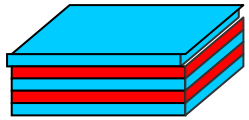
Photoemission study of coupled magnetic layers

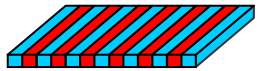
Z. Q. Qiu
Dept. of Physics, University of California at Berkeley

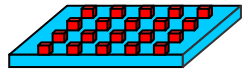
Outline

- Motivation
- Magnetic Phase Transition
- Spin Reorientation Transition
- Wish List

Motivation



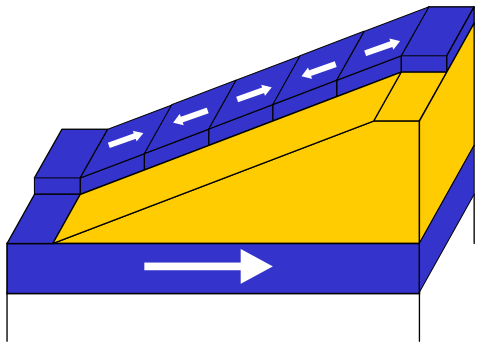


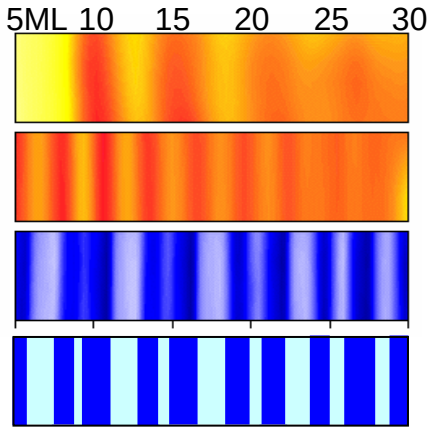


GMR and Oscillatory Coupling

- P. Grünberg, et. al., Phys. Rev. Lett. 57, 2442 (1986).
- M. N. Baibich, et. al., Phys. Rev. Lett. 61, 2472 (1988).
- S. S. P. Parkin et. al. Phys. Rev. Lett. 64, 2304 (1990).

Spectroscopy of valence electrons

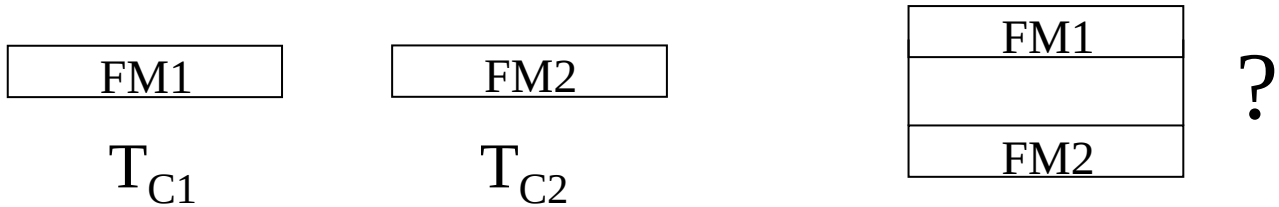




Microscopy of core electrons (PEEM)

- Element-specificity + imaging
- How does the interlayer coupling change the magnetic properties of the individual layer?

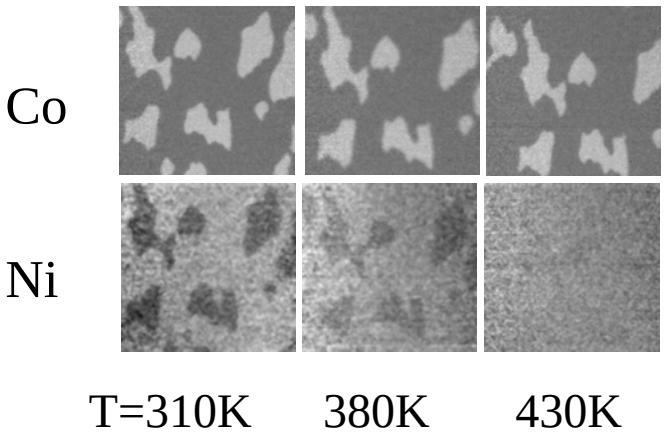
Magnetic Phase Transition



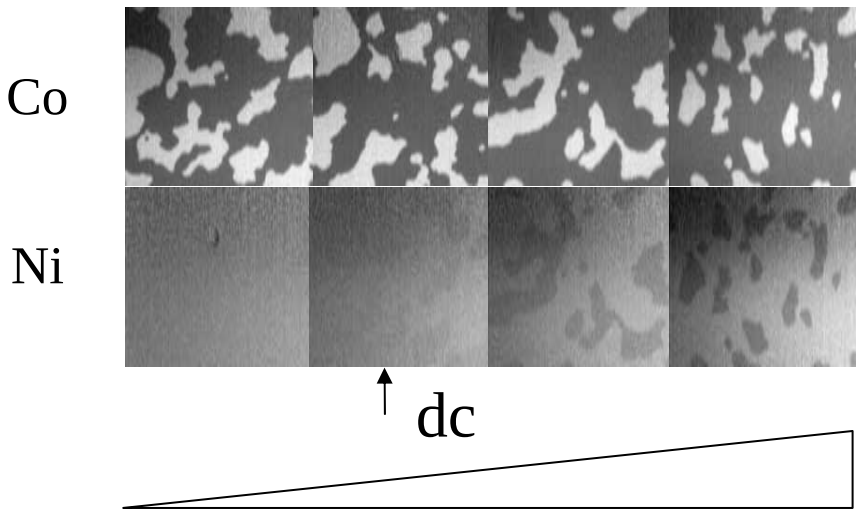
What is effect of the interlayer coupling on the phase transition?

