Antiferromagnetic domain nucleation and domain wall propagation in epitaxial Fe/CoO System

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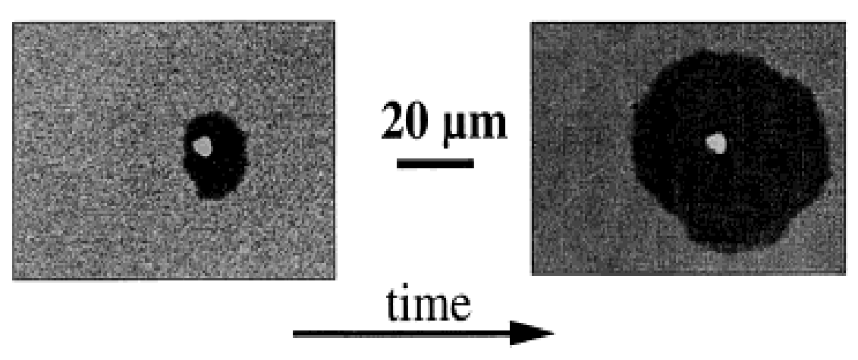
Introduction

Abstract: Antiferromagnetic (AFM) domain dynamics has been studied in the single-crystalline Fe/CoO system by magneto-optic Kerr effect (MOKE) measurement and X-ray linear dichroism (XMLD). This report showed that AFM domain could be tuned with magnetic field through ferromagnetic/antiferromagnetic interface exchange coupling. For the first time, two mechanisms of AFM domain dynamics- AFM Domain nucleation and domain wall propagation are clearly studied.

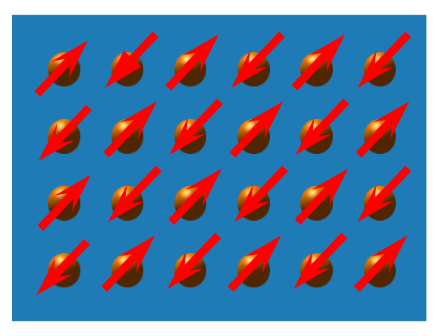
FM domain reversal



Phys. Status Solidi (a) 175, 213 (1999)

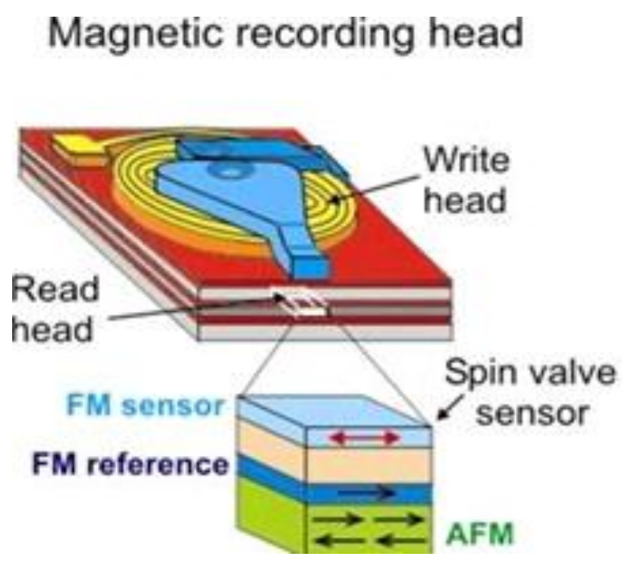
FM domain reversal { Domain nucleation / Domain wall propagation

Antiferromagnetic



<M>=0

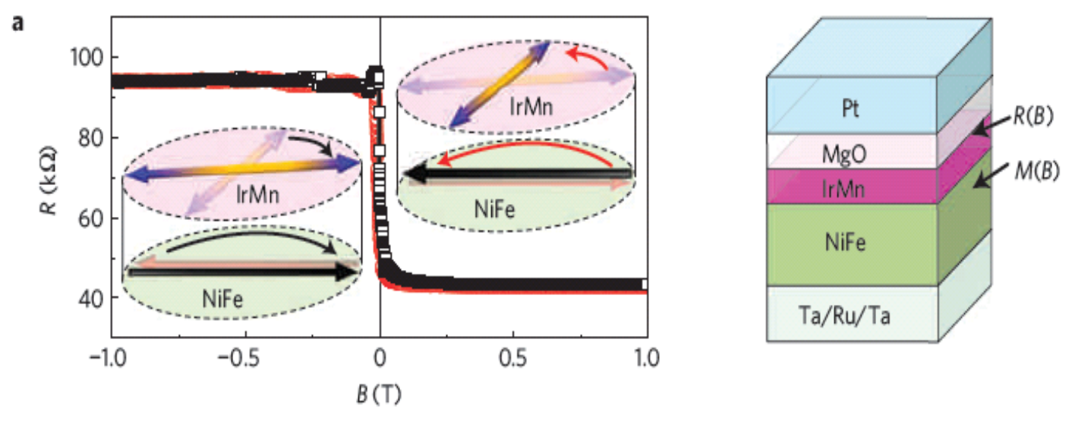
Pining layer in spin valve structure



Very few work on AFM domain dynamics!

