Training Effect in Ferro (F) / Antiferromagnetic (AF) Exchange Coupled Systems: Dependence on AF Thickness

Kunliang Zhang, Tong Zhao, and Hideo Fujiwara

*MINT Center and Department of Physics and Astronomy*

*The University of Alabama*

This project was partly funded by grant from DOD-ARO (DAAH04-96-1-0316) and made use of NSF MRSEC Shared Facilities (52417-55139)

Training Effect

• Observations of training effect
  (1) CoO/Co systems [1], [2]: *Tilting & Creep* [3]
  (2) FeMn/NiFe [4]: Change of interface net moment
  (3) NiO/NiFe systems [5]

• Try to get better understanding.

Characteristic fields vs IrMn thickness

A: NiFe(12nm)/IrMn(t nm)
B: IrMn(t nm)/NiFe(12nm)
Training effect-Type I
Si/Cu/NiFe(12nm)/IrMn(3.2nm)/Cu

(a) 
M (a. u.) vs. H (Oe)
- c1
- c2
- c5
- c10

(b) 
Characteristic fields (Oe)
- $H_{sw}^+$
- $H_c$
- $H_{eb}$
- $|H_{sw}|$

Training cycle (n)
Training effect-Type II
Si/Cu/NiFe(12nm)/IrMn(4.8nm)/Cu
Training effect ratio $\omega$ as a function of $t_{AF}$

$$\omega = \frac{(H_{sw} - (0) - H_{sw} - (20))}{H_{sw} - (0)}$$

A: NiFe(12nm)/IrMn ($t$ nm)
B: IrMn ($t$ nm)/NiFe(12nm)
Cycle number dependence of $H_{sw}^+$

**A**

- $t_{AF} = 3.2$ nm, Type I
- $t_{AF} = 4.0$ nm
- $t_{AF} = 4.8$ nm, Type II

**B**

- $t_{AF} = 3.2$ nm, Type I
- $t_{AF} = 4.0$ nm, Type I
- $t_{AF} = 5.6$ nm, Type II
- $t_{AF} = 4.8$ nm
- $t_{AF} = 32$ nm, Type II
Simulation of training effect

Both the normalized magnetization ($M_{\parallel}/M_s$) and net spin moment ($S_{\parallel}/S_s$) are shown. 1, 2 and 3 indicate the cycle number of the training.

$r_{\text{mean}} = 0.45 \ (J_{F-AF} = 0.25 \ \text{ergs/cm}^2), \ \sigma_r = 0.24,$

normalized standard deviation of $J_{AF-AF}: \ \sigma_{AF-AF} = 0.4.$

(a) $|J_{AF-AF}^{\text{mean}}|/ J_{F-AF}^{\text{mean}} = 0.4$, Type I; (b) $|J_{AF-AF}^{\text{mean}}|/ J_{F-AF}^{\text{mean}} = 0.04$, Type II
Conclusions

• With increasing $t_{\text{AF}}$, the training effect starts to appear with the appearance of the exchange bias field, then it increases drastically to a peak and then decreases quickly, eventually to almost zero.

• With increasing $t_{\text{AF}}$, the type of the training effect changes from Type I to Type II.

• Samples A (AF:top) and B (AF:bottom) show similar dependence on $t_{\text{AF}}$, except that the training effect decays faster for A than for B.

• Similar results are also obtained for other F/AF exchange coupled bilayers (AF: FeO$_x$ and FeMn).
Conclusions (Continued)

• Training effect is understood as the agitation and stabilization process of the net surface moment of those AF grains contributing to $H_{eb}$ and $H_c$.

• At smaller $t_{AF}$ where the majority of the AF grains are of the class $0.5 < r < 1$, the reduction of $H_c$ is dominant, resulting in Type I training effect, while at larger $t_{AF}$ where the majority of the AF grains are of the class $r < 0.5$, the reduction of $H_{eb}$ is dominant, resulting in Type II training effect. ($r = J/2K_{AF}t_{AF}$)