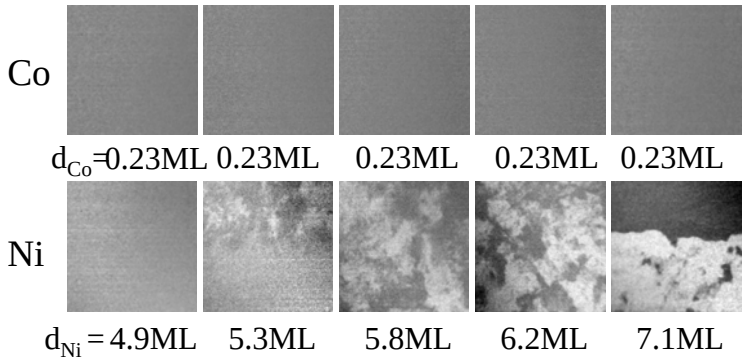
- Single or separate phase transitions?
- How is the T_C of the coupled sandwich compared to T_{C1} and T_{C2}?

Ni(3ML)/Fe(5ML)/Co(10ML)/Cu(100)

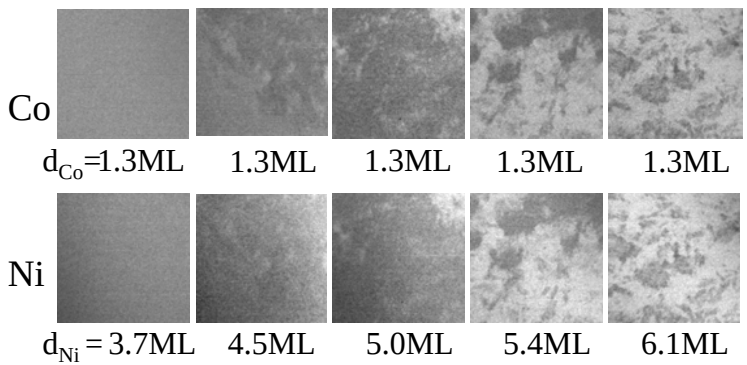


Ni(wedge)/Fe(5ML)/Co(10ML)/Cu(100)

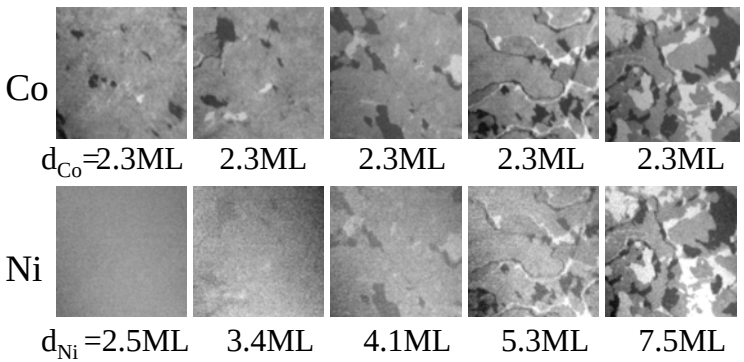




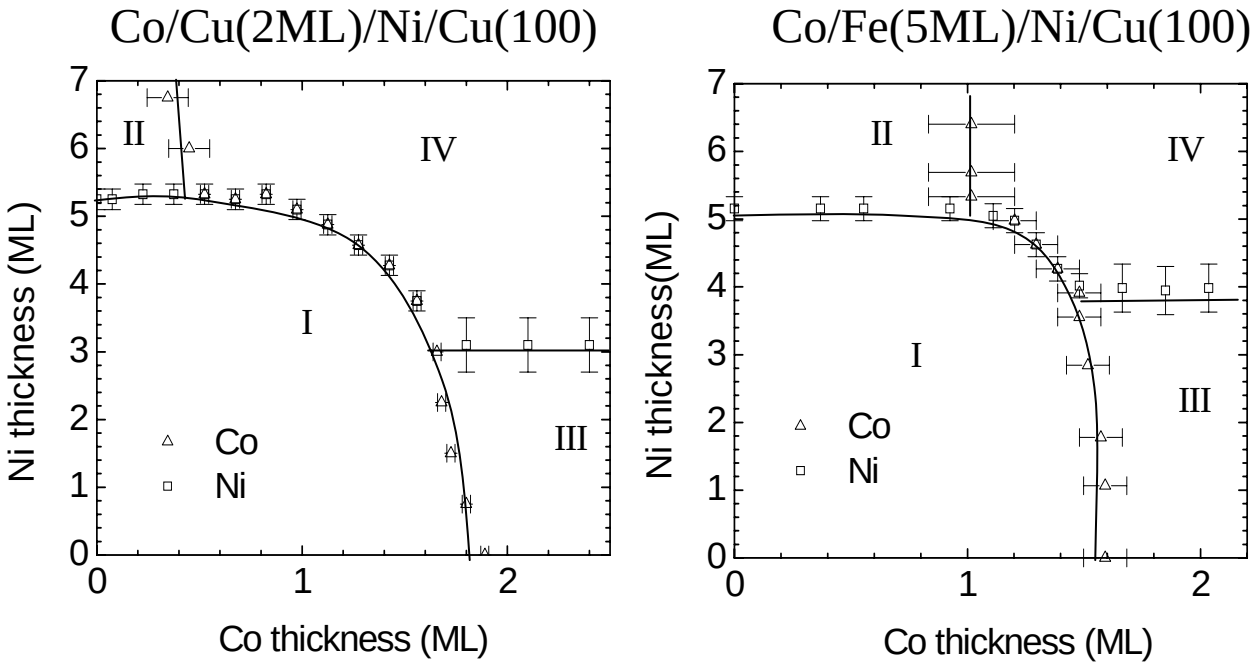
Co(0.23ML)/Cu(2ML)/Ni/Cu(100)



Co(1.3ML)/Cu(2ML)/Ni/Cu(100)