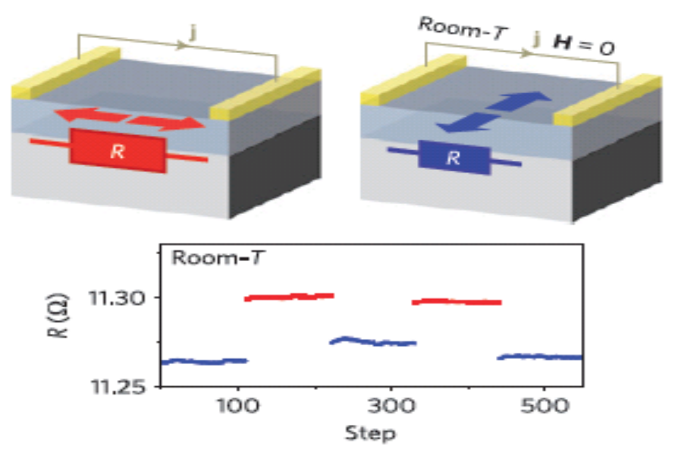
AFM spintronics

AFM TAMR effect



Nat.Mat. 10, 347 (2011)

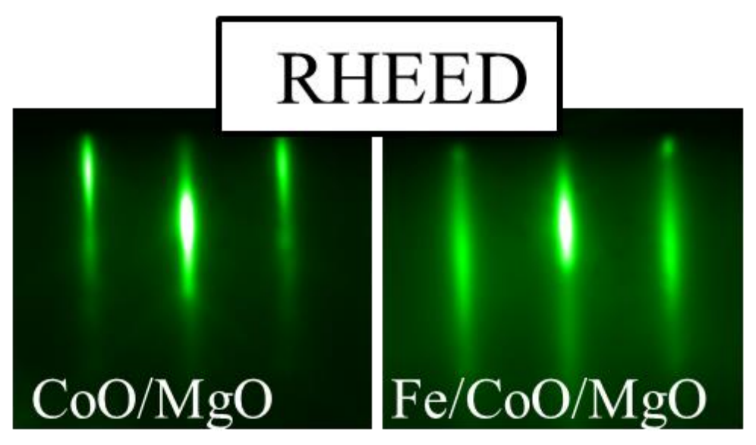
AFM AMR



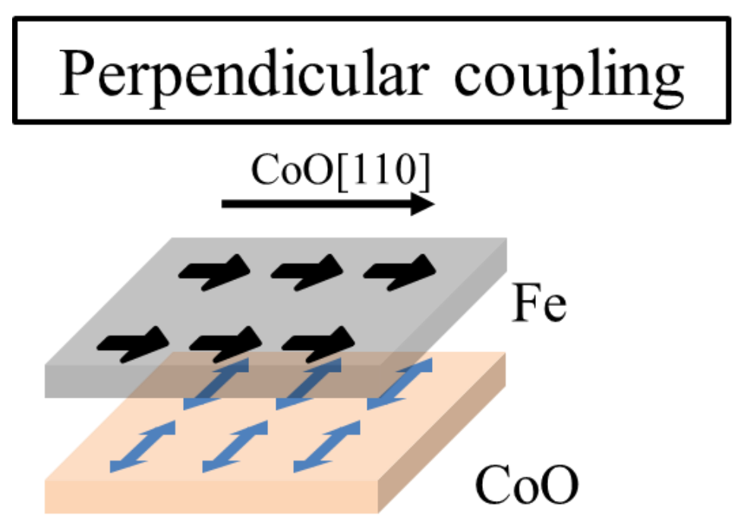
Nat. Mat. 13, 367 (2014)

Antiferromagnetic has been increasingly important.

