Manipulation of pure spin currents with synthetic antiferromagnets

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XIX Meeting of Physics, Lima Peru

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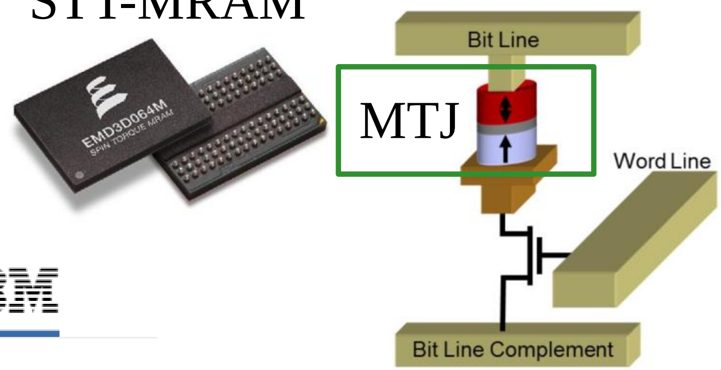
  Polarization direction of the spin current
  Sign of the inverse spin Hall effect signal

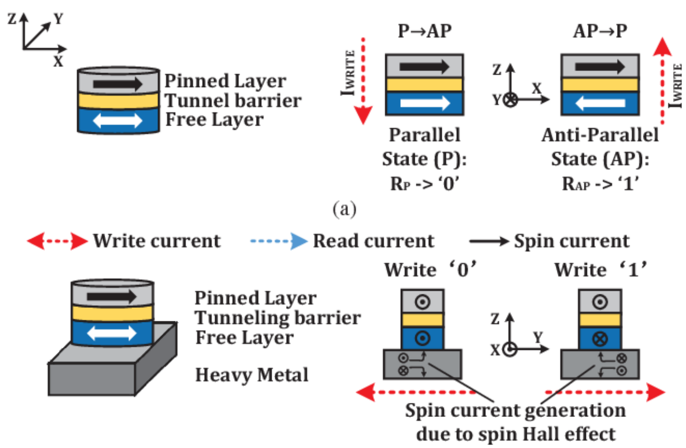
3. Conclusions

Motivation

STT-MRAM

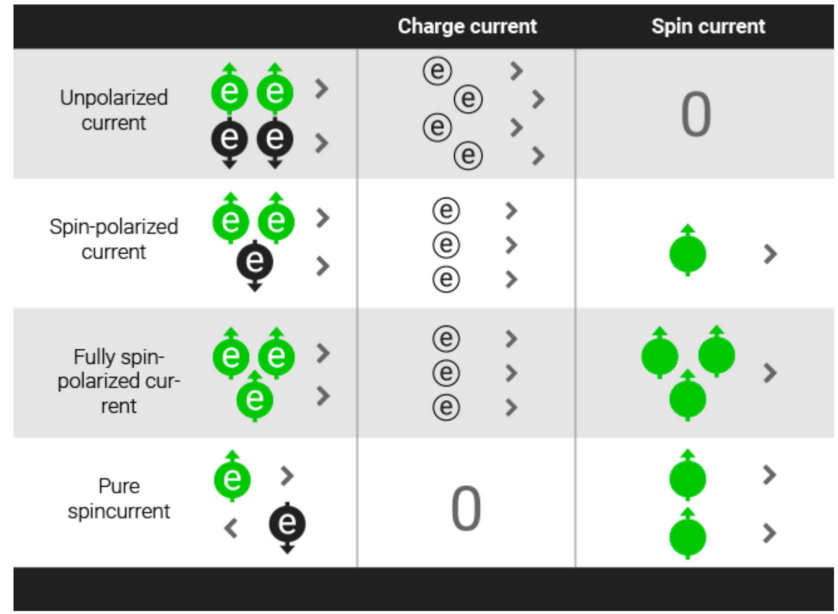


IBM



Z. He et al. IEEE/ACM Intern. Symp. On Nanos. Architec. 2017

Spin current



Pure spin current

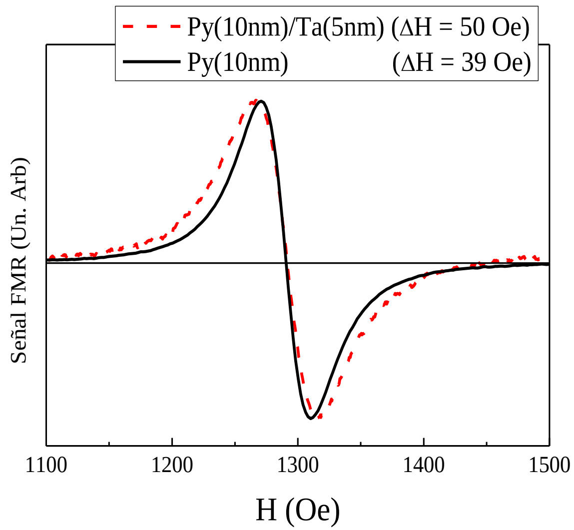
➔ No Joule heating!