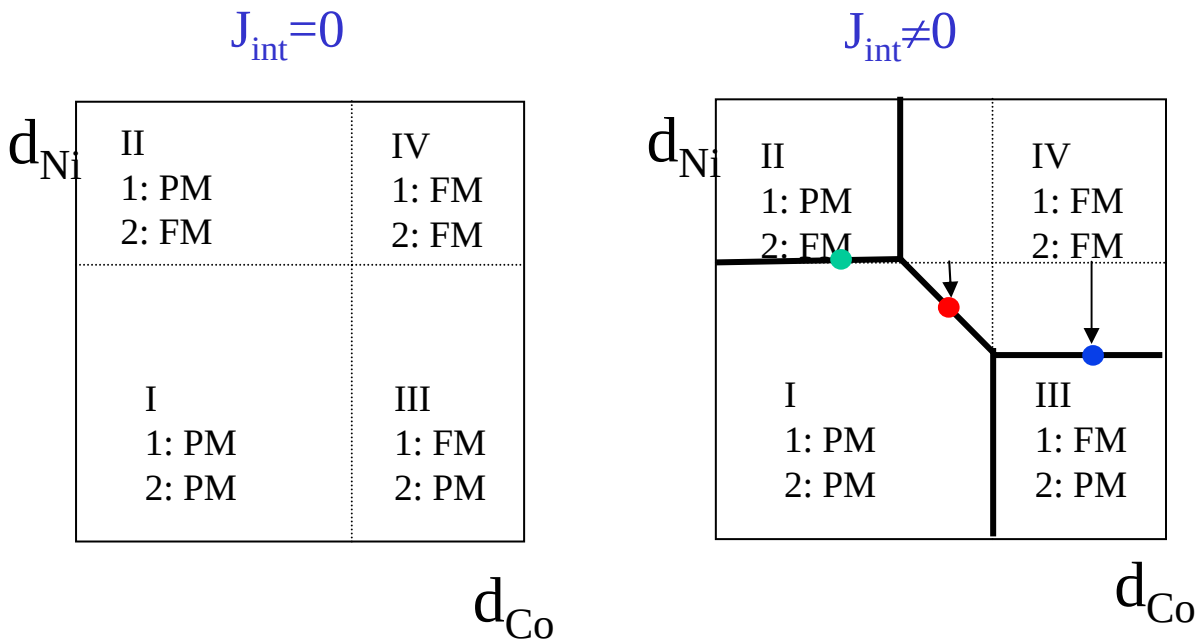


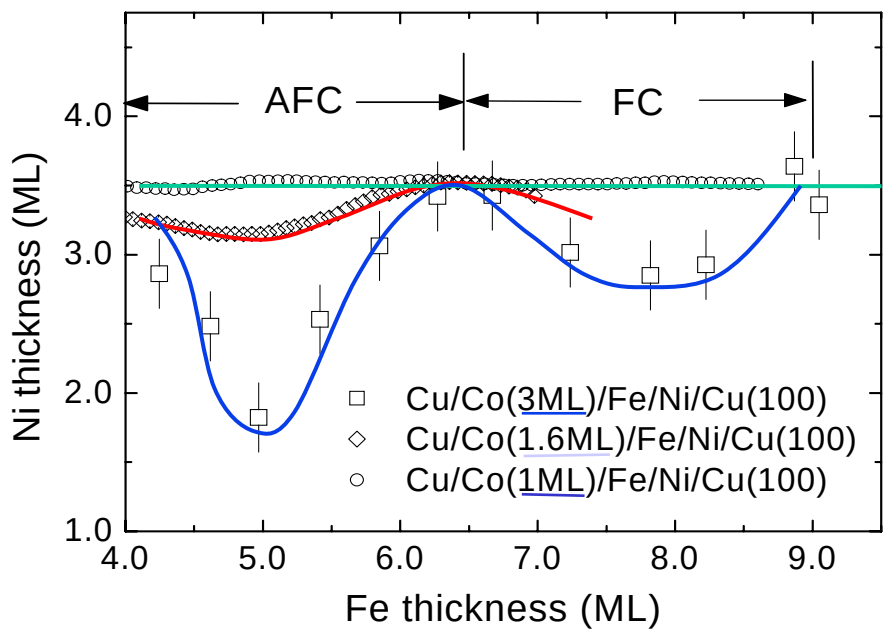
Co(2.3ML)/Cu(2ML)/Ni/Cu(100)



	I	II	III	IV
Ni	PM	FM	PM	FM
Co	PM	PM	FM	FM

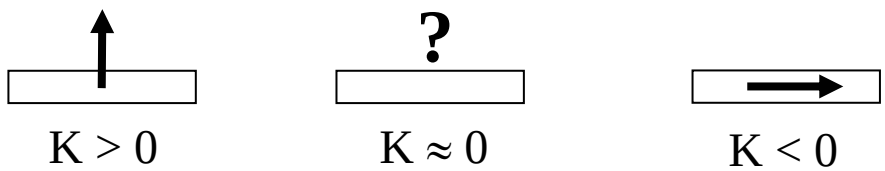
- **PM state of one layer has little effect on the Tc of the other film.**
- **FM state of one layer reduces the dc of the other layer.**


$J_{int}=0$
$J_{int}\neq 0$
d_{Ni}
II
1: PM
2: FM
IV
1: FM
2: FM
I
1: PM
2: PM
III
1: FM
2: PM
d_{Co}


AFC
FC
Ni thickness (ML)
Fe thickness (ML)
4.0
3.0
2.0
1.0
4.0
5.0
6.0
7.0
8.0
9.0
Cu/Co(3ML)/Fe/Ni/Cu(100)
Cu/Co(1.6ML)/Fe/Ni/Cu(100)
Cu/Co(1ML)/Fe/Ni/Cu(100)

Spin Reorientation Transition (SRT)

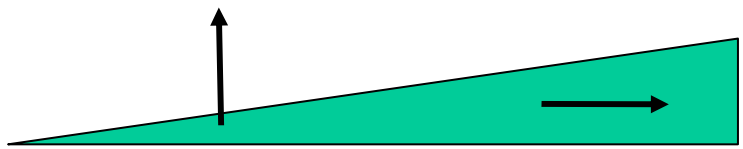
$H = -J \Sigma S_i \bullet S_j - K \Sigma S_{iz}^2$ What will happen at $K \approx 0$?



- **Spin-orbit interaction gives $-KS_z^2$ if z symmetry is broken.**
- **Dipolar interaction gives $2\pi M^2 S_z^2$.**

$$E = -KS_z^2 = -(K_S/d - 2\pi M^2)S_z^2$$

Changing d or T to tune K around zero.