1. Sample growth and spin-flop coupling

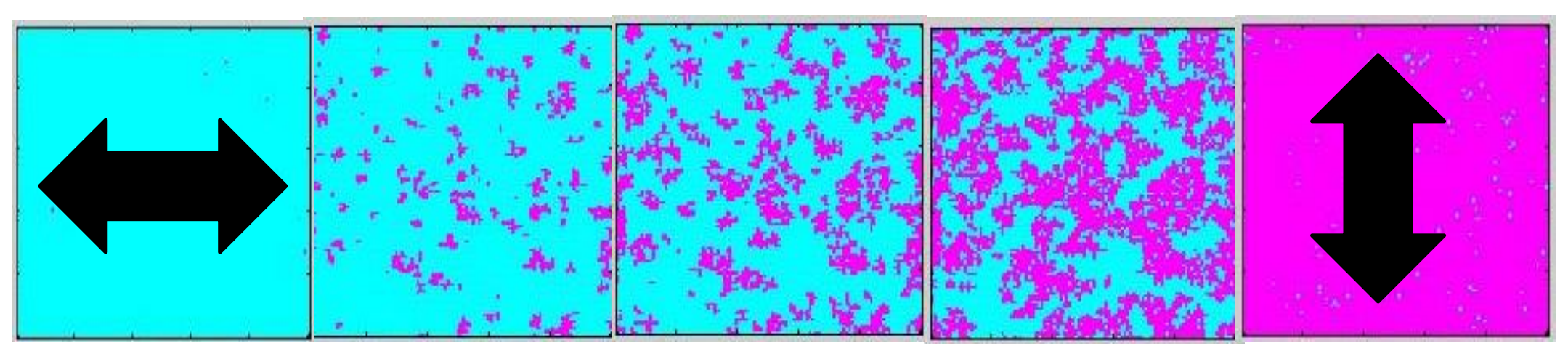


Molecular beam epitaxy



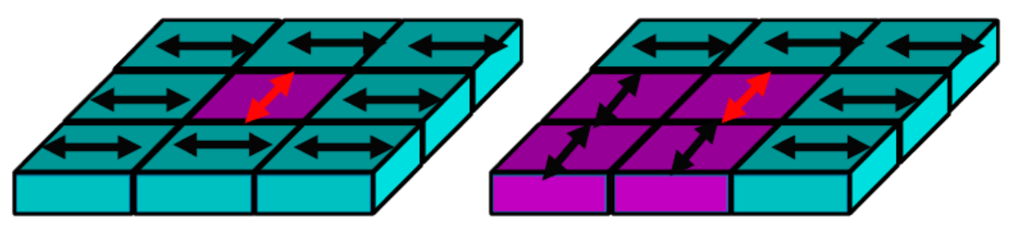
XMCD/XMLD

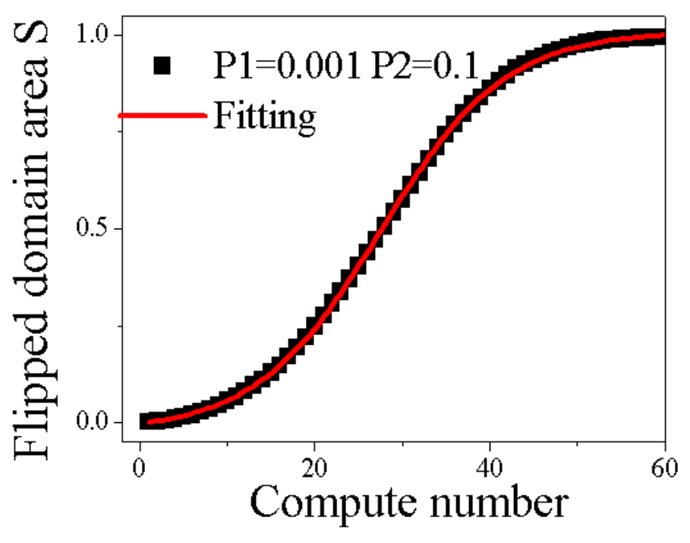
3. Monte Carlo simulation and analytical model



Flipping possibility:

P_1 in the domain **P_2 in the wall**





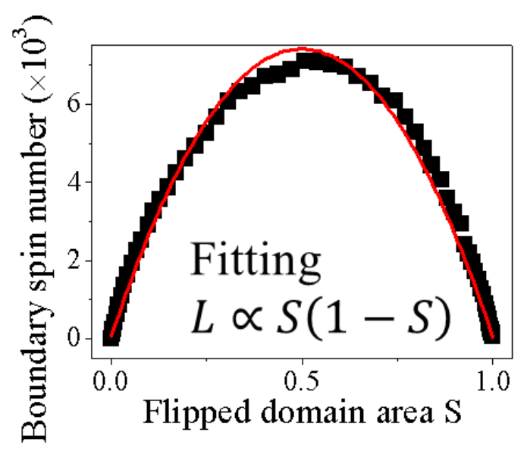
AFM domain flipping process { Domain nucleation / Domain wall propagation

Nucleation / Propagation

$$\underline{\Delta S} = \underline{\eta_{DN} \times (1 - S)} + \underline{\eta_{DP} \times f(S)}$$