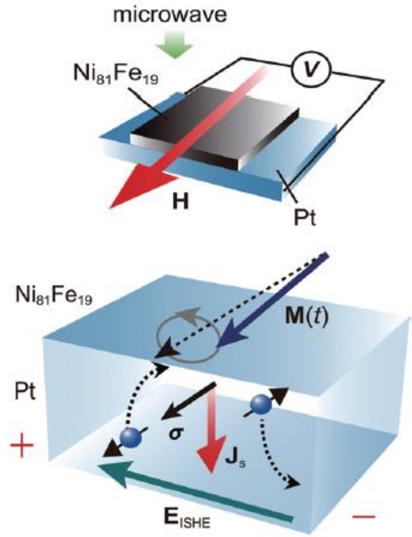
➔More efficient devices!

How to generate, detect and **control** them?

Spin pumping

$$\frac{\partial \mathrm{M}}{\partial t} = \underbrace{-\gamma\left[\mathrm{M}\times(\mu_0 \mathrm{H}_{\mathrm{eff}})\right]}_{\text{torque}} + \underbrace{\frac{\eta}{M_s}\left[\mathrm{M}\times\frac{\partial \mathrm{M}}{\partial t}\right]}_{\textit{damping}}$$

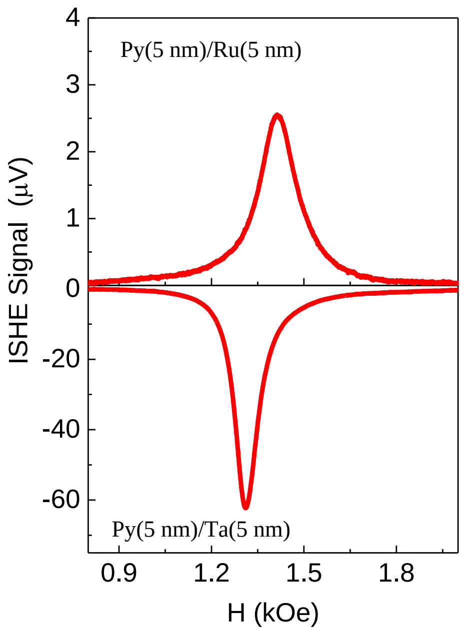




$$J_s^{\mathrm{pump}}\hat{\mathrm{s}} = \frac{\hbar}{4\pi}\mathrm{Re}(g^{\uparrow\downarrow})\left[\hat{\mathrm{m}}\times\frac{\partial \hat{\mathrm{m}}}{\partial t}\right]$$

Inverse spin Hall effect

$$\mathbf{J}_c^{\mathrm{ISH}} = \alpha_{\mathrm{SH}}\left(-\frac{2e}{\hbar}\right) J_s\left[\hat{\mathrm{z}}\times\hat{\mathrm{s}}\right]$$



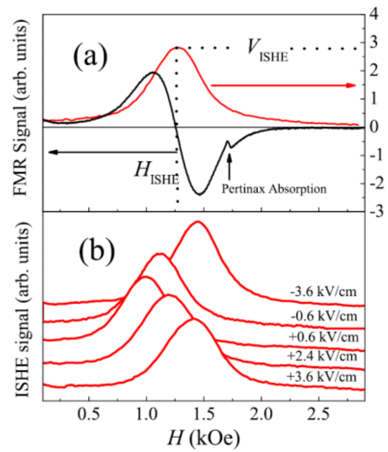
$\alpha_{SH} < 0$: Mo, Nb, Ta, W
$\alpha_{SH} > 0$: Pd, Pt, Ru, Si

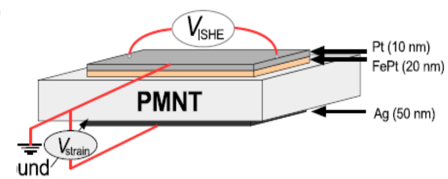
J. Gómez *et al.*, PRB **90** 184401 (2014)

