Manipulating Exchange Bias by Spin-Orbit Torque

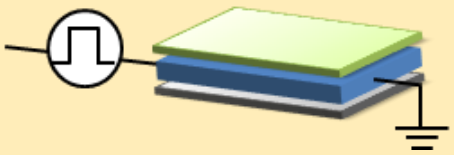
Chih-Huang Lai

Materials Science and Engineering,

National Tsing Hua University, Taiwan

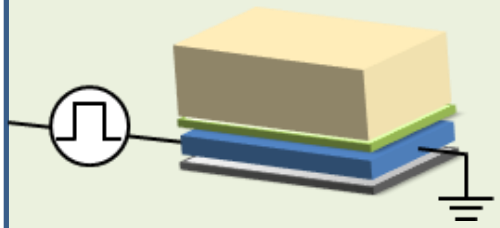
Outline

HM/FM/HM



[Pt/Co/Pt]

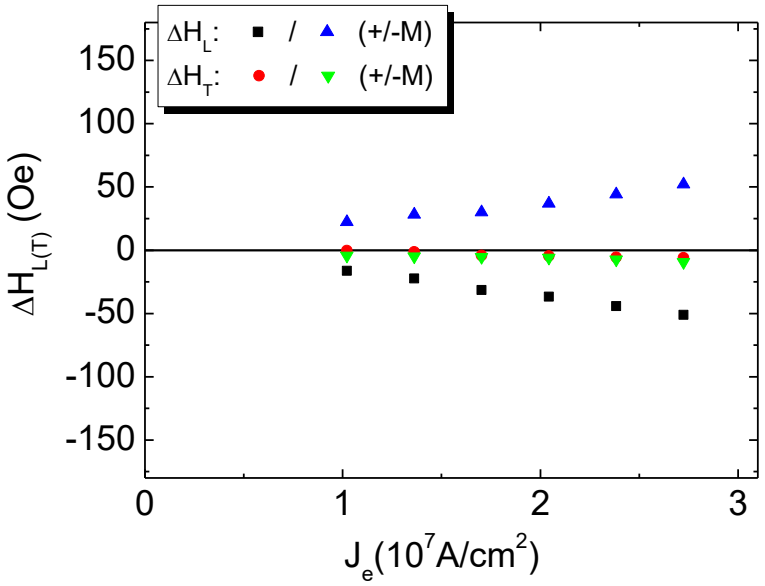
HM/FM/AFM



[Pt/Co/IrMn]

Exchange bias switching

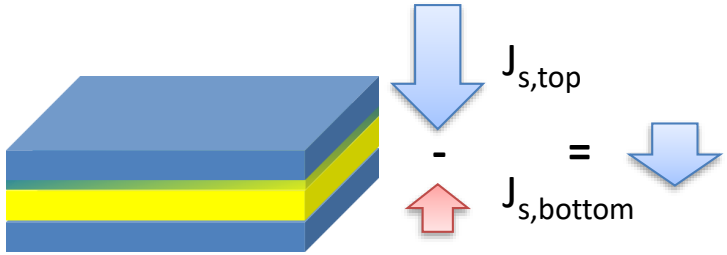
Effective fields induced by Spin-orbit torque in Pt/Co/Pt



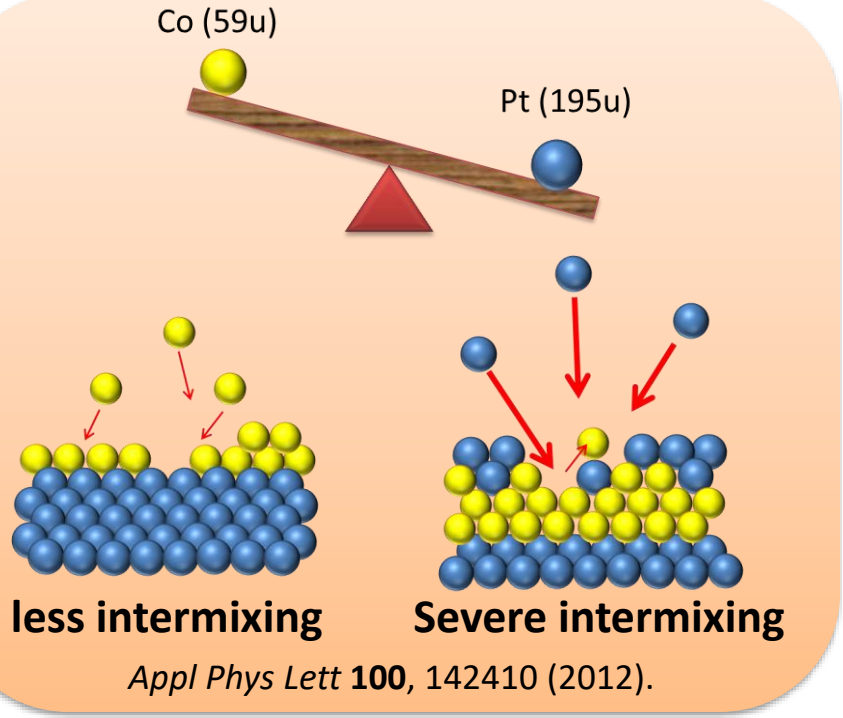
Pt (2 nm)/ Co (0.9 nm)/ Pt (2 nm)/

- Spin Hall effect dominated (ΔH_L >> ΔH_T)

Huang and Lai, APL, 107, 232407(2015)



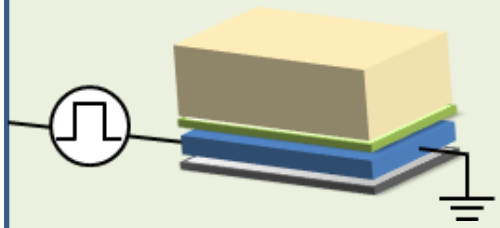
Different interface structure



Appl Phys Lett **100**, 142410 (2012).

SOT in Pt/Co/IrMn

HM/FM/AFM

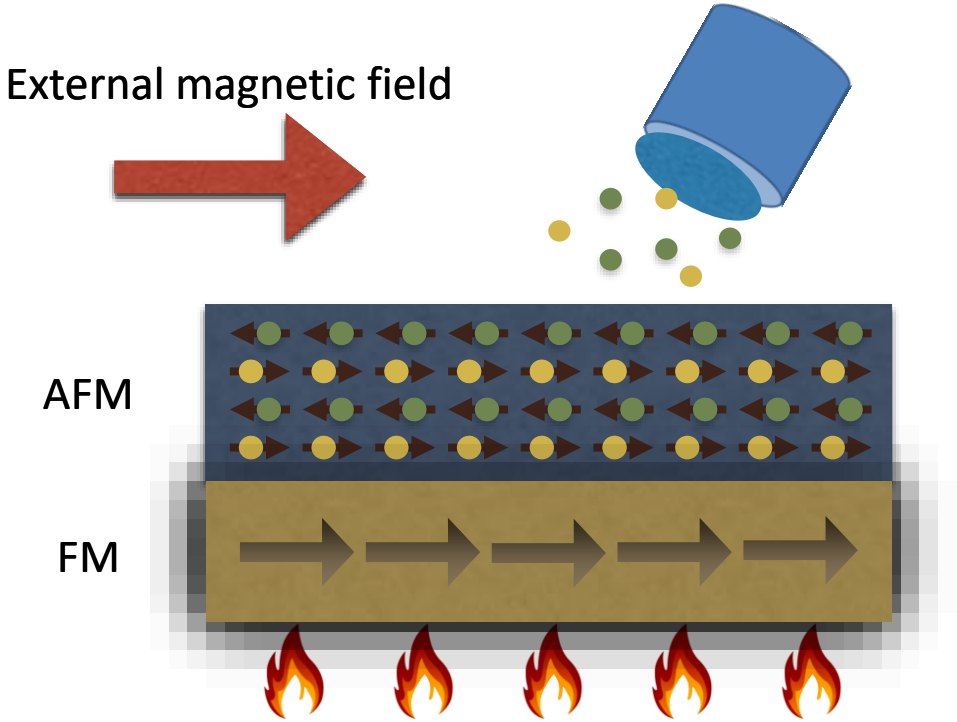


[Pt/Co/IrMn]