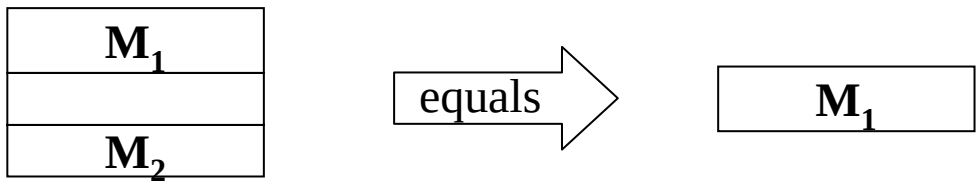
How do the stripe domains respond to H ?

- **Electron microscope is used for domain imaging.**

- **It is difficult to apply H in an electron microscope.**

- **SRT of M_1 in a coupled sandwich for H=0 is equivalent to the SRT of M_1 single layer within a H=J< M_2>.**

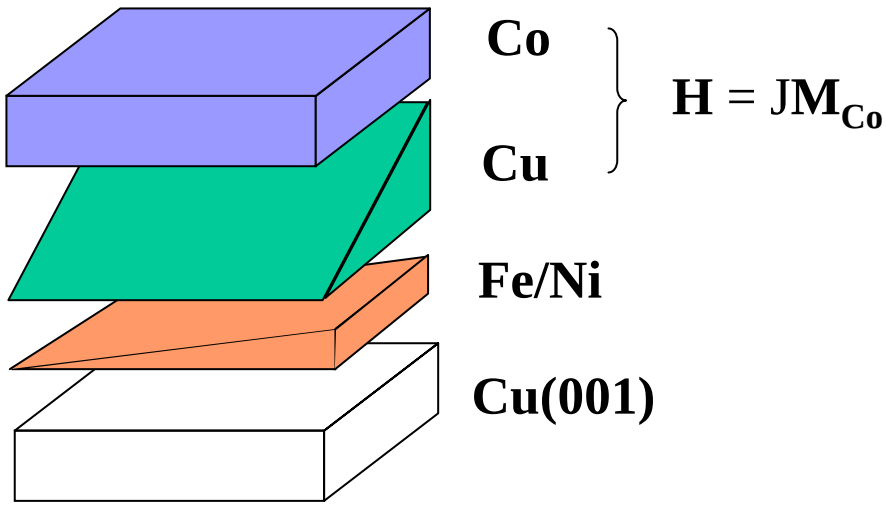
If $\partial \mathbf{M}_2 / \partial \mathbf{r} \approx \mathbf{0}$, $E = -J\, \mathbf{M}_1 \cdot \mathbf{M}_2 = -\, \mathbf{M}_1 \cdot \mathbf{H}$ with $\mathbf{H} = J \langle \mathbf{M}_2 \rangle$

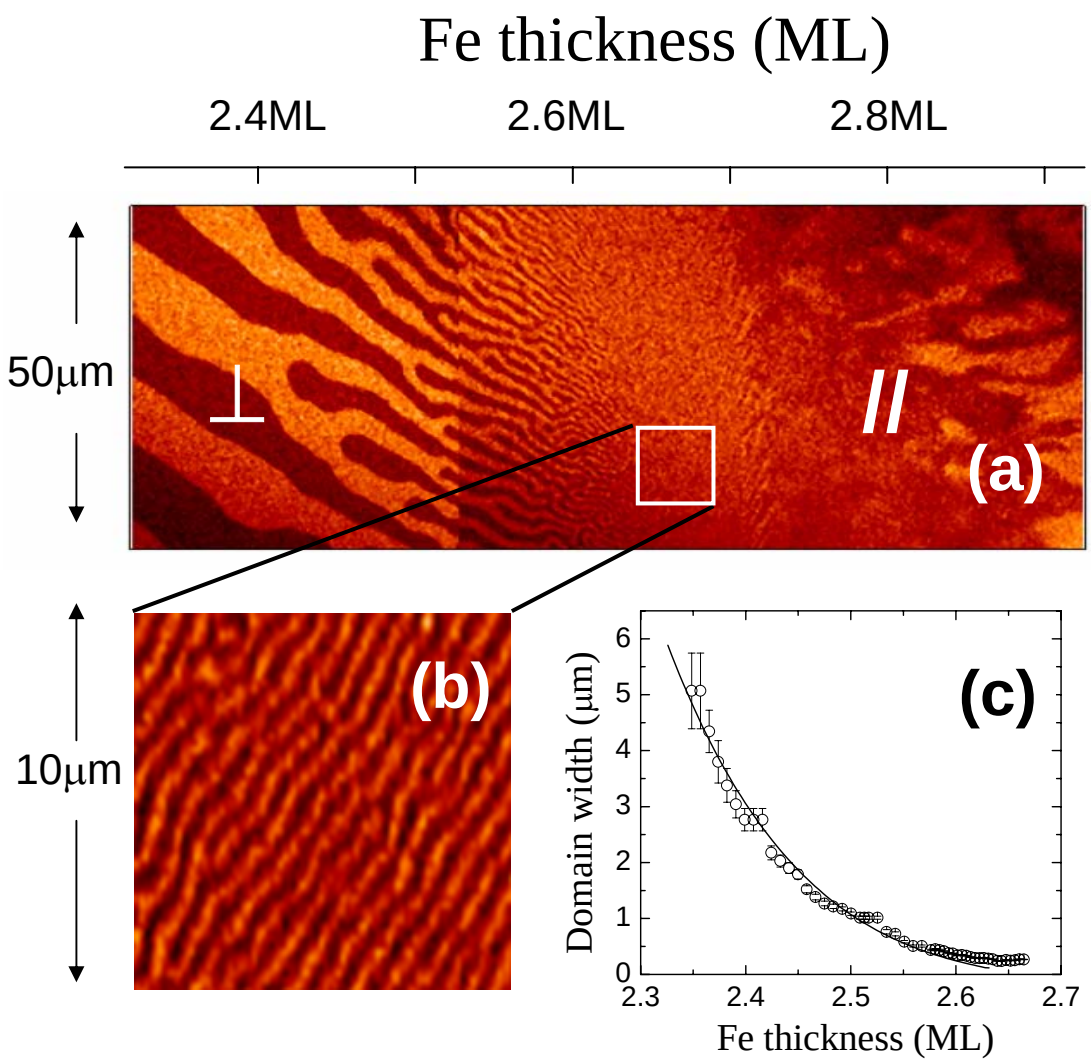


$\mathbf{H} = 0$ $\qquad\qquad$ $\mathbf{H} = J\langle \mathbf{M}_2 \rangle \neq 0$