Introduction

Spin pumping - Inverse spin Hall effect
- Ferromagnetic/non-magnetic bilayer

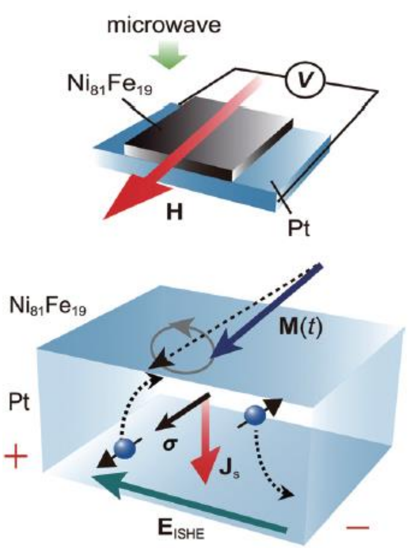
Piezo//Ferromagnet/non-magnetic

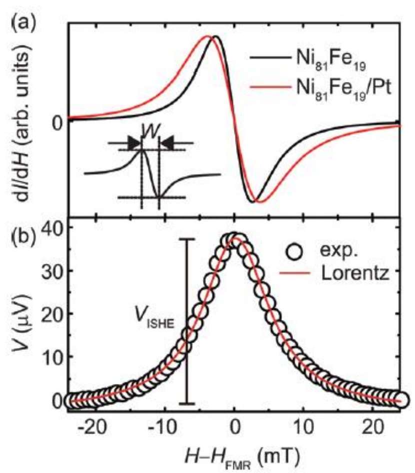




J. E. Gómez *et al*., APL (2016)

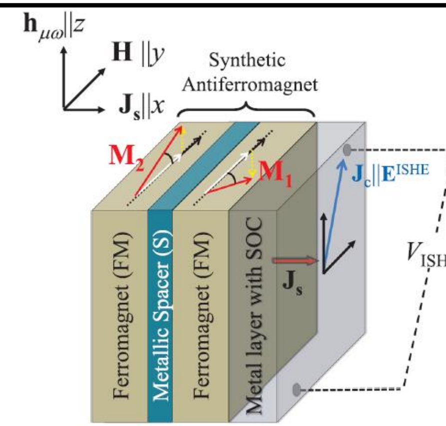
Ferromagnetic/non-magnetic bilayer





K. Ando *et al*., JAP (2011)

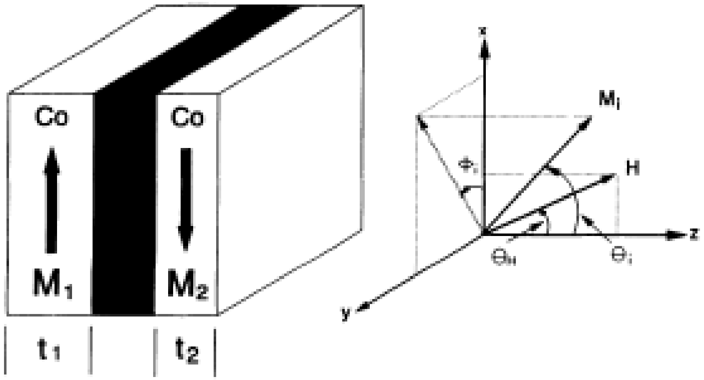
Synthetic Antiferromagnet/non-magnetic



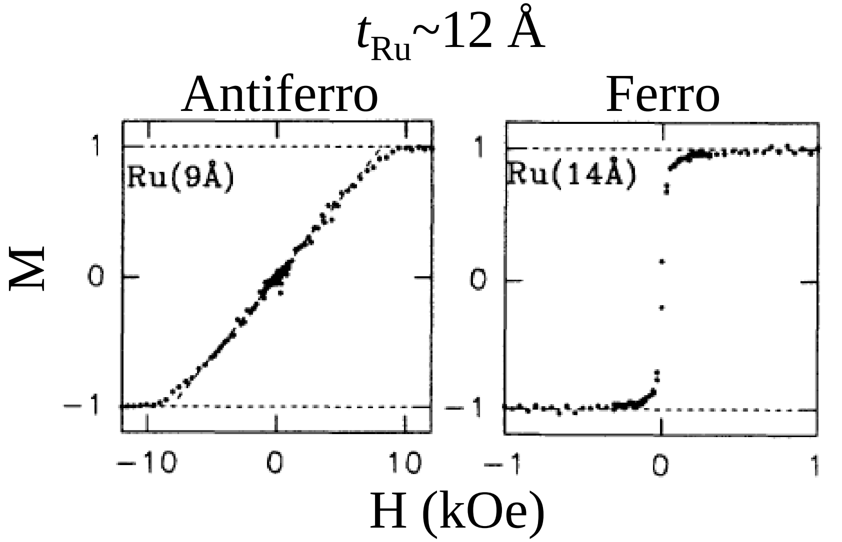
L. Avilés Félix *et al*., APL (2017) y JAP (2018)