Assume $f(S) \propto S(1 - S)$

$$\Delta S = \eta_{DN} \times (1 - S) + \eta_{DP} \times S(1 - S)$$

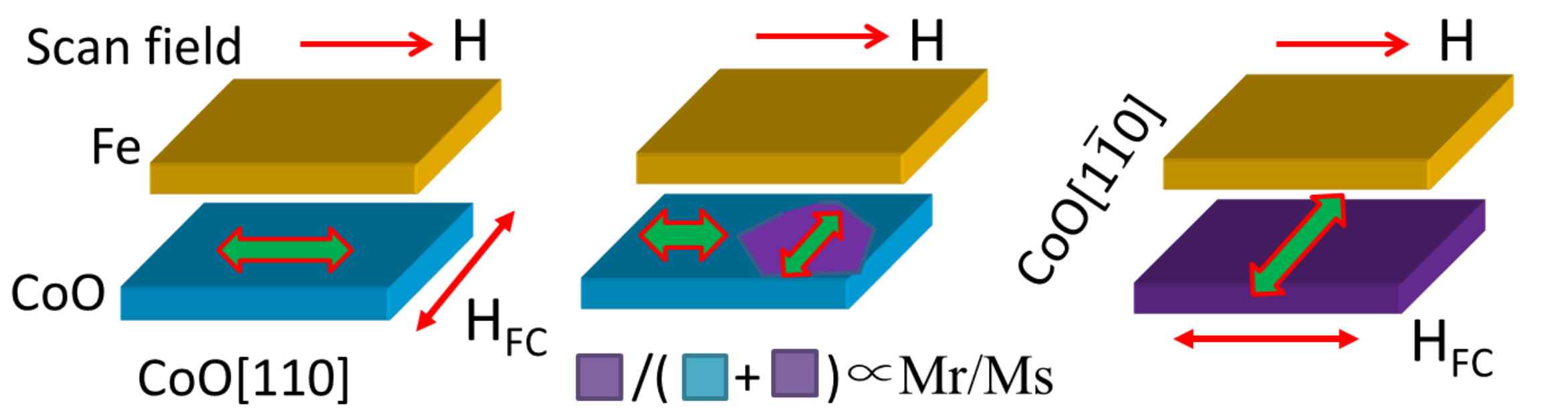


Solution:

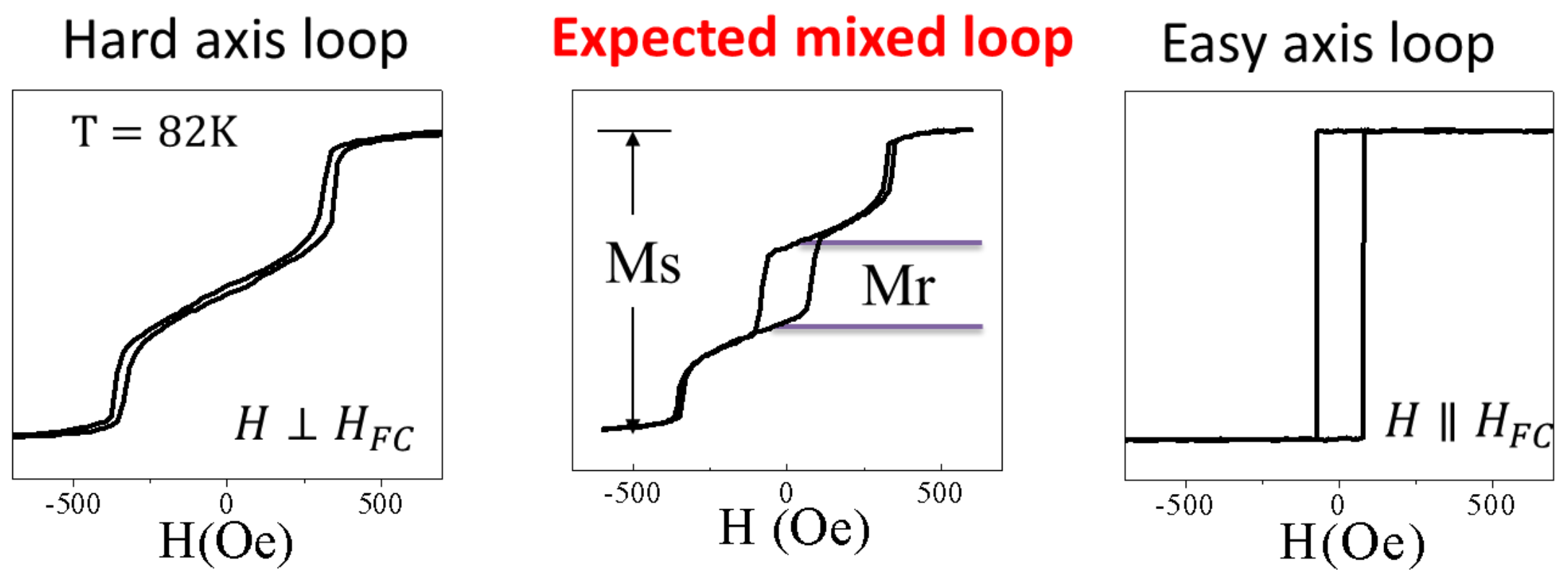
$$\boxed{S = \frac{1 - e^{-N(\eta_{DN}+\eta_{DP})}}{1 + \frac{\eta_{DP}}{\eta_{DN}} e^{-N(\eta_{DN}+\eta_{DP})}}}$$

