Current induced effects in various stacks of layers containing antiferromagnet

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Antiferromagnetic Spintronics: AFM materials as an active element

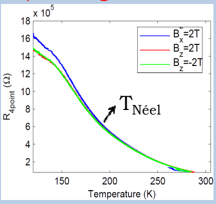
Examples of AFM Spintronics:
[1-5]

Why?
- more materials available
- more robust in external magnetic field/radiation…
- could be faster switched
- lower energy to switch
- stray field smaller

Hurdles:
- detection of AFM moments
- **manipulation of AFM moments**

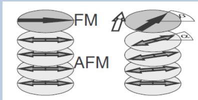
Manipulation of AFM Moments

1) cooling in field



[4]

2) exchange spring

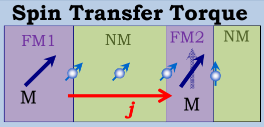


[6], [1], [2]

3) spin orbit torque in AFM?

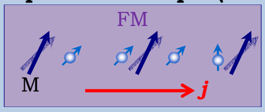
Current Induced Torques

Spin Transfer Torque



transfer of spin momentum from FM1 to FM2

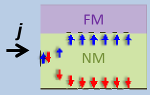
Spin Orbit Torque (SOT)



transfer of orbital to spin momentum
broken inversion symmetry required

Origin of SOT

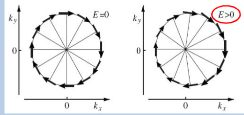
1) Spin Hall Effect



bulk NM: transverse spin current torque induced on FM layer [7]

2) Inverse Spin Galvanic Effect

interface FM/NM: broken inversion symmetry

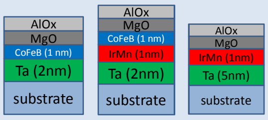


example: Rashba spin accumulation ~ effective field

[8]

Sample Fabrication

- aluminum mask (contacts)
- negative resist HSQ (Hall bar)
- Hall bar 2 x 7 µm

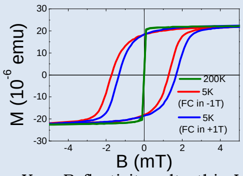


reference sample | $5K<T_N$ (IrMn) $300K>T_N$ (IrMn) | cooled in field

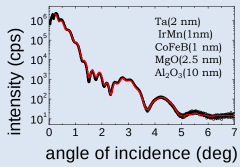
Part A | **Part B**

Sample Characterization

-SQUID: AFM/FM coupling

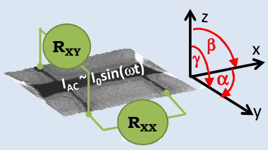


- Xray Reflectivity: ultrathin IrMn



Second Harmonic Signal Detection

- current induced effective field H_{eff}



- measured $R^{1\omega}$ and $R^{2\omega}$ under magnetic field H_0

$M=M(H_0+H_{eff})$
$V_{meas} = R(M).I_{AC}$
$= I_0 (dR/dH_0) H_{eff}/2 + \ldots$ — **"DC offset"**
$I_0 R \sin(\omega t) + \ldots$ — **"First Harmonic"**
$I_0 H_{eff}/2 (dR/dH_0) \cos(2\omega t)$ — **"Second Harmonic"**

Contributions to Second Harmonic Signal

effective fields:
Antidamping-like $H_{AD} \sim m \times y$
Field-like $H_F \sim y$
tilt of M from equilibrium => detection in 2ω

thermal effects:
Anomalous Nernst Effect (ANE)
Spin Seebeck Effect (SSE)

2ω contributions have different angular dependencies
(for full table of symmetries, please, ask me)
-> rotate magnetic field $H_0(\alpha)$, $H_0(\beta)$, $H_0(\gamma)$
-> separate contribution by comparing angular dependency
-> H_{AD} and SSE linear in current density