Exchange bias switching

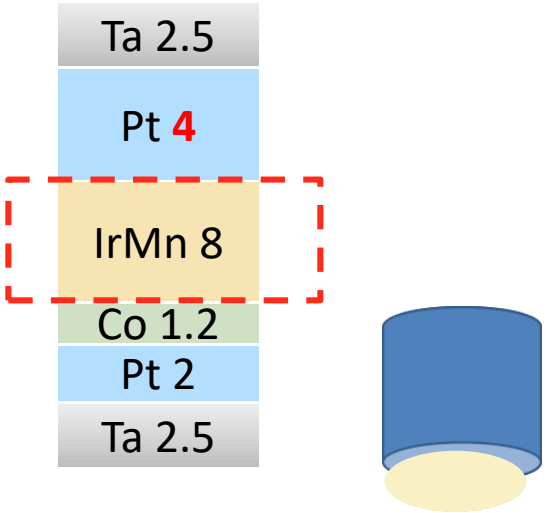
Exchange bias of FM/AFM

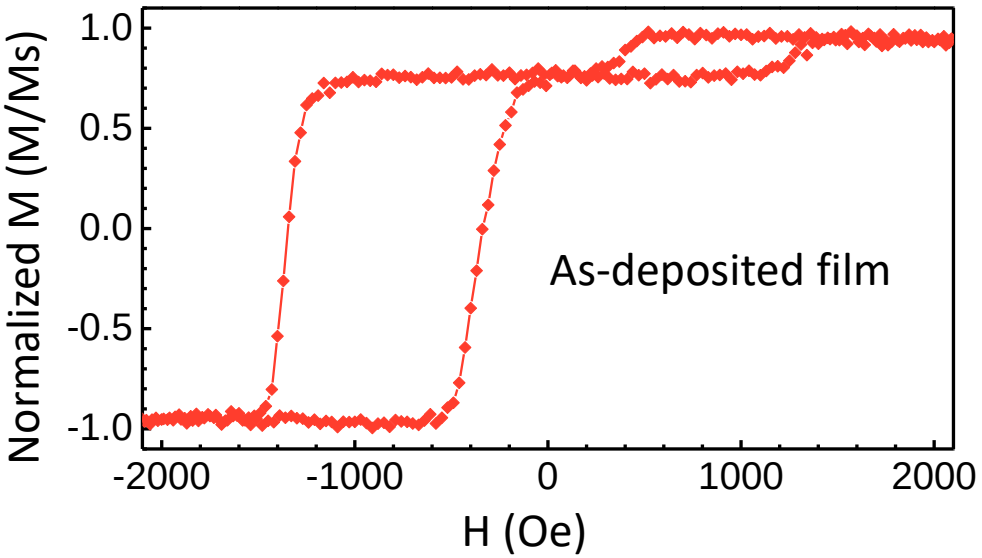
- **Align the interfacial spins of AFM with FM magnetization**

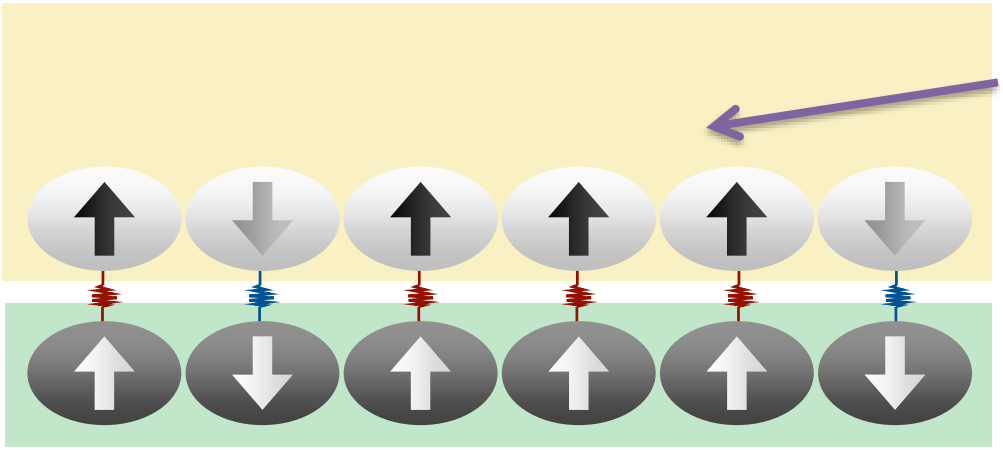


1. Deposition with external magnetic field.
2. Field-cooling

Magnetic property of as-deposited film







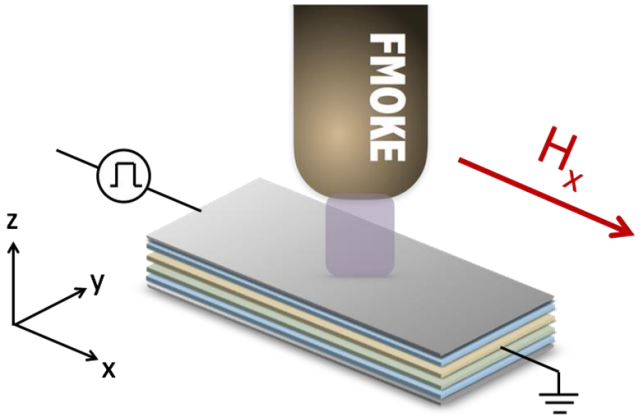
Interfacial spin

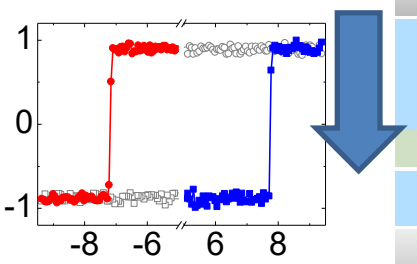
IrMn

Co

Magnetic domain

SOT switching curve



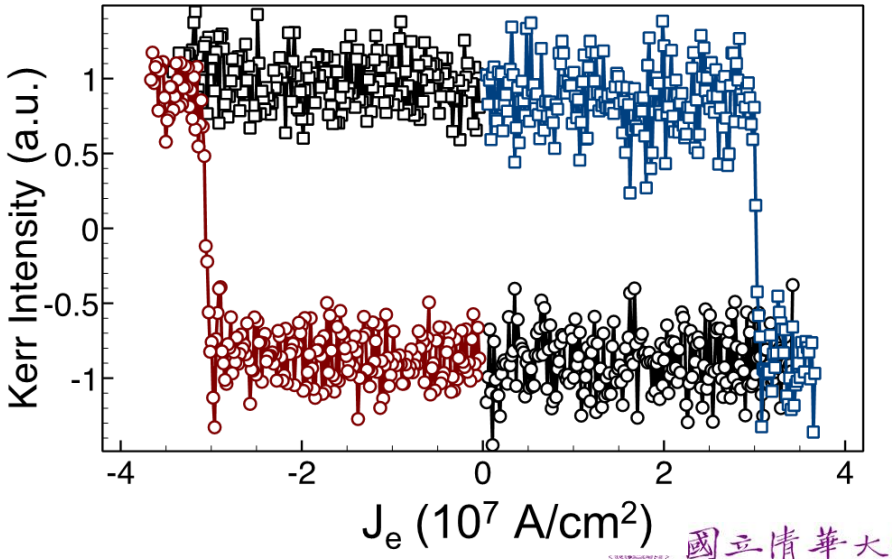


Ta 2.5
Pt 4
Co 1.2
Pt 2
Ta 2.5

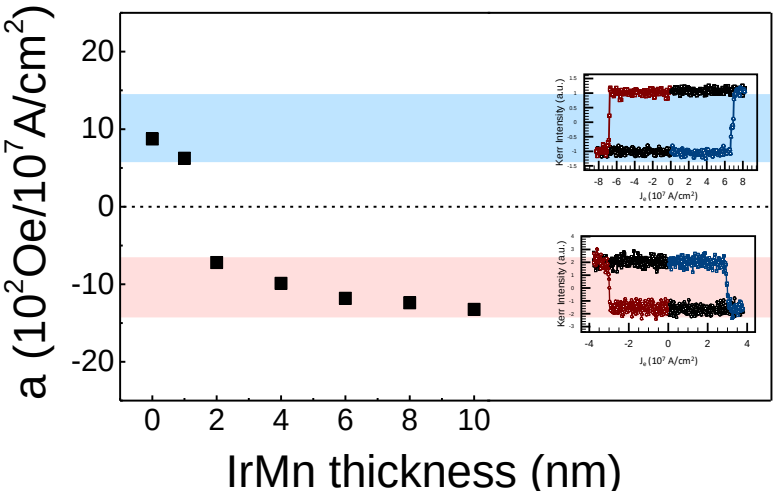
Device: 5×10 μm^2 Hx= 300 Oe I_{pulse}=20 ns-10 us

