mtlin@phys.ntu.edu.tw (M.-T. Lin).

The values of H_e at various temperatures were plotted with respect to the Cu spacer thickness in Fig. 1, and the inset shows a representative result of the measurement of H_e by a superconducting quantum interference device (SQUID) magnetometer. The pronounced oscillation aspect was mainly attributed to the thermally assisted oscillatory exchange bias coupling [5]. The competition between the AFM–FM interlayer coupling and the thermally fluctuated AF ordering is responsible for this consequence. Further discussion in detail has been published elsewhere [5]. In this work, two samples prepared with 8 and 2 Å Cu spacer layer are labeled as S1 and S2. It is worthwhile to note that the values of exchange bias field for S1 and S2 correspond to the local

Fig. 1. The values of exchange bias field for the samples with different measurement temperatures and Cu spacer thickness. The inset is the hysteresis loop of NiO/Cu/NiFe with 8 Å Cu spacer measured at 70 K by SQUID.

maximum and minimum of H_e at 145 K in Fig. 1, respectively. The investigation of whether there is any drastic difference or not between their behavior of magnetic domains then attracts immediate interests. Fig. 2(a) is the domain image of S1 at 85 K, whose width on the long edge is about 500 μm. The polarizer and the analyzer were so arranged as to monitor the magnetization in the NiFe Layer along the easy axis, as indicated in the figure.

The magnetic domain images in the NiFe layer taken above T_N of NiO are found to be retained for S1 as the temperature is cooling down below T_N . Figs. 2(b)–(e) exhibit a series of magnetization relaxation process at 85 K. The magnetic field was kept at -93.6 Oe along the easy axis, and the time interval between images is about 30 s. At variation of the magnetic field, the magnetic domain wall observed at room temperature was found to coincide with certain frozen-in border or boundary, within which magnetization reversal takes place. This frozen-in border was found even stable at 85 K, and then collapsed gradually as the temperature is close to Néel temperature, as shown in Figs. 3(a)–(c). The temperature-dependent domain images clearly indicate the strong correspondence of the frozen-in border to the AFM ordering in the NiO layer. Also, the magnetic domain wall structure at room temperature in the ferromagnet NiFe might provide preferable boundary condition for the formation of AFM ordering, giving rise to strong coupling between NiO and NiFe layer along the magnetic domain wall.

Two types of domain reversal process at 145 K for S1 [Figs. 4(a) and (b)] and S2 [Figs. 4(c) and (d)] are

Fig. 2. The domain images of NiO/Cu/NiFe with 8 Å Cu spacer at: (a) 85 K, $H = 0$, $t = 0$; (b)–(e) 85 K, $H = -93.6$ Oe; $t = 30, 60, 90$, and 120 s, respectively. The directions of magnetization and the axis of magnetic field are as indicated.

Fig. 3. The domain images of NiO/Cu/NiFe with 8 Å Cu spacer at (a) 145 K, $H = 0$; (b) 185 K, $H = 0$; (c) 195 K, $H = 0$. The frozen-in border collapses gradually, as indicated by the arrow. The directions of magnetization are as indicated.

Fig. 4. The domain images of NiO/Cu/NiFe at 145 K with (a) 8 Å Cu spacer, $H = 14$ Oe; (b) 8 Å Cu spacer, $H = 65$ Oe; (c) 2 Å Cu spacer, $H = 0$; (d) 2 Å Cu spacer, $H = 60$ Oe. The directions of magnetization and the axis of magnetic field are as indicated.

illustrated in Fig. 4. In contrast to the sharp-edged stable border in S1 that persisted in various directions and relatively high field, similar frozen-in magnetic structures are not observed in S2. Instead, the domain images of S2 expand with frustrated domain wall. The difference between the stability of magnetic domain structures may be correlated to the difference between the values of the effective exchange bias field and may exhibit the complicated interplay between AFM ordering and interlayer coupling, which is in turn embedded in the increasing tendency to oscillation of exchange bias field with increasing temperature, as reported in Ref. [5].

In summary, characteristic frozen-in borders were found below Néel temperature of NiO in NiO/Cu/NiFe with 8 Å Cu but not in that with 2 Å Cu. The difference between the stability of magnetic domain structures may reflect the complicate interplay mechanism between NiO and NiFe layers through Cu spacer and could be traced back to the physical origin of the thermally

assisted oscillatory exchange bias coupling in the previous report [5].

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