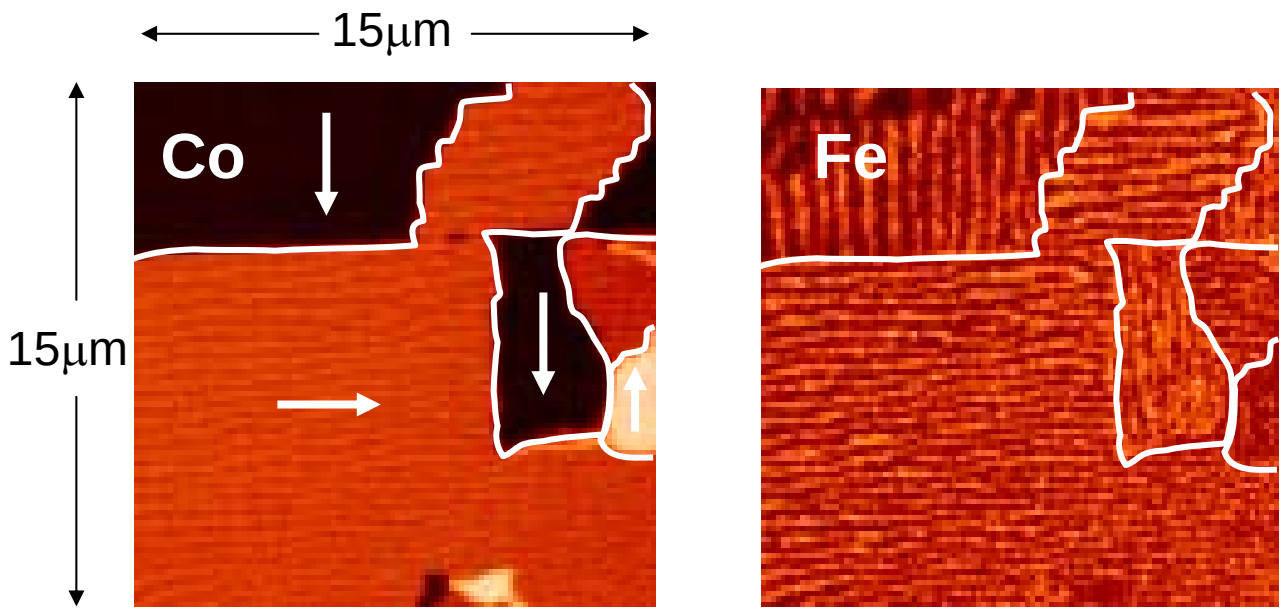
- **Electron Microscope can be used to study stripe domains as a function of "magnetic field".**

- **Sample is grown by MBE.**
- **Fe/Ni(5ML) film as the SRT layer.**
- **Cu/Co(10ML) provides the in-plane magnetic field.**