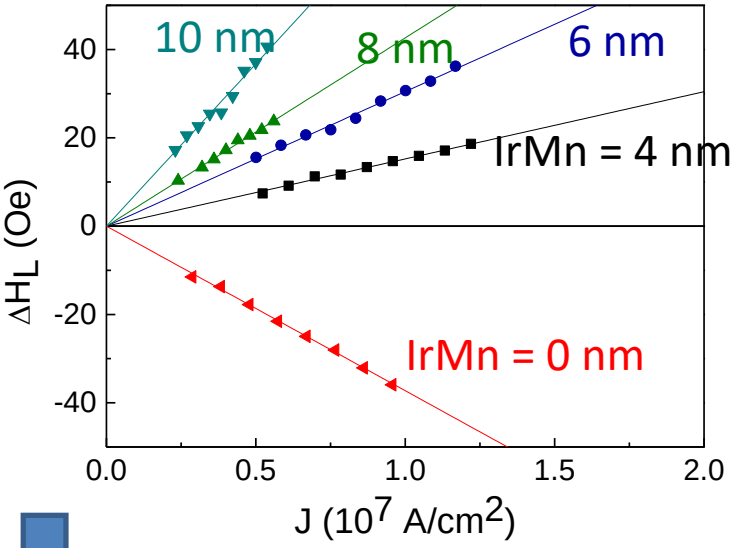
Ta 2.5
Pt 4
IrMn 8
Co 1.2
Pt 2
Ta 2.5

Js



Dominant spin current source

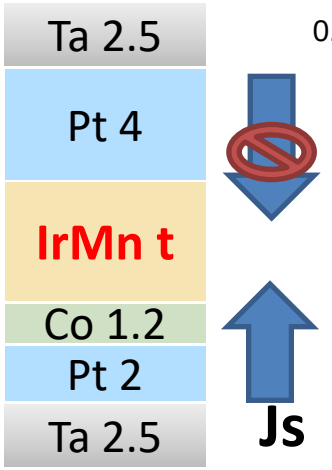




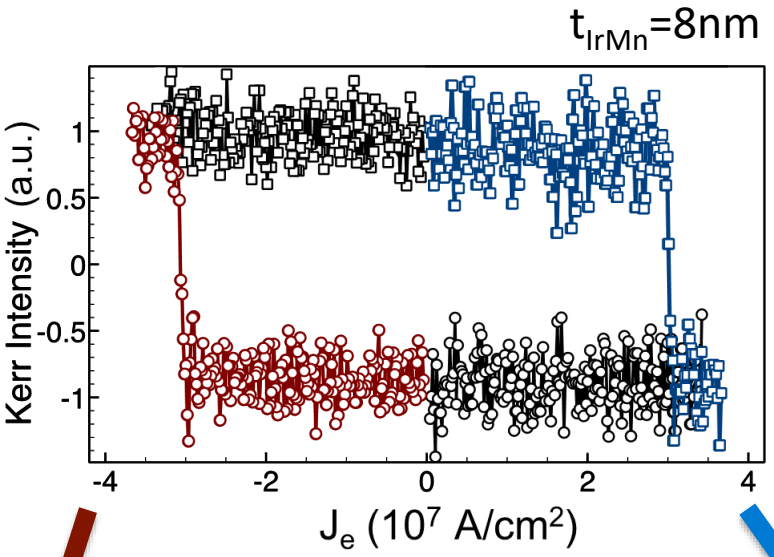
SOT efficiency $\alpha=H_K/J_c$

H_K :anisotropy field

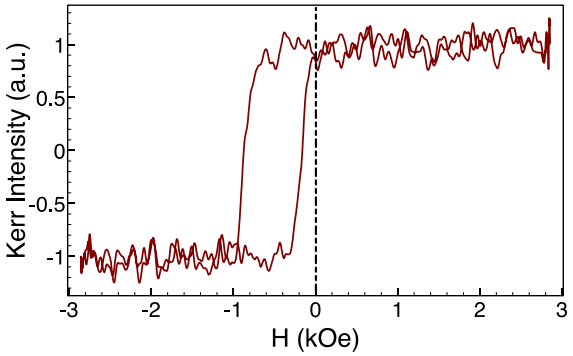
J_c :threshold current density



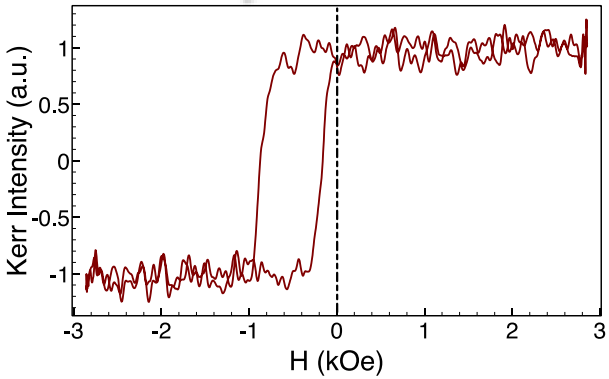
Current-pulse-induced EB switching



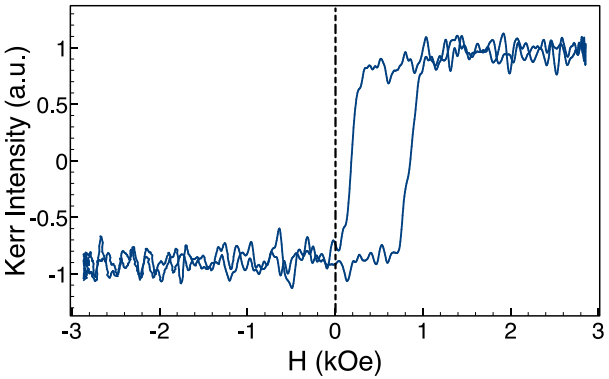
Initial EB



After -I SOT switching

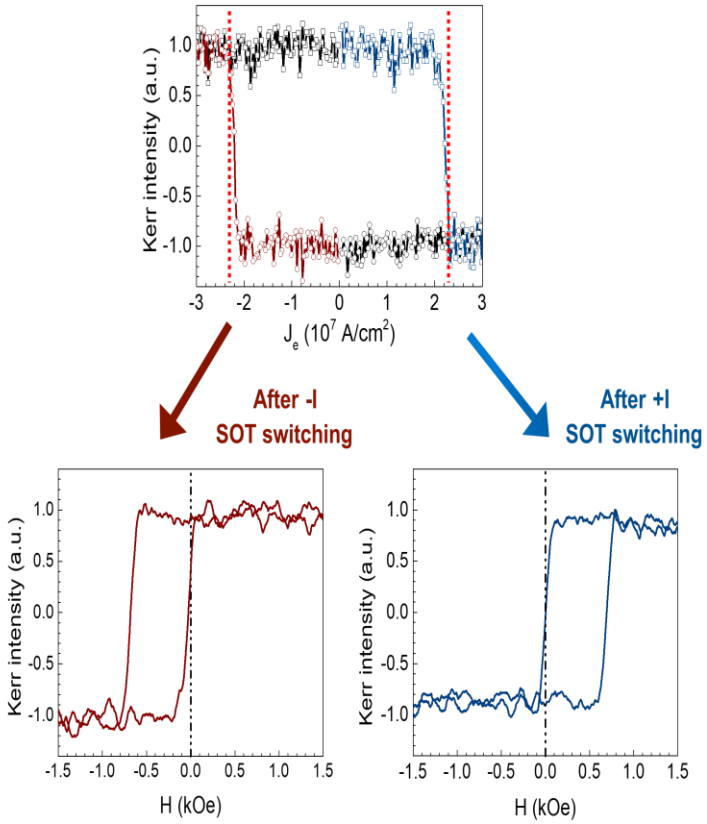


After +I SOT switching



Lin and Lai, Nature Materials, **18**, 335 (2019)