Synthetic Antiferromagnet: Co/Ru/Co

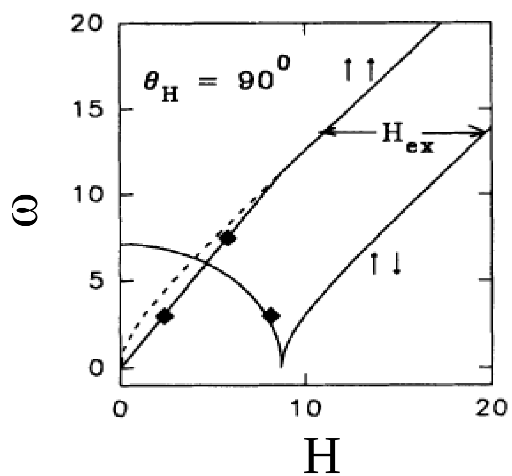
Z. Zhang *et al*., PRB **50** 6094 (1994)



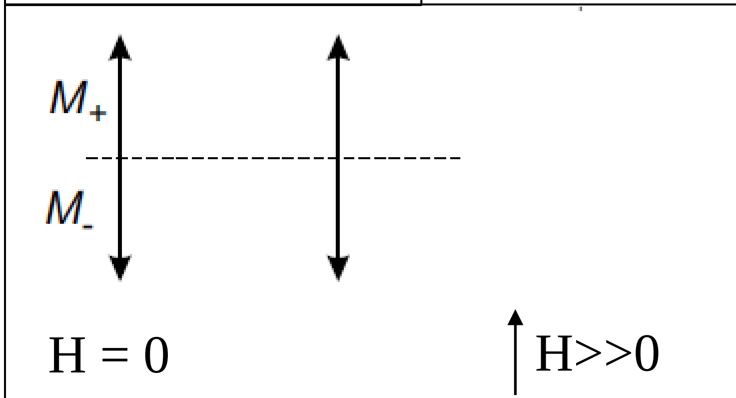
RKKY coupling



Dispertion relation ω(H)