S : switched AFM domain area
ΔS: switched area in each loop
L: domain boundary spin number
η_{DN}: *AFM domain nucleation rate*
η_{DP}: *AFM domain wall propagation rate*

2. MOKE measurement of AFM domain dynamics

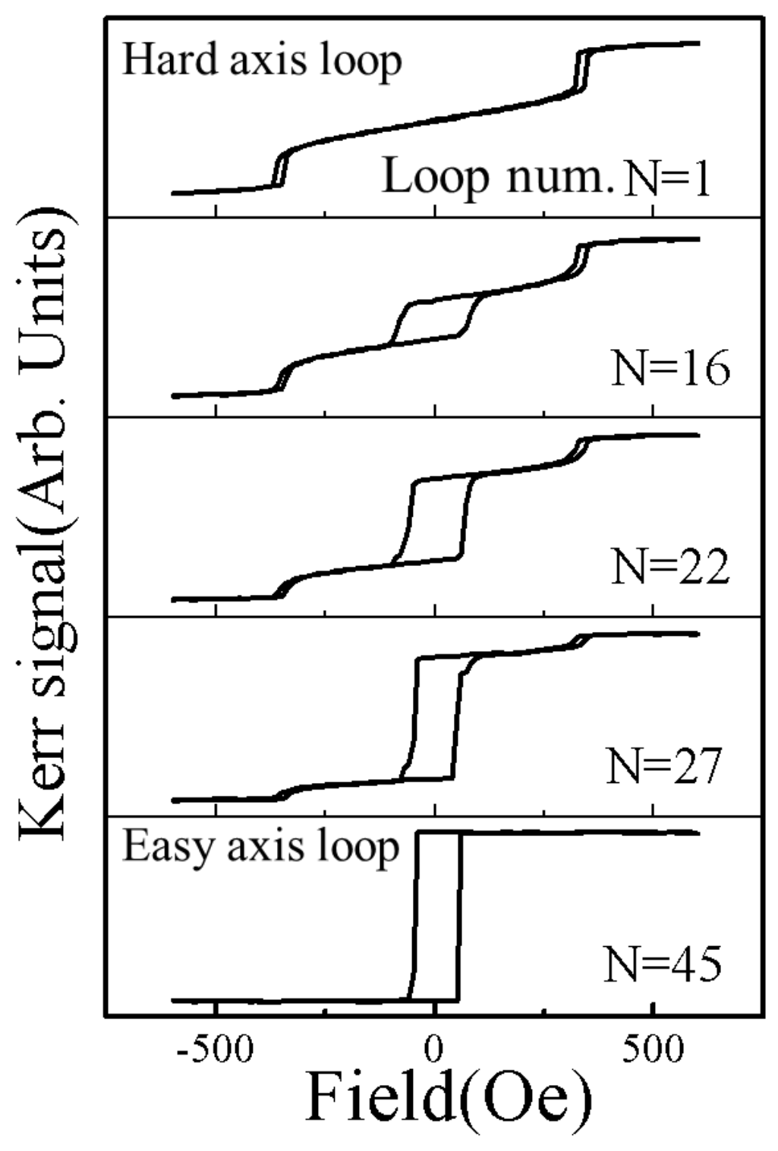


▨/(▨+▨)∝Mr/Ms