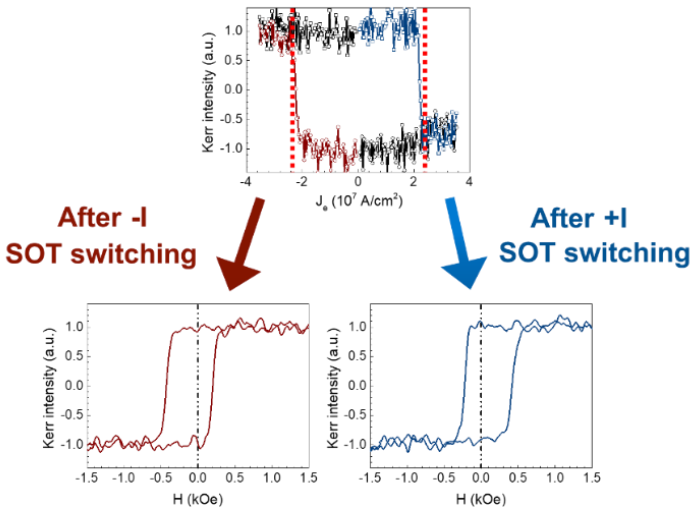
Dominant spin current source- bottom Pt

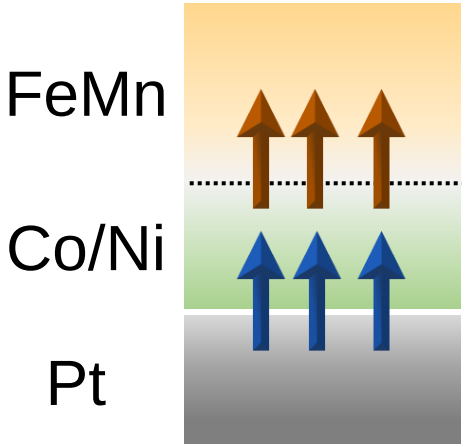


Ta 2.5
Pt 4
IrMn 8
Co 1.2
Pt 2
Ta 2.5

Ti 5
IrMn 8
Co 1.2
Pt 2
Ti 2.5

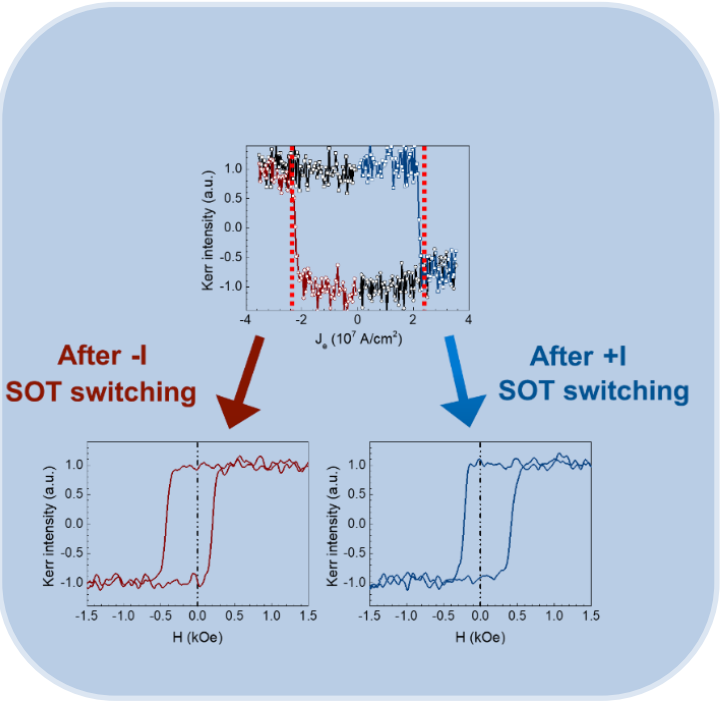
Joule heating effect?

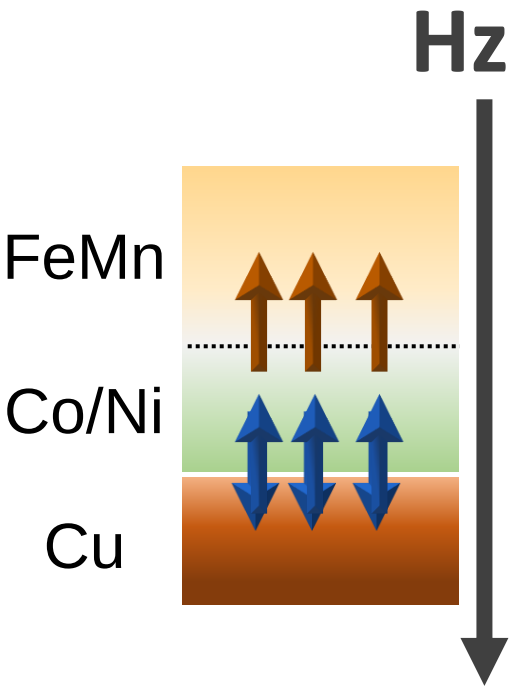


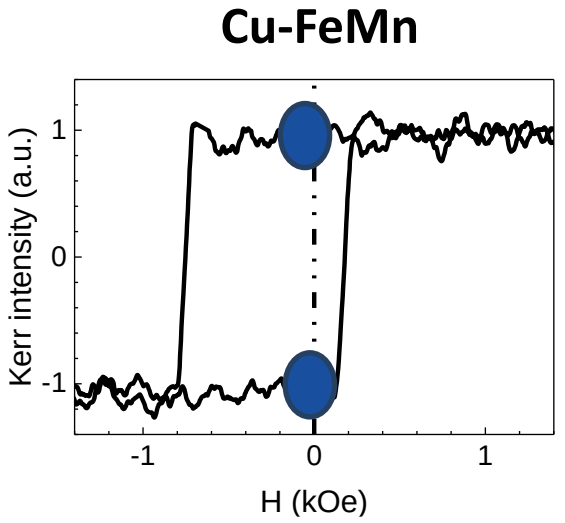


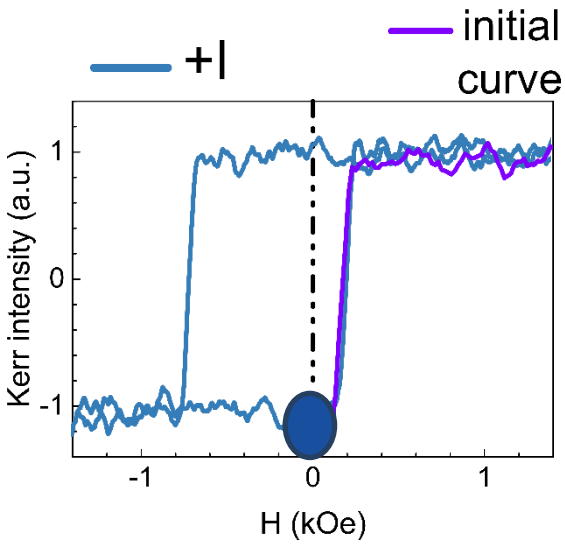
Sub.//Ti(5)/Pt(5)/[Co(0.3)/Ni(0.6)]$_2$/**FeMn**(10)/Ti (2)

Joule heating effect?



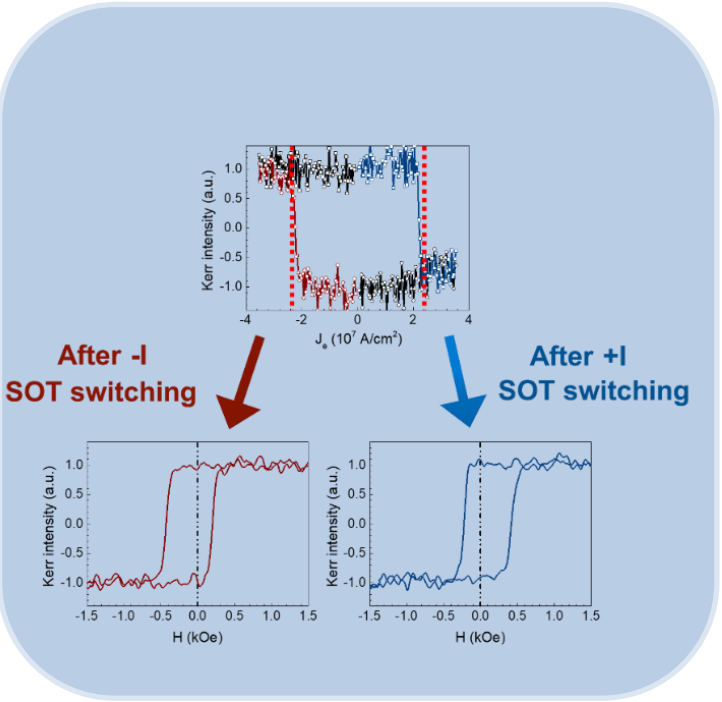






Sub.//Ti(5)/**Pt(5)**/[Co 0.3)/Ni(0.6)]$_2$/**FeMn**(10)/Ti (2)

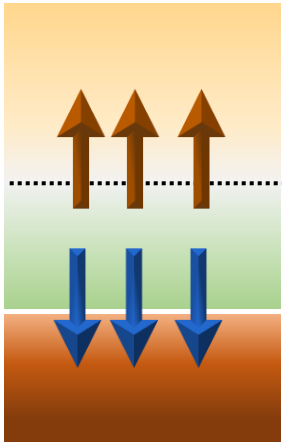
Joule heating effect?