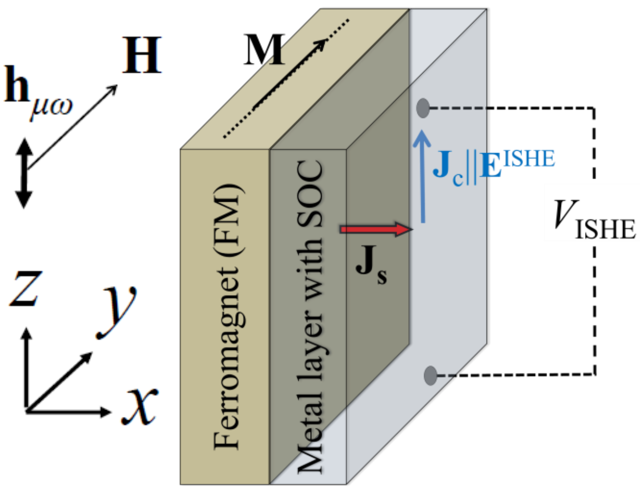


Spin-flop process

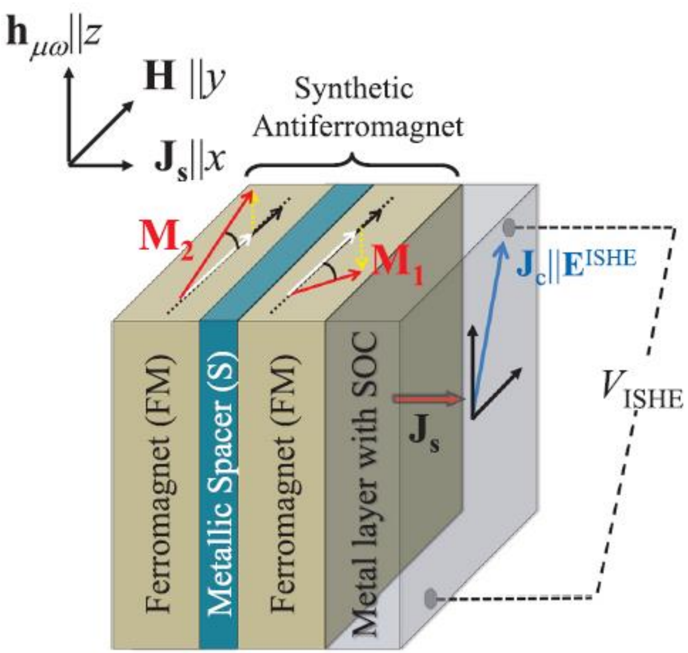


Results

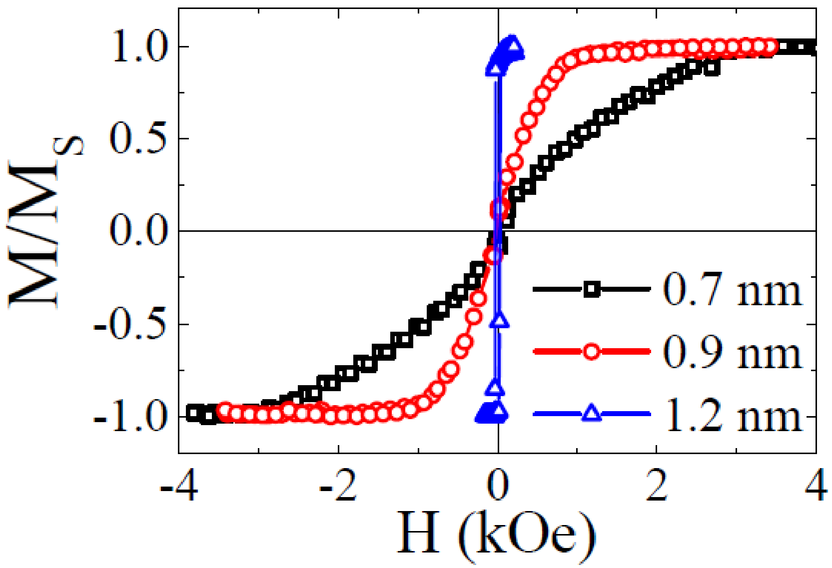
Ferromagnetic/Metallic layer



[Synthetic antiferromagnet]/ Metallic layer



[Co/Ru(t_{Ru})/Co]/Pt: M(H)

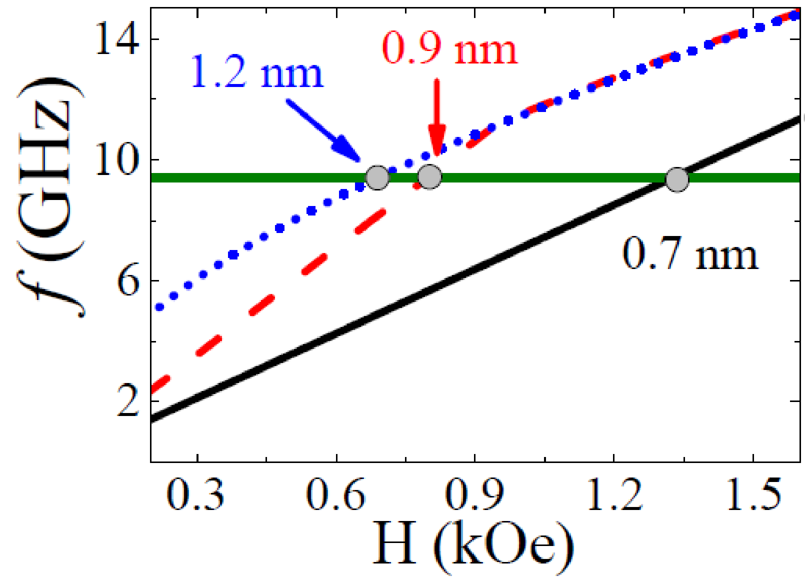


- ✓ Exchange coupling field H_E
- ✓ Saturation magnetization

$$F_a = \sum_{i=1}^{2}\left(-d_i\mathbf{M}_i\cdot\mathbf{H} + \frac{d_i}{2}\mathbf{M}_i\underline{\mathbf{N}}_i\mathbf{M}_i - d_iK_n^{(i)}\frac{(\hat{\mathbf{e}}_{\perp}\cdot\mathbf{M}_i)^2}{|\mathbf{M}_i|^2}\right) - J\frac{\mathbf{M}_1\cdot\mathbf{M}_2}{|\mathbf{M}_2||\mathbf{M}_1|}$$