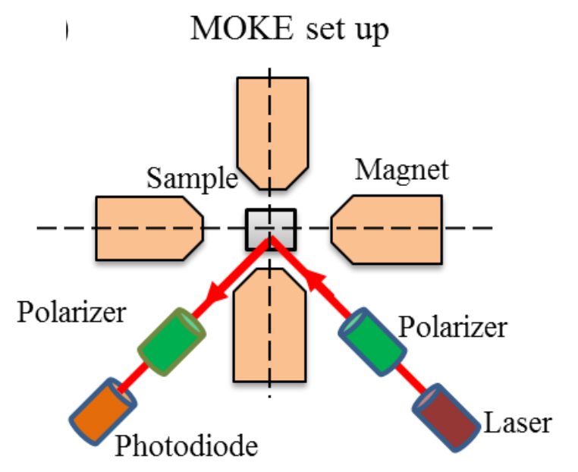


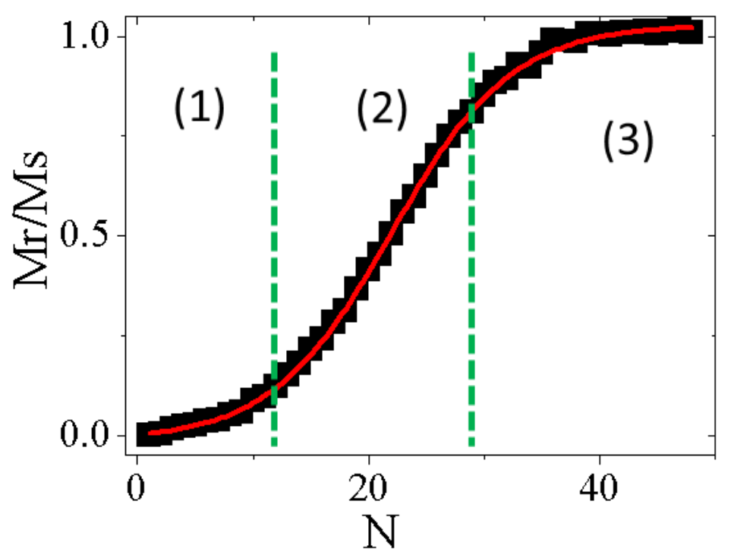
Sample: Fe(25nm)/CoO(5nm)/MgO(001)

T=143K



Training effect

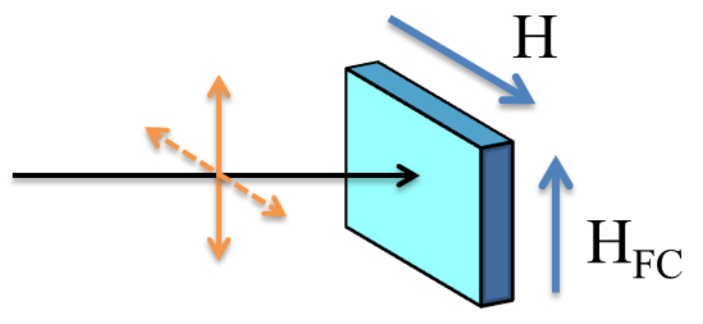




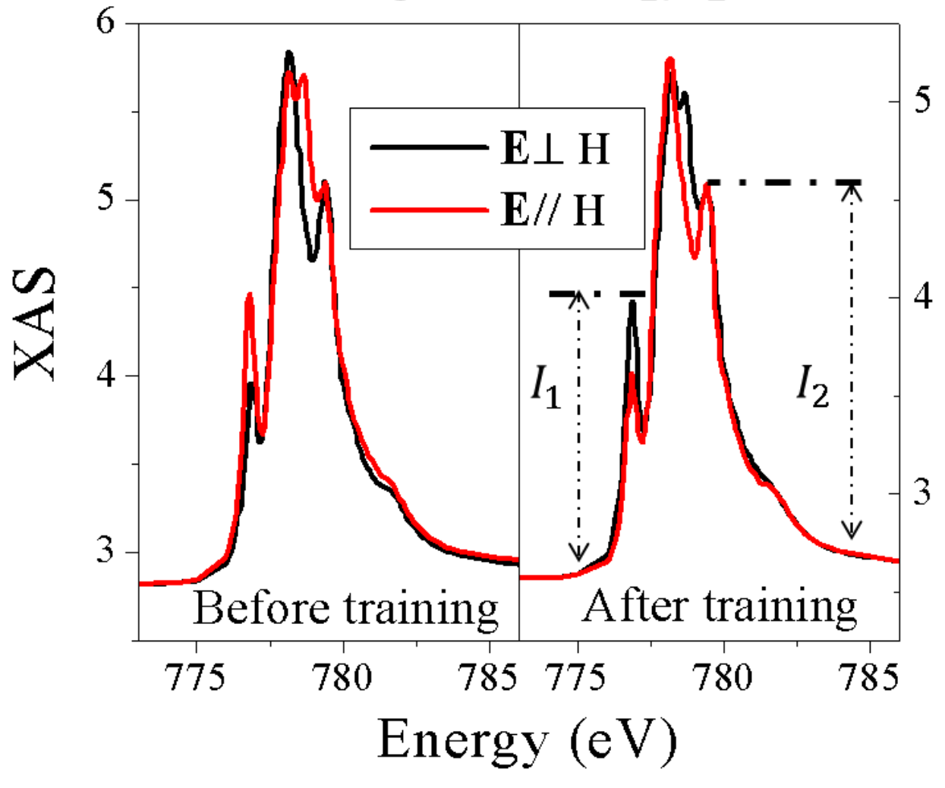
$$\text{fitting}: y = \frac{1-e^{-Ax}}{1+Be^{-Ax}}$$