FeMn

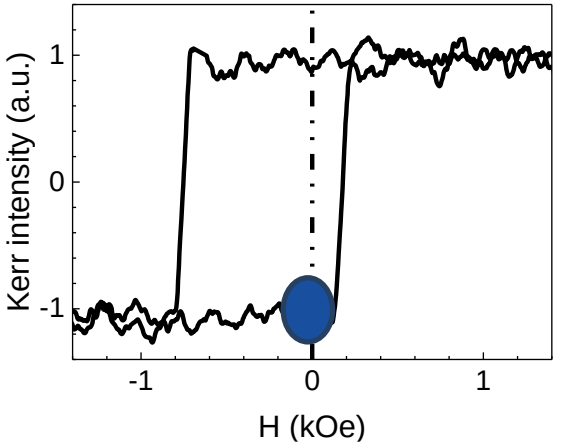
Co/Ni

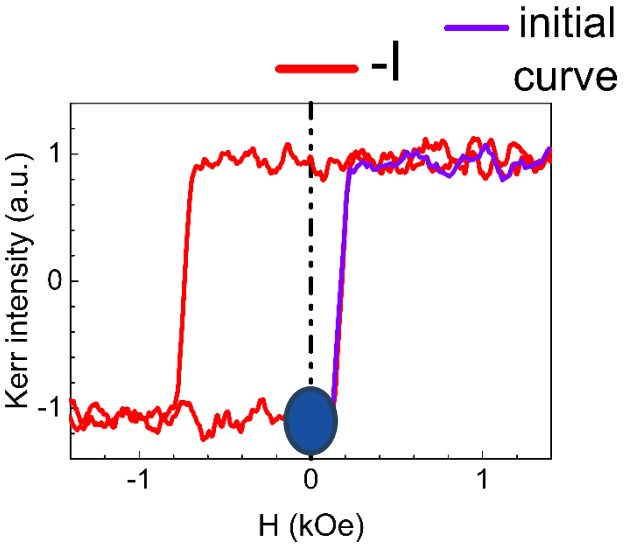
Cu



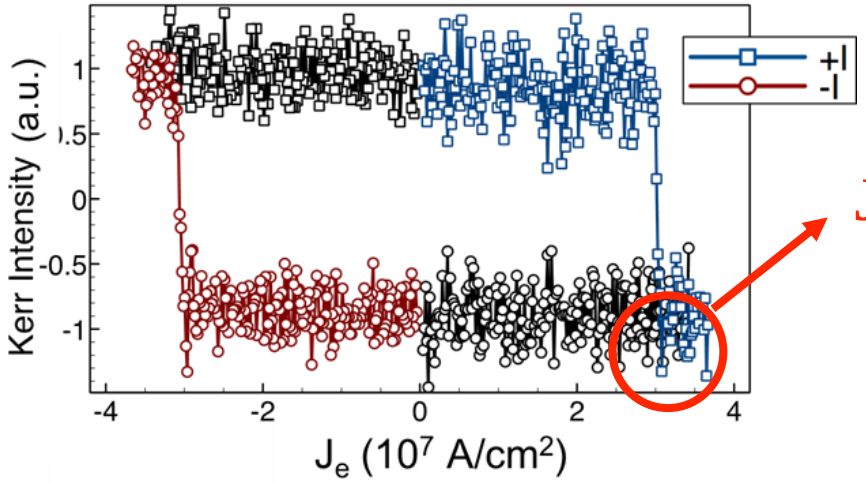
Sub.//Ti(5)/**Pt(5)**/[Co 0.3)/Ni(0.6)]$_2$/**FeMn**(10)/Ti (2)

Cu-FeMn

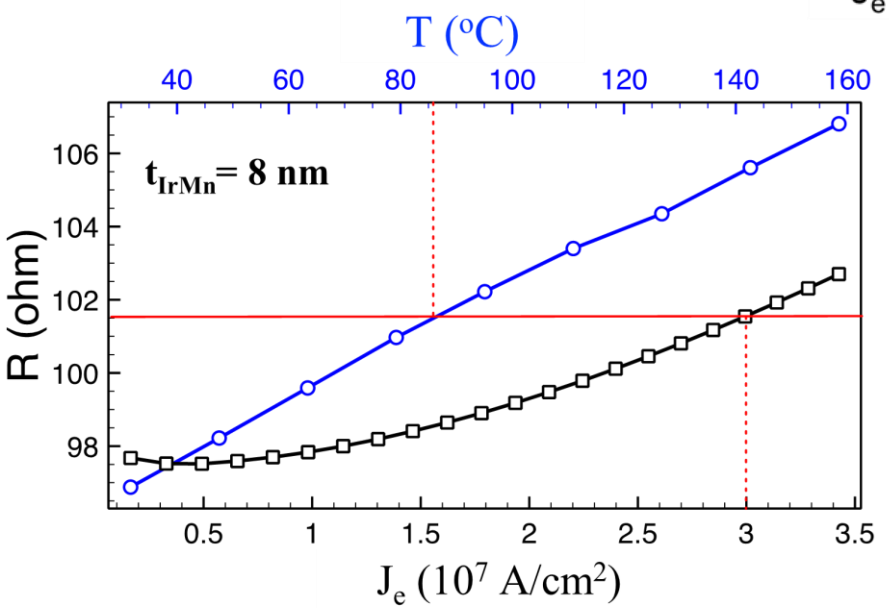


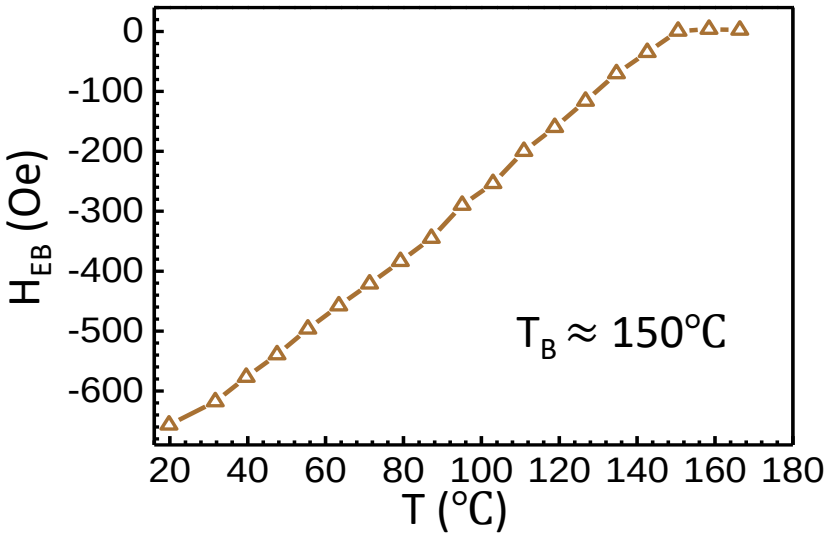


Joule heating effect?



J_c~ 3*10^7 A/cm^2

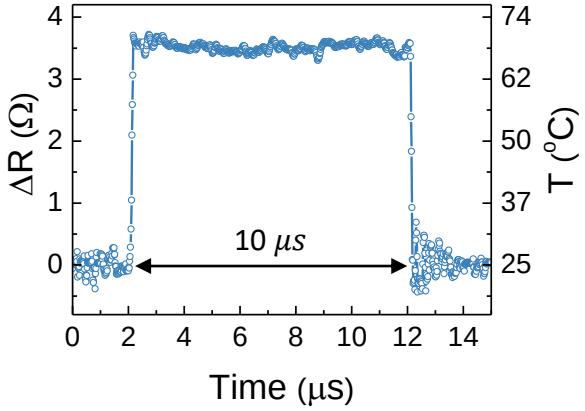


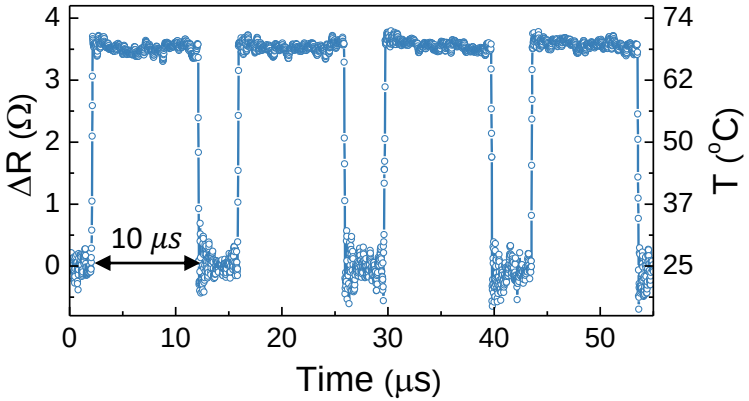


Measurement of device temperature

Time-resolved resistance measurement (TRRM)

Pt 2/Co 1.2/IrMn 6 (nm)





$$\Delta R = R - R_0$$

$$T = T_0 + \gamma\,\Delta R = \mathbf{67.5} \pm 1.7°C$$

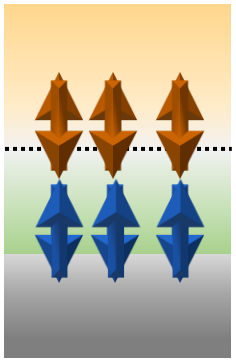
$$\gamma = 12.27\ K/\Omega\,, where\ \gamma = dT/dR$$

Keithley 4200-SCS (Semiconductor Characterization System) with **4225-PMU** Ultra Fast I-V Module

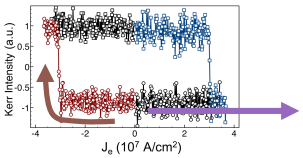
Pulse width = 10 us.
Current pulse amplitude =Jc