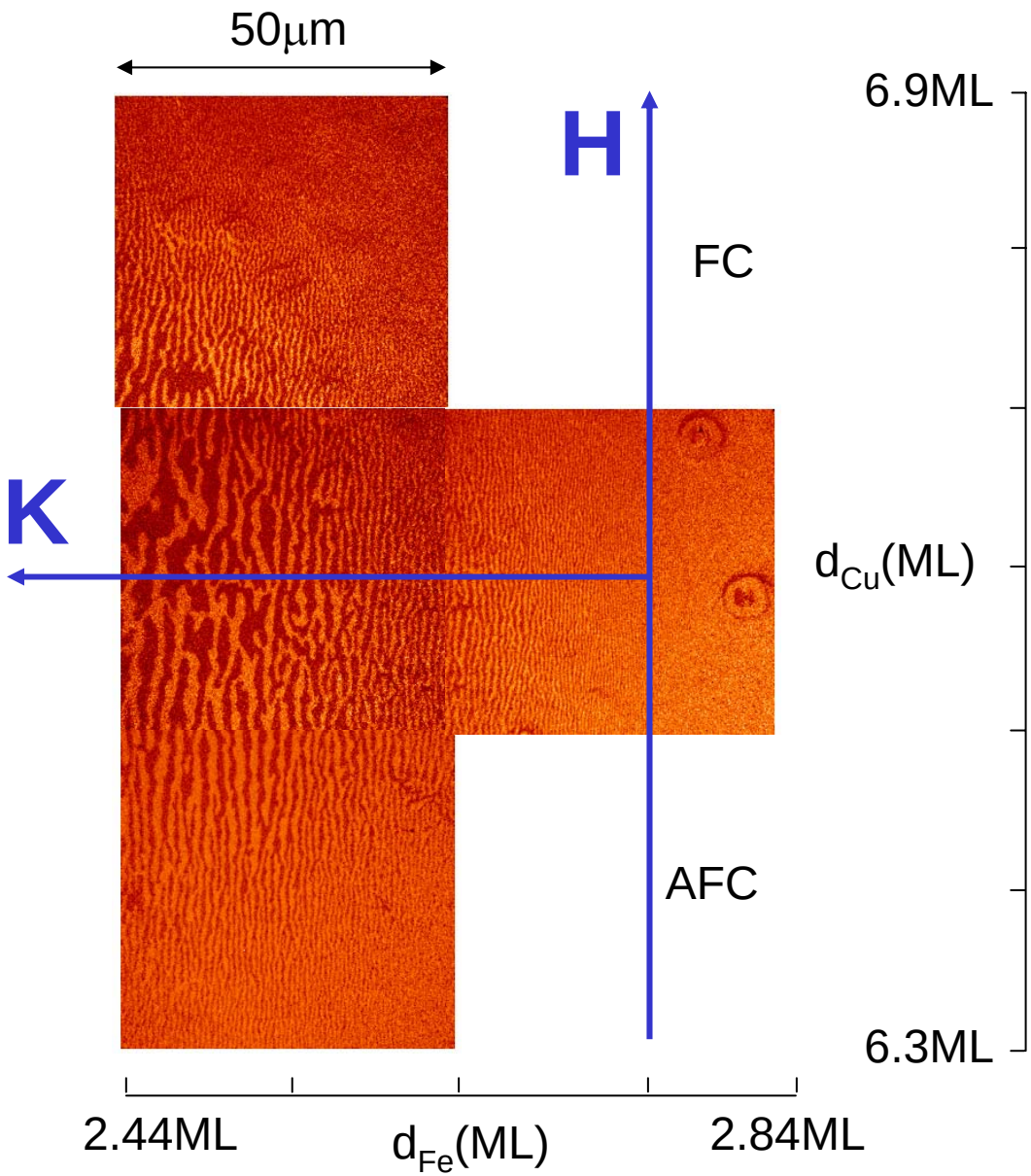

Fe thickness (ML)
2.4ML
2.6ML
2.8ML
50μm
⊥
//
(a)
10μm
(b)
(c)
Domain width (μm)
0
1
2
3
4
5
6
2.3
2.4
2.5
2.6
2.7
Fe thickness (ML)

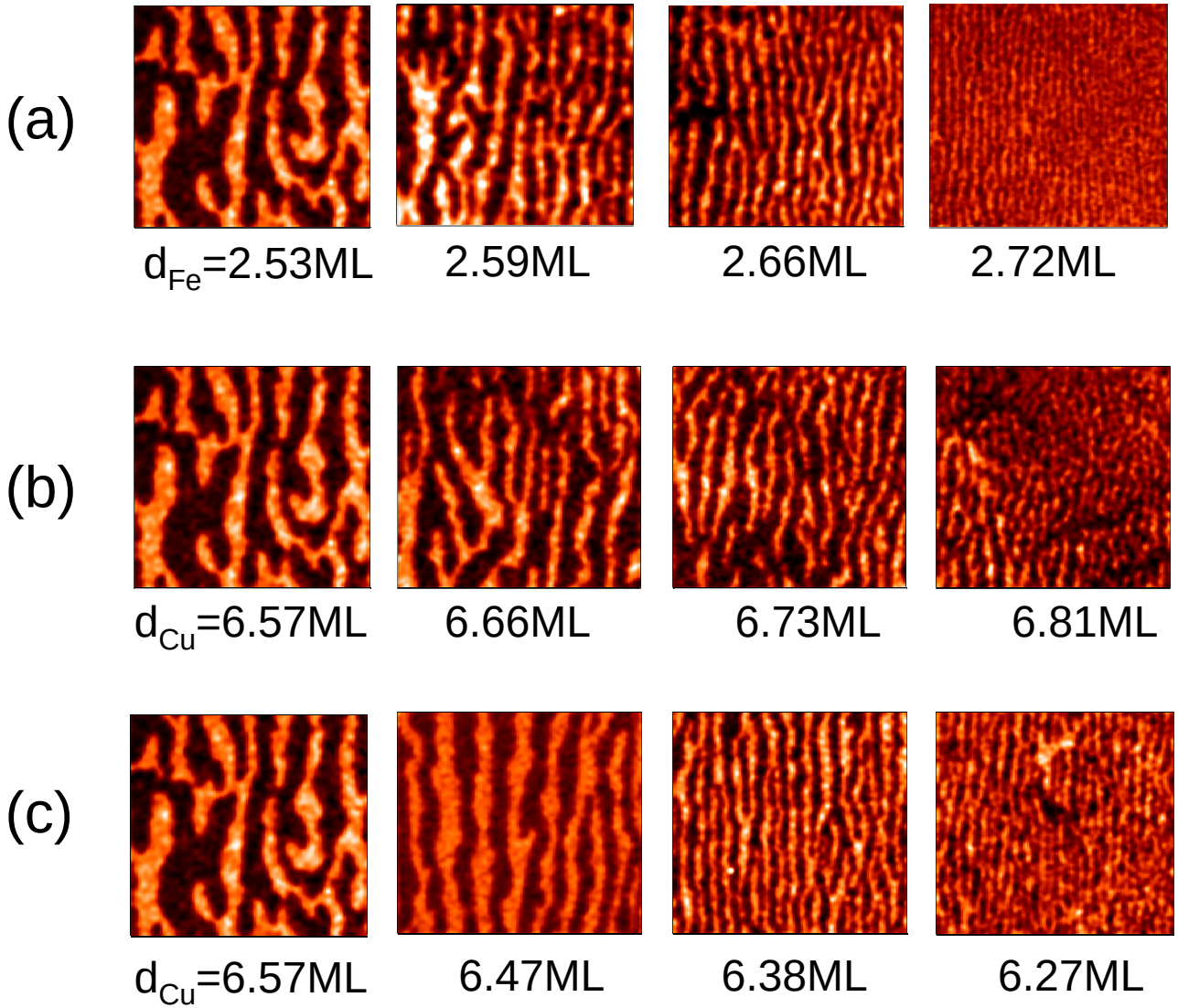
Co(10ML)/Cu/Fe/Ni(5ML)/Cu(001)