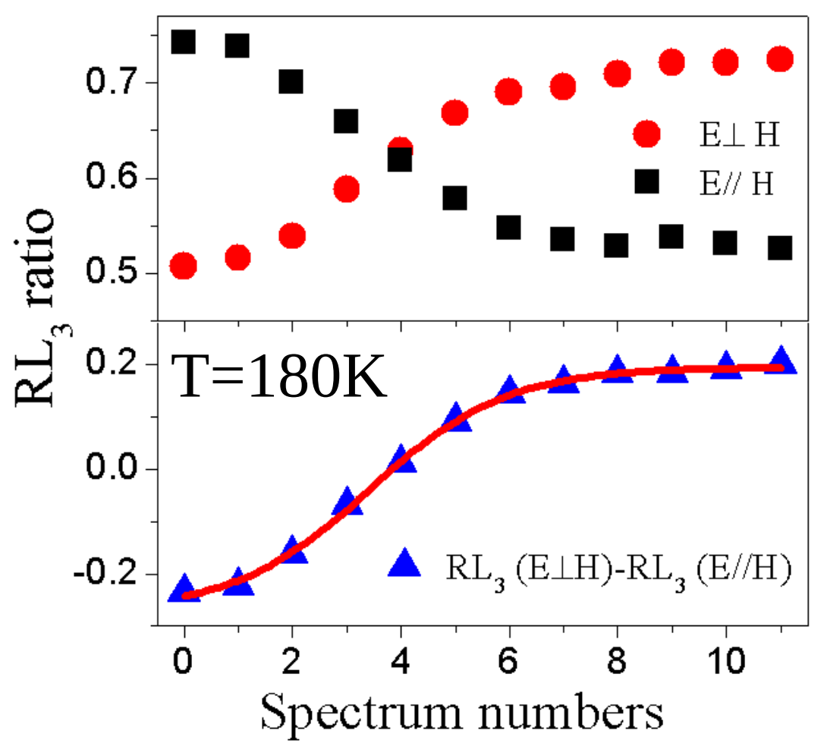
4. Direct measurement of AFM domain dynamics