+

$$\frac{\partial\mathbf{M}}{\partial t} = -\gamma\left[\mathbf{M}\times(\mu_0\mathbf{H}_{\mathrm{eff}})\right] + \frac{\eta}{M_s}\left[\mathbf{M}\times\frac{\partial\mathbf{M}}{\partial t}\right]$$



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[Co/Ru(t_{Ru})/Co]/Pt: ω(H)

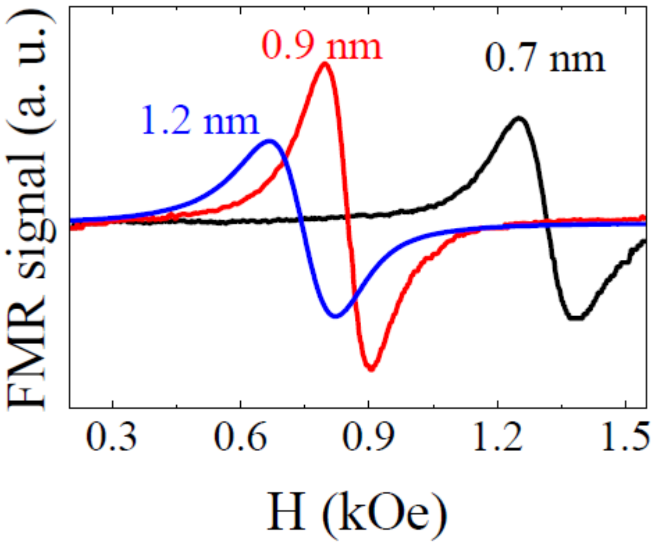
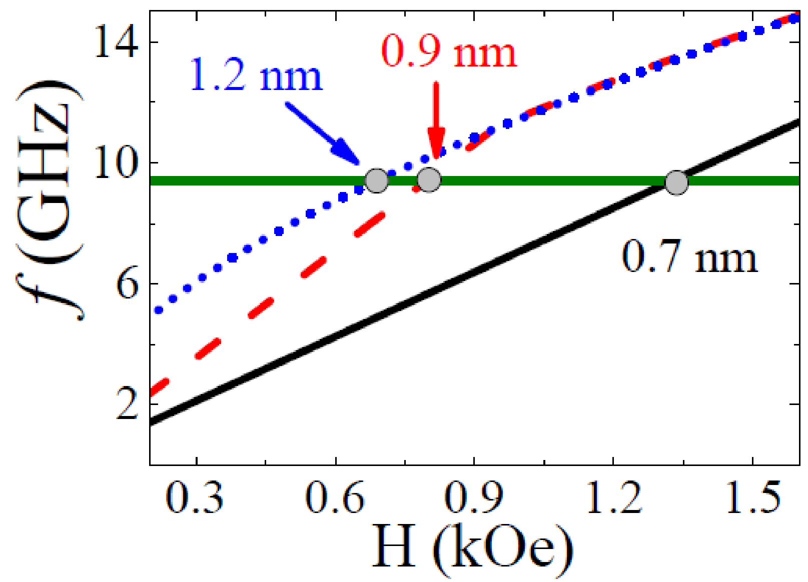


TABLE I. Resonance and exchange fields of the coupled Co(4 nm)/Ru(t_{Ru})/Co(4 nm) trilayers as a function of t_{Ru}.

t_{Ru} (nm)	H_E^{exp} (Oe)	H_R^{exp} (Oe)	H_E^{sim} (Oe)	H_R^{sim} (Oe)
0.7	3021	1322	3000	1328
0.9	913	853	950	870
1.2	...	680	...	740

Resonance field is lower than exchange coupling field!