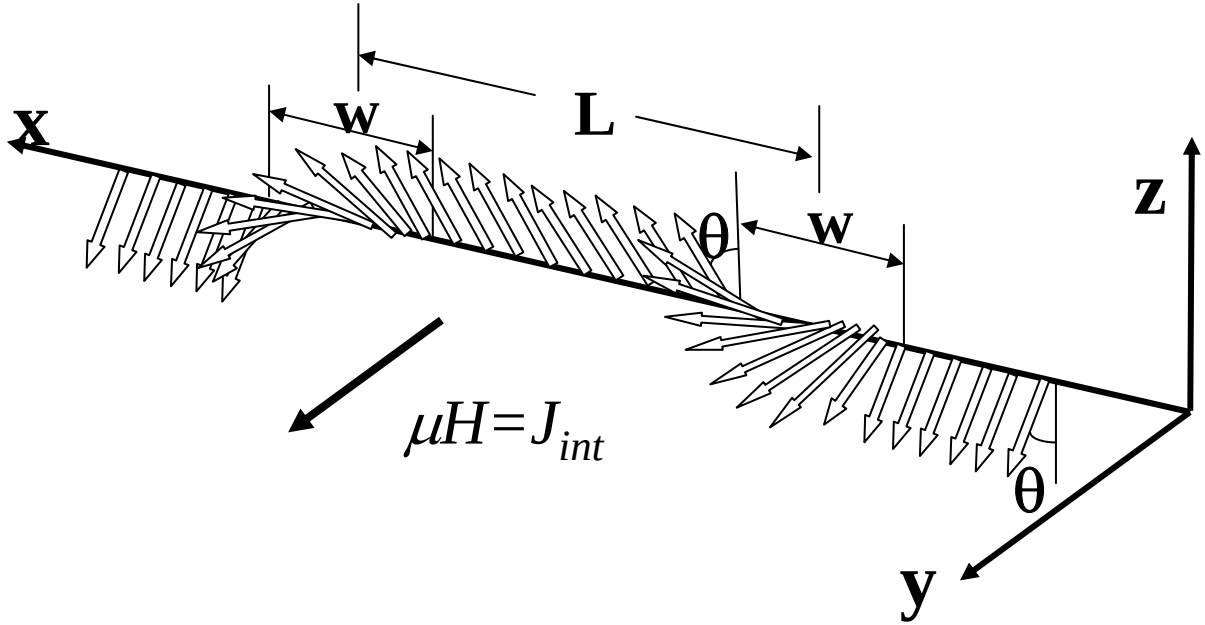


The Co magnetization (in-plane field) aligns the stripe domains of the Fe/Ni layer.

Co(10ML)/Cu/Fe/Ni(5ML)/Cu(001)




(a)
d_{Fe}=2.53ML
2.59ML
2.66ML
2.72ML
(b)
d_{Cu}=6.57ML
6.66ML
6.73ML
6.81ML
(c)
d_{Cu}=6.57ML
6.47ML
6.38ML
6.27ML



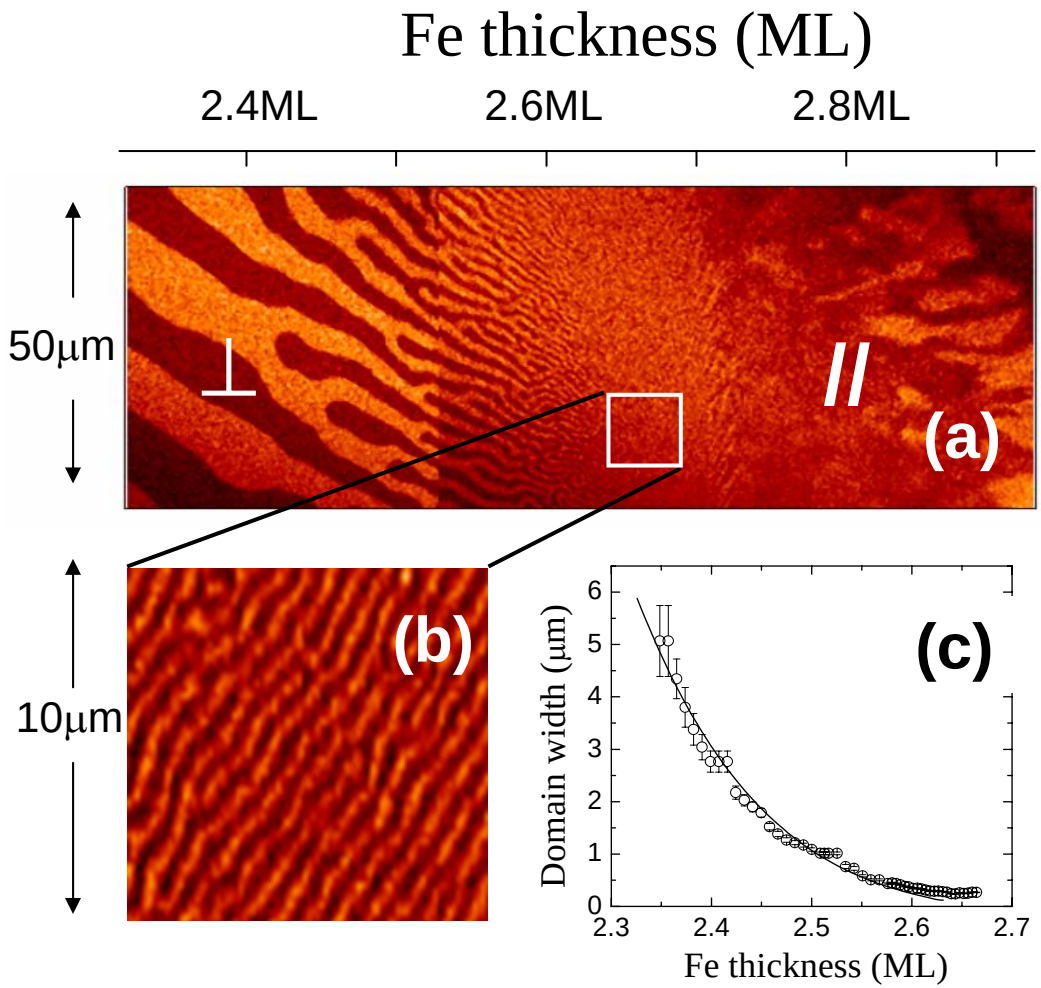
$$\varepsilon = \frac{J\pi^2(1-\sin\theta)}{Lw} - \left(1-\frac{w}{2L}\right)(K-\Omega)\cos^2\theta - \frac{2\Omega\cos^2\theta}{\pi L}\ln\left(\frac{6\pi L}{5w}\right)$$
$$- J_{\text{int}}\left(1-\frac{w}{L}\right)\sin\theta - \frac{2J_{\text{int}}w}{\pi L}\int_0^{\pi/2} d\phi\sqrt{1-\cos^2\theta\sin^2\phi}$$