Using XMLD



$RL_3\ ratio = I_1/I_2$

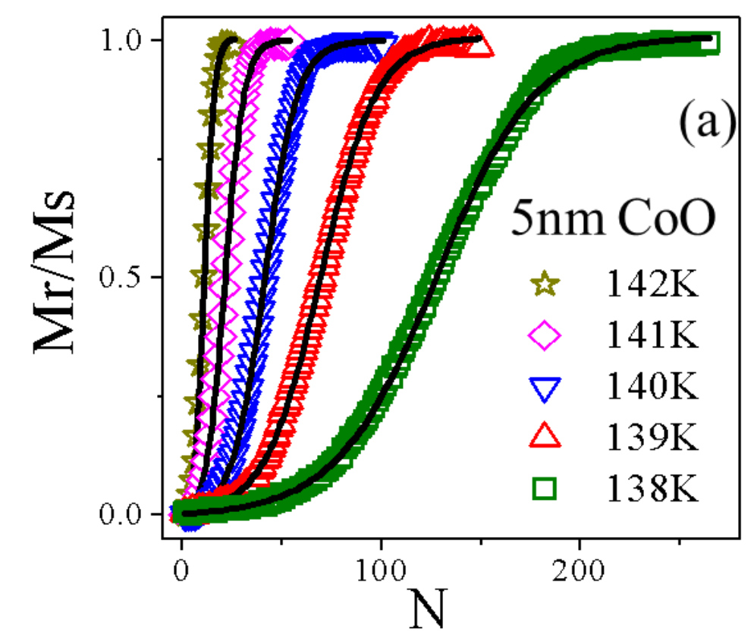


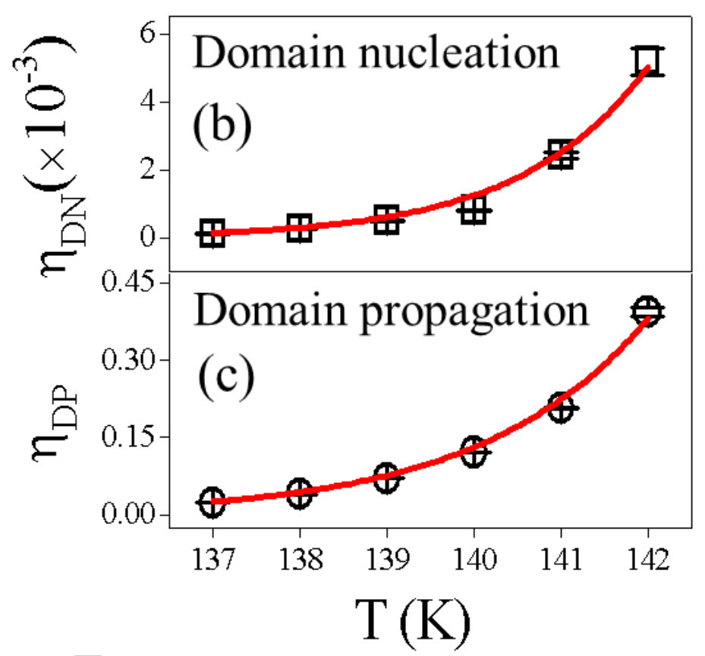


Sample: Fe(3nm)/CoO(3.5nm)/MgO(001) H=800Oe

Advanced Light Source
Beamline 4.0.2

5. Energy barrier

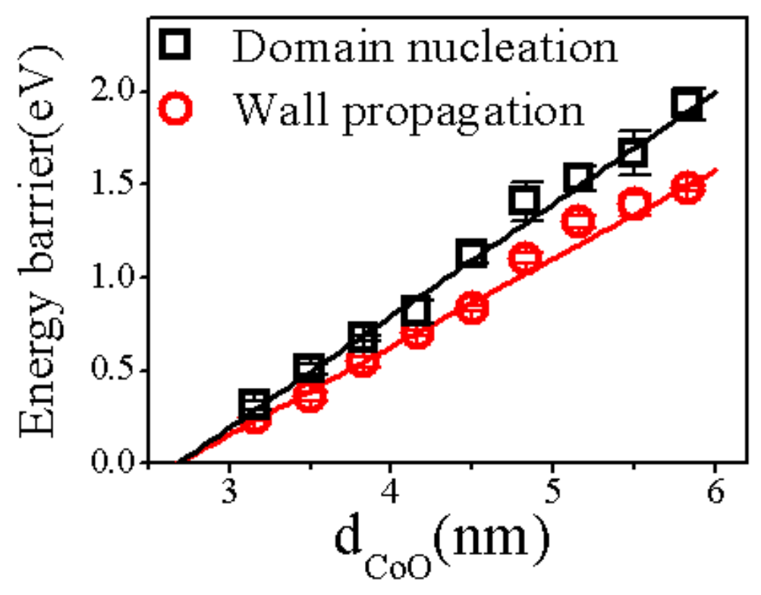




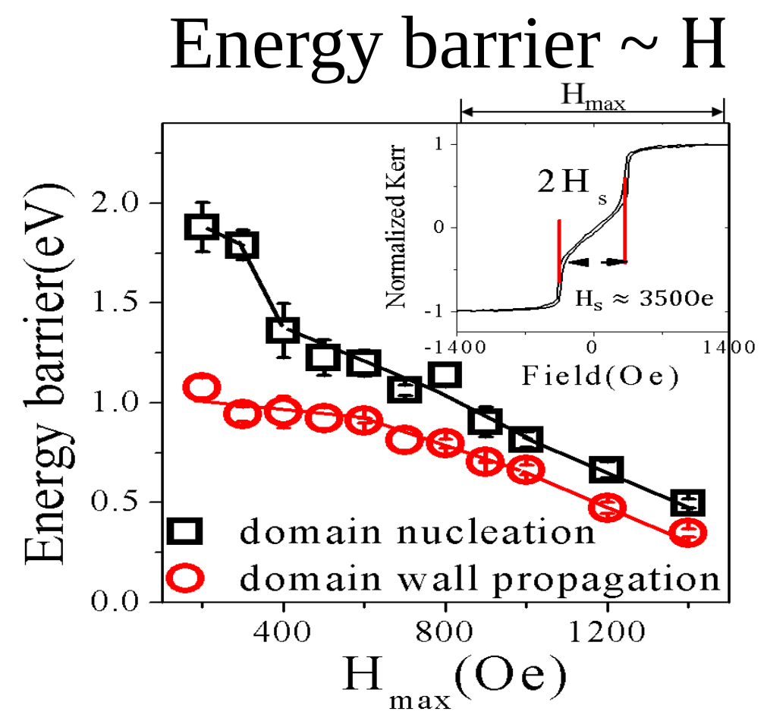
Arrhenius Law

Flipping probability: $\eta = A \cdot \exp\left(-\frac{E_{barrier}}{k_B T}\right)$

Energy barrier ~d_{CoO}



Energy barrier ~ H



Conclusion

1. We develop a universal formula to describe the antiferromagnetic domain dynamics in epitaxial Fe/CoO system.
2. Antiferromagnetic domain nucleation and domain wall propagation energy barrier can be determined from temperature dependence measurement. Energy barriers increase linearly with CoO thickness and decrease with magnetic field increasing.