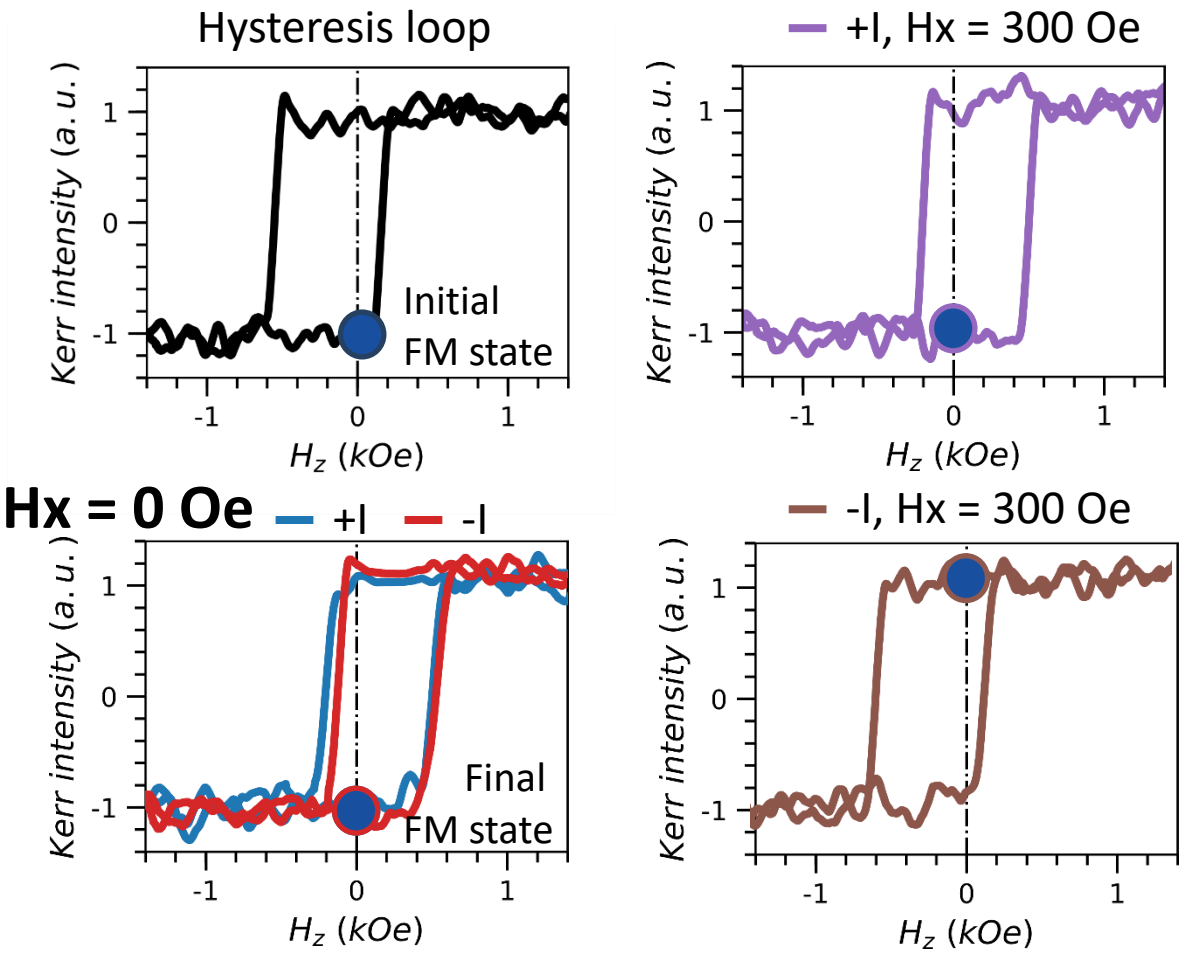
Effects of Hx on SOT switching of FM and EB

AP-mode



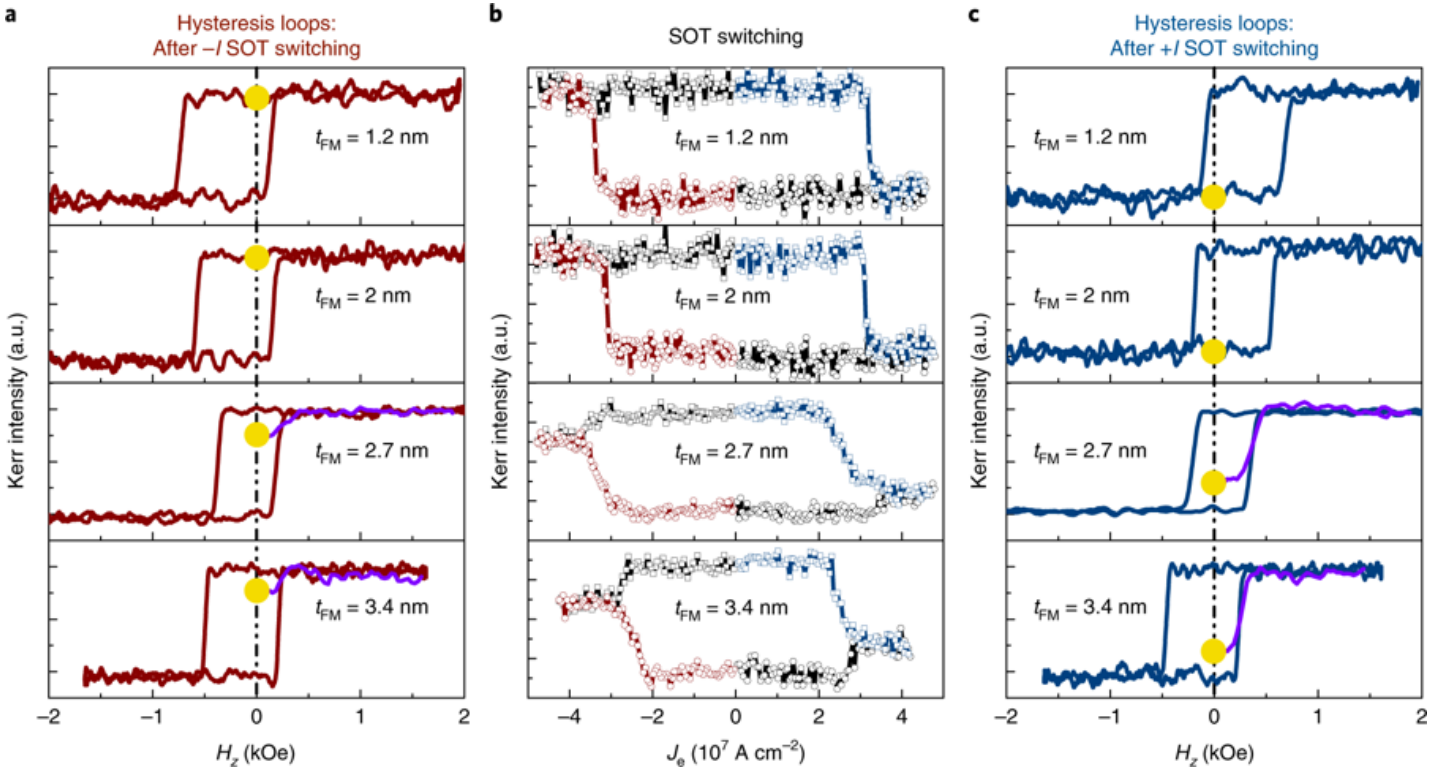
SOT switching, Hx=300 Oe





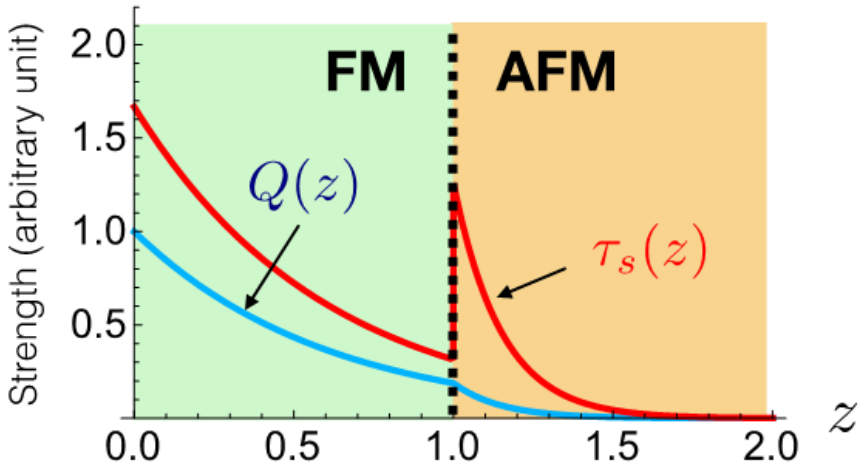
The reversal of interfacial spins depends on FM magnetization, regardless of Hx.
The spin current provides disturbance for the interfacial spins to be aligned with FM.