$$\boxed{L = \frac{5J\pi^2}{6\Omega}\cdot\frac{\exp\left\{\sqrt{\frac{J\pi^4}{\Omega^2}\left[K_e-\left(\frac{4}{\pi}+\frac{1}{2}\right)J_{\text{int}}\right]+1}\right\}}{\sqrt{\frac{J\pi^4}{\Omega^2}\left[K_e-\left(\frac{4}{\pi}+\frac{1}{2}\right)J_{\text{int}}\right]+1}}}$$

$$K_e \equiv K-\Omega+\frac{\Omega^2}{J\pi^4} \approx K-\Omega$$

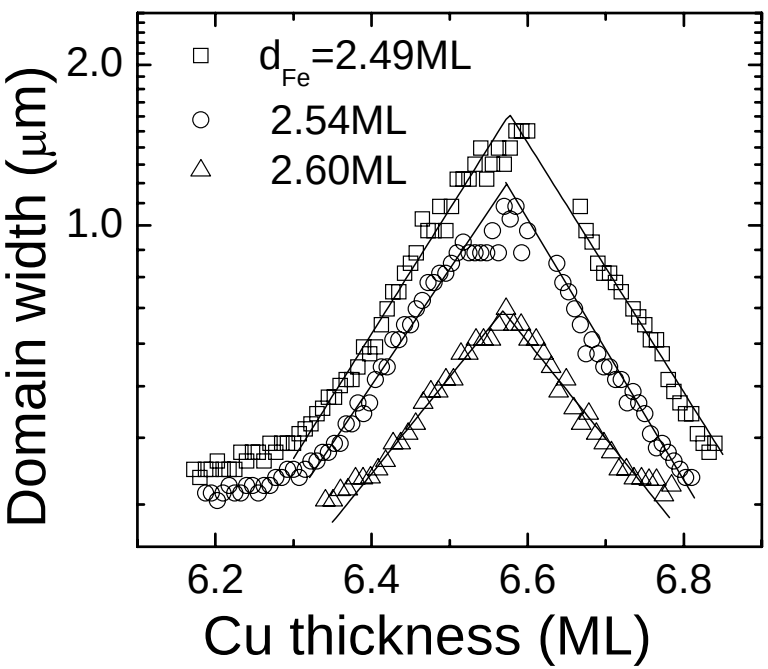
Discussion of J_{int}=0.

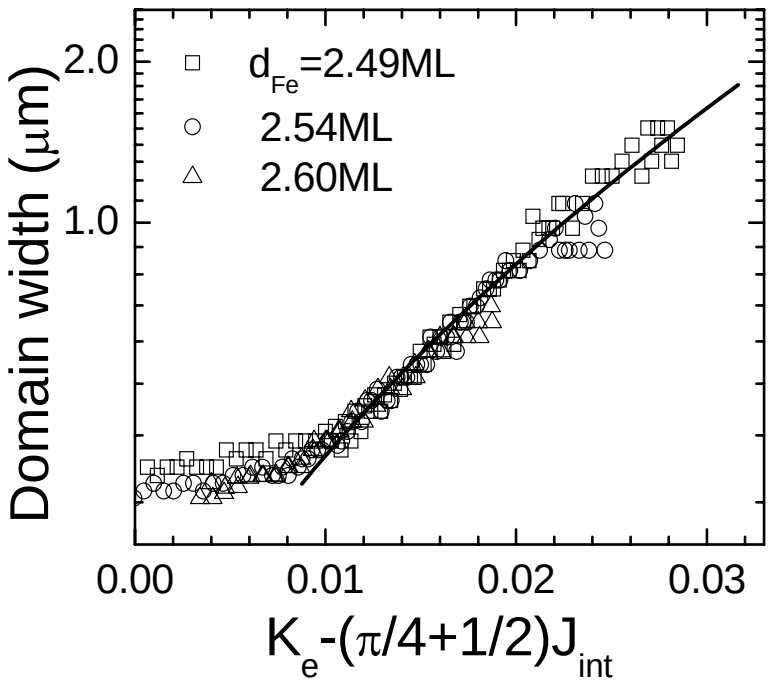
$$L = \frac{5J\pi^2}{6\Omega} \cdot \frac{\exp\left(\sqrt{J\pi^4 K_e / \Omega^2} + 1\right)}{\sqrt{J\pi^4 K_e / \Omega^2} + 1}$$



Discussion

$$L = \frac{5J\pi^2}{6\Omega} \cdot \frac{\exp\left\{\sqrt{\frac{J\pi^4}{\Omega^2}\left[K_e - \left(\frac{4}{\pi}+\frac{1}{2}\right)J_{\text{int}}\right]}+1\right\}}{\sqrt{\frac{J\pi^4}{\Omega^2}\left[K_e - \left(\frac{4}{\pi}+\frac{1}{2}\right)J_{\text{int}}\right]}+1} \approx L(J_{\text{int}}=0)\exp\left\{-0.88\sqrt{\frac{J\pi^4}{\Omega^2 K_e}}\cdot J_{\text{int}}\right\}$$





Wish List

1. Develop techniques that are unique for certain type of problems (e.g., element-specificity).
2. Attract users who are doing outstanding research on magnetic nanostructures, but not yet using synchrotrons.

- Keep pushing the spatial resolution down to nm for laterally modulated structures (vicinal surfaces, wires, and dots …).
- Element-specific measurement of antiferromagnetic materials other than oxides (Mn, Cr, FeMn).
- Microscopy within magnetic field.
- Fast spin Dynamics (t<1-10ps).
- Improve in-situ sample preparation capability.

Collaborators

- **Department of Physics, University of California at Berkeley**
  Y. Z. Wu, C. Won, and H. W. Zhao

- **Advanced Light Source, Lawrence Berkeley National Laboratory**
  A. Doran and A. Scholl

- **Department of Physics, Fudan University**
  X. F. Jin

Thank you!