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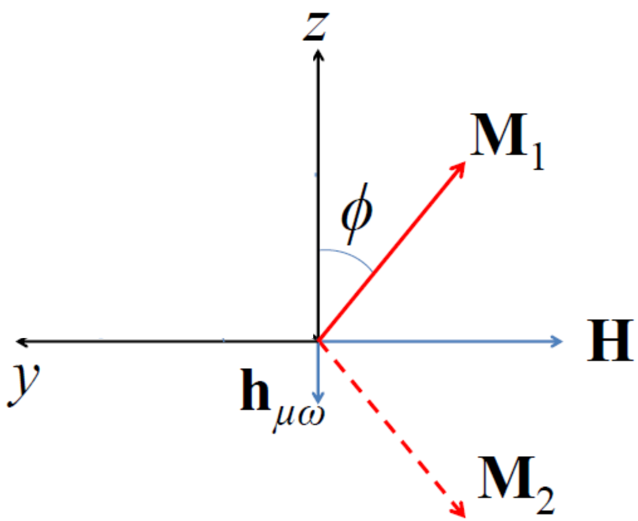
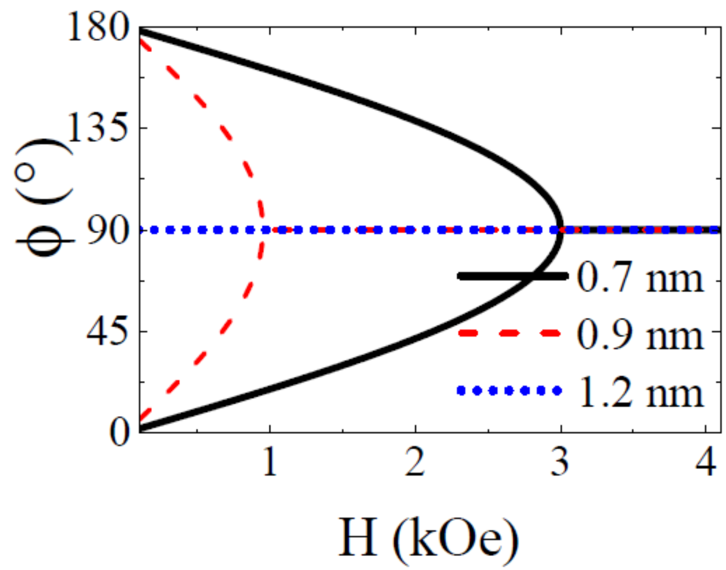
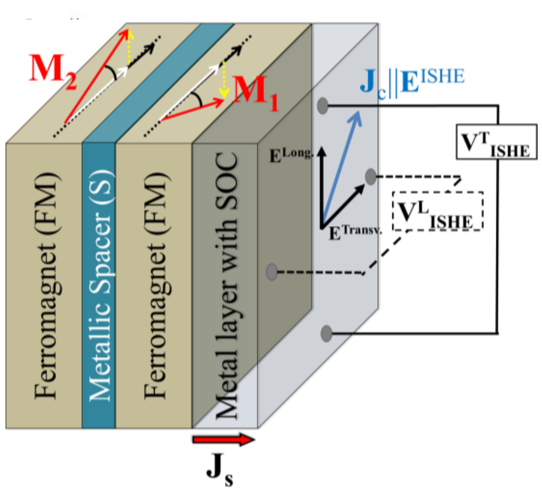
[Co/Ru(t_{Ru})/Co]/Pt: φ(H)

Magnetic Resonance Division

At resonance condition: **M** & **H** are not parallel!







It is possible to tune the polarization direction of a pure spin current!

$$V^{T}_{\mathrm{ISHE}}/V^{L}_{\mathrm{ISHE}} = \tan\phi$$

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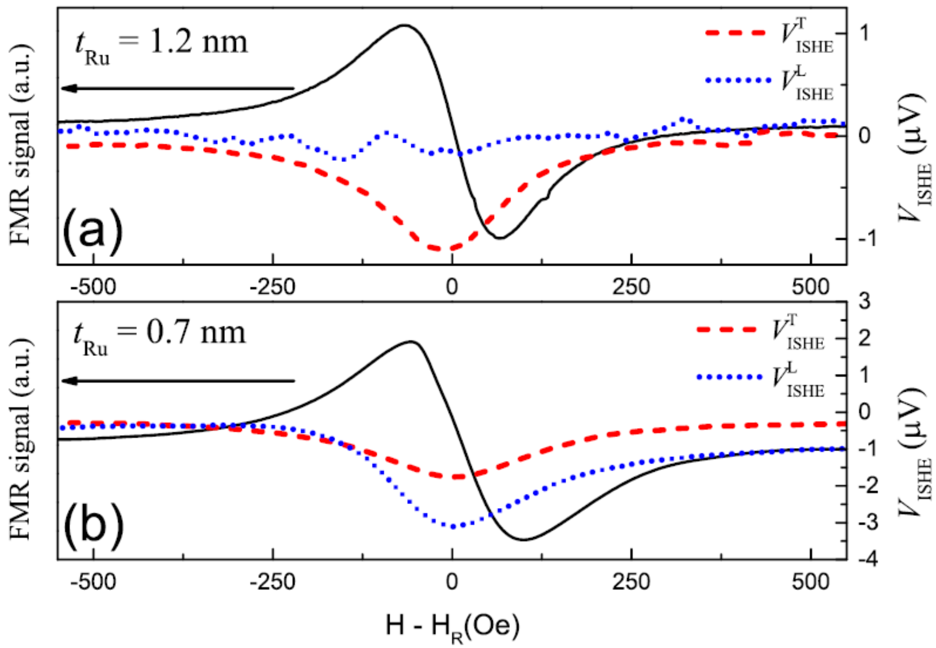
[Co/Ru(t_{Ru})/Co]/Pt: V_{ISHE}(H)