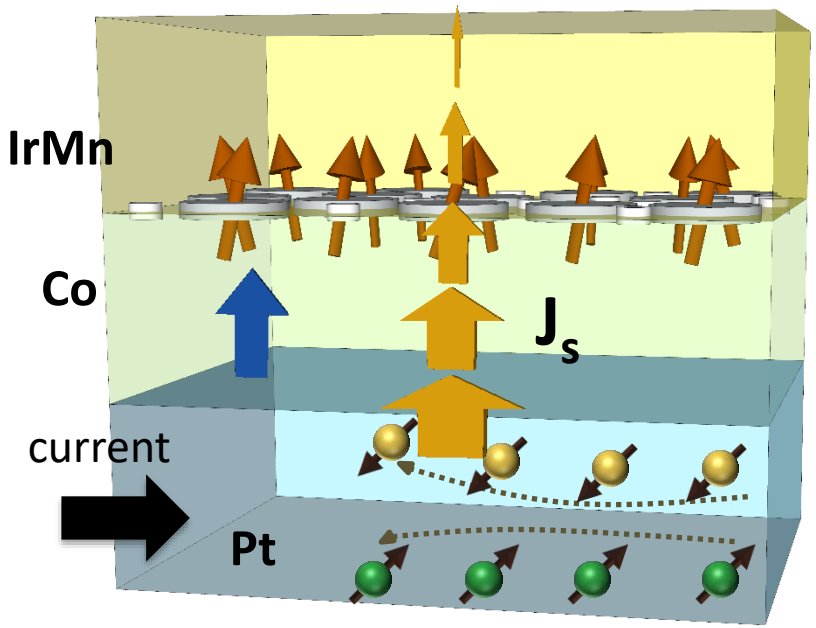
How far can spin current go through the FM



For ferromagnetic layer thickness > 3.4 nm, the EB is not switched

Enhanced spin torque at FM/AFM interface



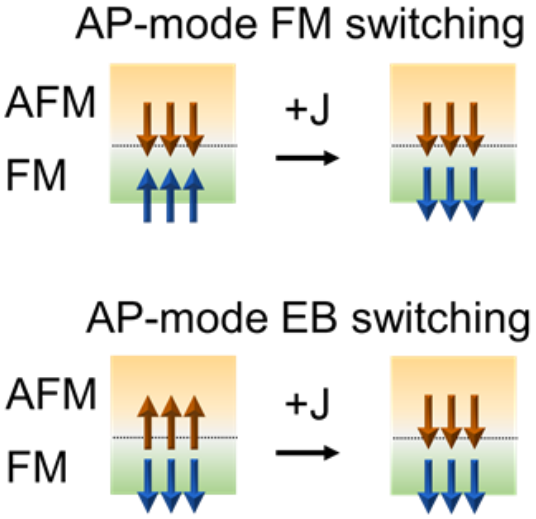


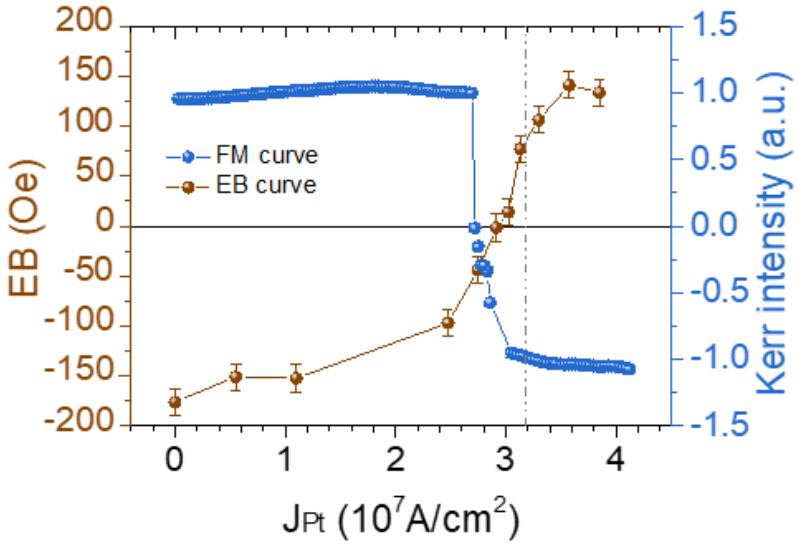
$$\frac{\partial \boldsymbol{m}}{\partial t} = -\gamma \boldsymbol{m} \times \boldsymbol{H}_{\text{eff}} + \alpha\, \hat{\boldsymbol{m}} \times \frac{\partial \boldsymbol{m}}{\partial t} - \frac{\delta \boldsymbol{m}}{\tau} - \nabla \cdot \boldsymbol{Q}$$

Phys. Rev. B **73**, 054428 (2006).

SOT switching in AP-mode

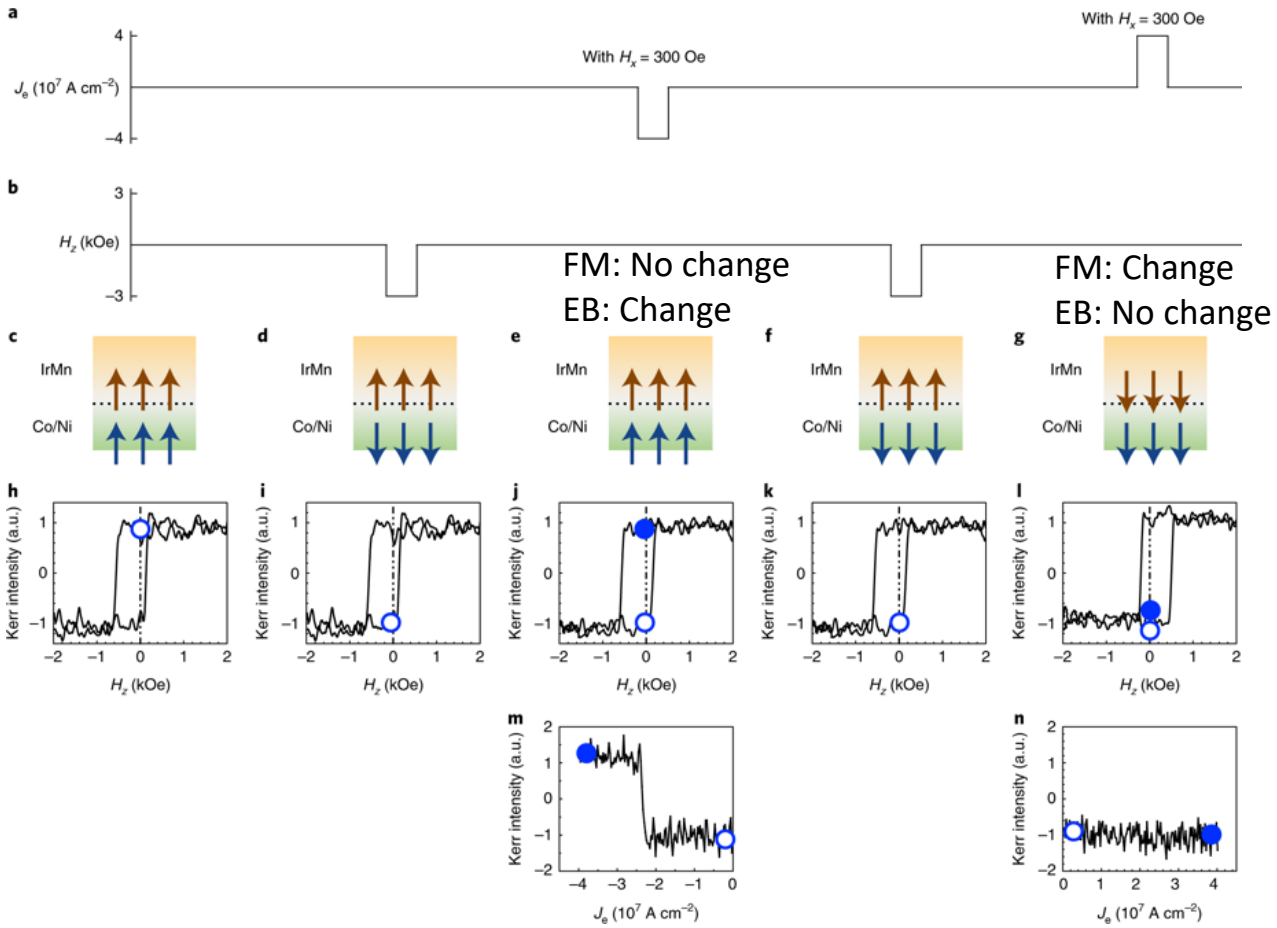
$Pt(2)/\ [Co(0.2)/Ni(0.8)]_2/IrMn(8)$





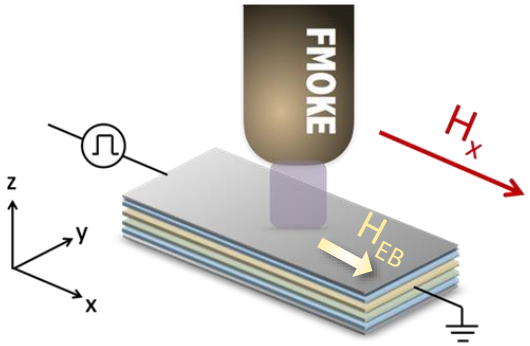
The closeness of FM and EB switching thresholds provides an indirect hint that SOT is the key for the switching mechanism.
Flipping interfacial spins is accumulative and leads to smooth EB reversal, different from FM reversal.

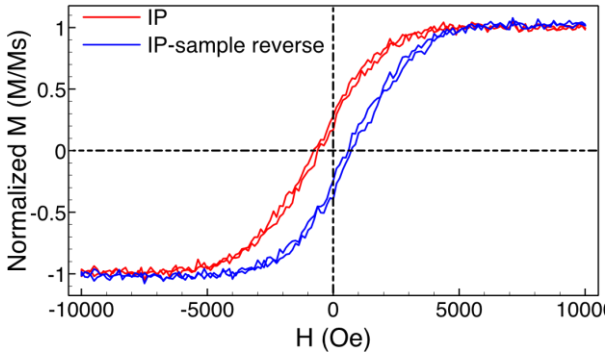
Independent SOT switching of ferromagnetic magnetization and exchange bias.

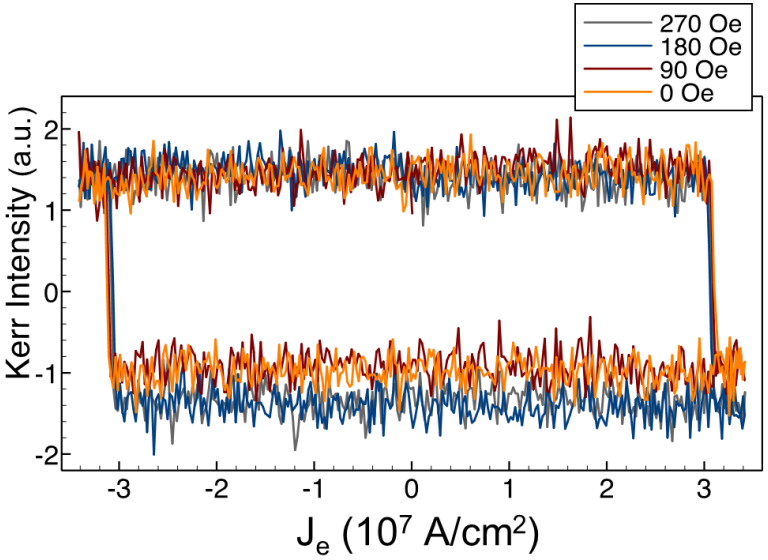


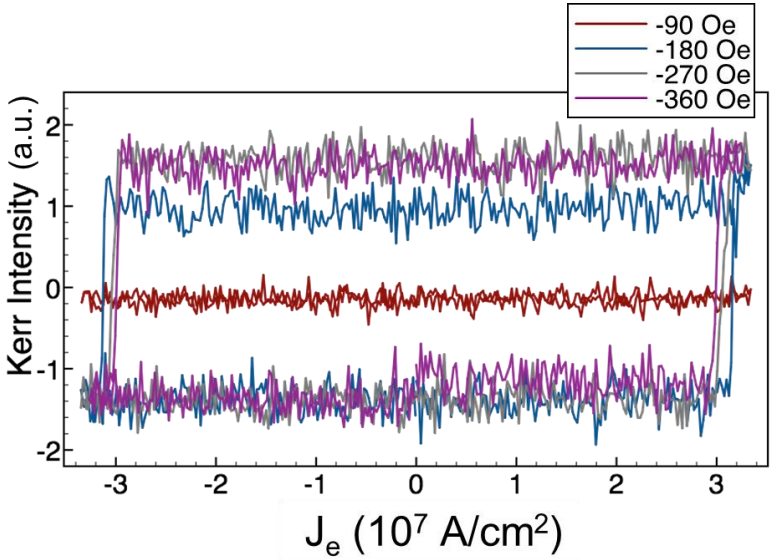
Field-free switching

→ after In-plane annealing, the field free SOT switching can be accomplished



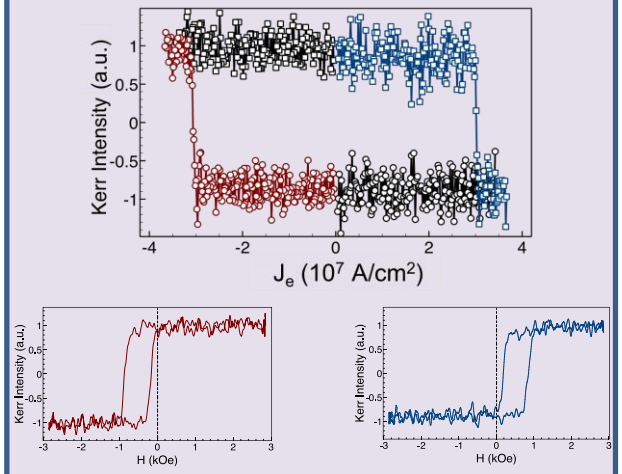






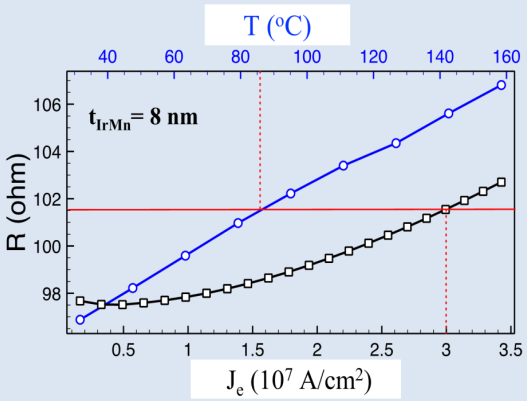
Summary

Current pulse-induced EB switching



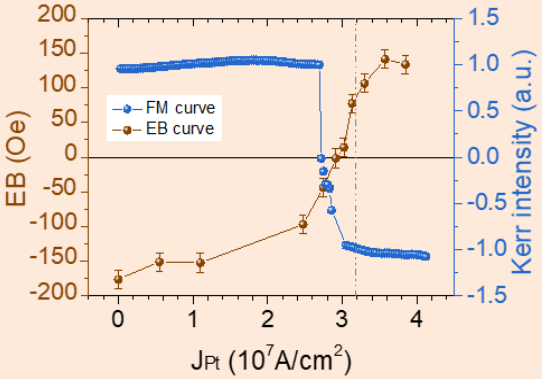
SOT does not only switch FM but interfacial AFM

Joule heating is not a major factor



Temperature rise is much lower than T_B

SOT effects on FM and AFM are different

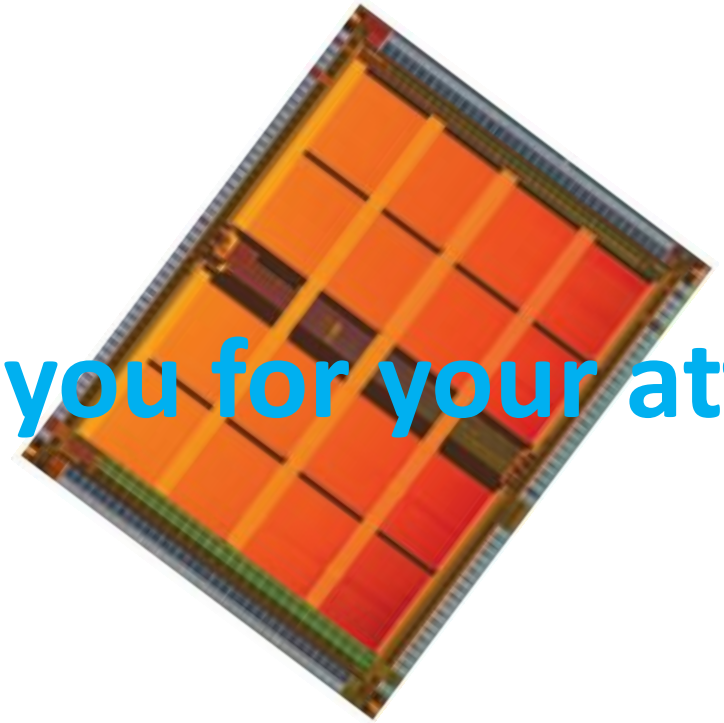


Nat. Mater. 18, 335 (2019)

Acknowledgement

- Dr. Kuo-Feng Huang
- Dr. Ding-Shou Wang
- Mr. Po-Hung Lin
- Prof. Hsiu-Hau Lin(Physics, NTHU)
- Funding supported by Ministry of Science and Technology (MOST), Taiwan

  and Applied Materials Co.



Thank you for your attention!

Web page of our lab:
Prof. Chih-Huang Lai

Chih-Huang Lai
chlai@mx.nthu.edu.tw