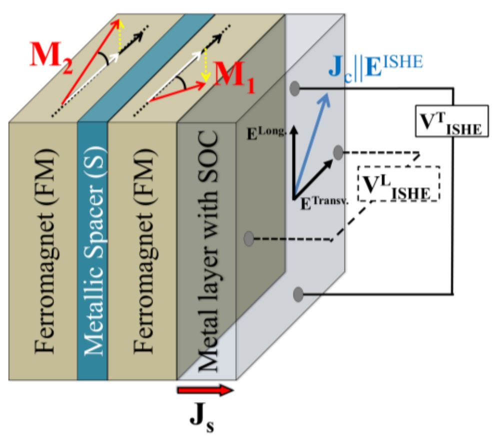
Magnetic Resonance Division



$$V^T_{ISHE}/V^L_{ISHE} = \tan\phi$$

$t_{Ru} = 0.7$ nm
0.46(5) (calculated)
0.54(5) (experimental)

$t_{Ru} = 0.9$ nm
3.1 (calculated)
5.3 (experimental)



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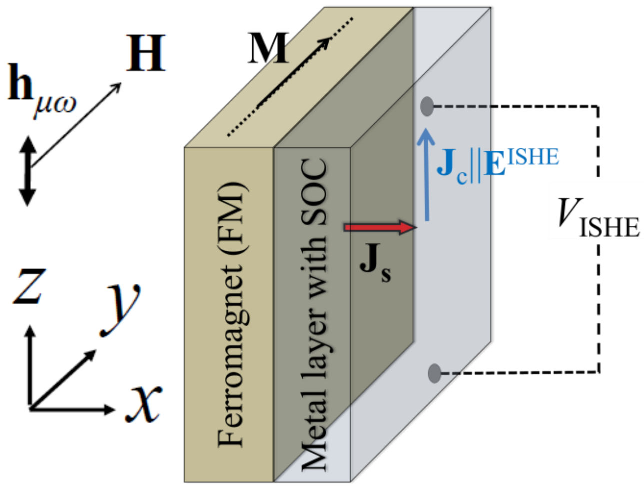
Conclusions

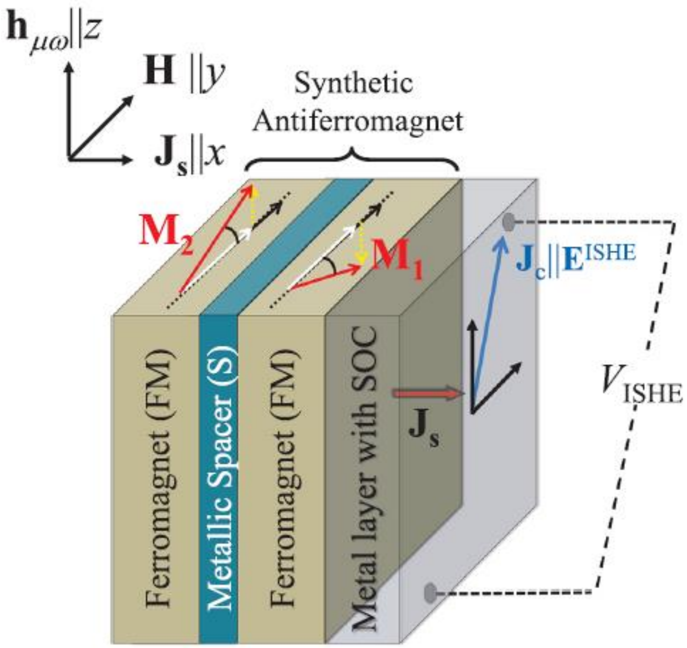
Ferromagnet/non-magnetic

1. Spin pumping from FM single layer
2. Polarization direction of $\mathbf{J}_s$ depends on **H** and **M**
3. V_{ISHE} sign determined by NM: spin Hall angle α^{SH}



[Synthetic Antiferromagnet]/non-magnetic

1. SP from the adyacent non-magnetic layer
2. Control of the polarization direction of $\mathbf{J}_s$.
3. Control of the V_{ISHE} sign.



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