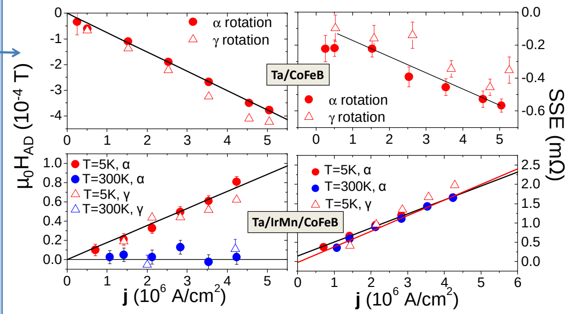
Part A

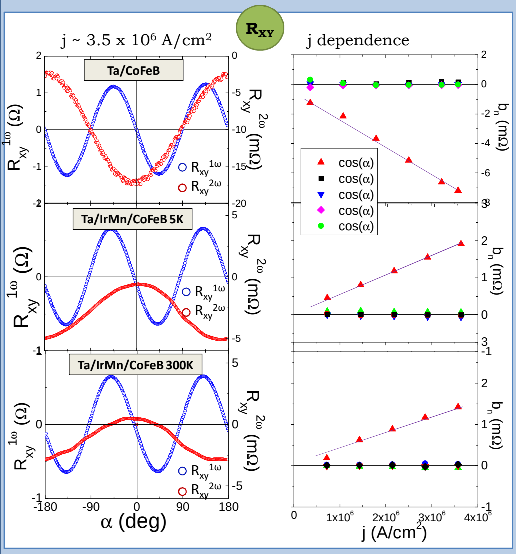
Measured data & analysis [9]

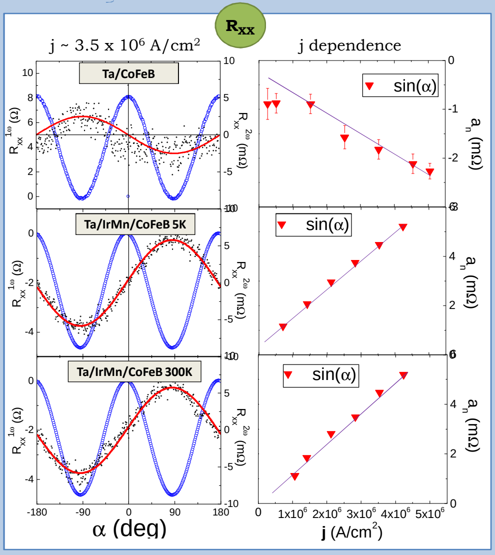
- shown data: $H_0(\alpha)$
(for $H_0(\beta)$, $H_0(\gamma)$ data, please, ask me)

expected symmetry:
Rxy ~ (H_{AD}+ SSE) cosα
Rxx ~ SSE sinα

✓ correct angular dependency
✓ linearly increasing with j
$H_{AD} \sim R_{xy}$ – SSE (known from R_{xx})
recalculate H_{AD}: mΩ -> mT







sample with IrMn:
1) opposite sign compared to the reference without IrMn
2) SSE identical at 5K and 300K
3) H_{AD} present only when IrMn antiferromagnetic (red)
supported by out-of-plane rotation (triangles)

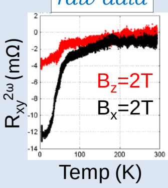
anti-damping like torque on CoFeB via SHE in Ta and IrMn:
a) above T_N SOT from Ta and IrMn canceled
b) below T_N IrMn strongly increases, Ta suppressed
(IrMn because of the sign of SOT)

SHE from Ta is absorbed by IrMn AFM moments

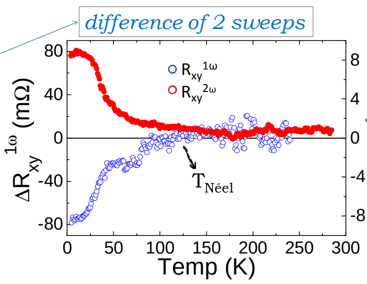
Part B

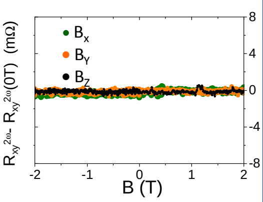
$R_{xy}^{2\omega}$ while sample cooled in magnetic field

raw data



difference of 2 sweeps





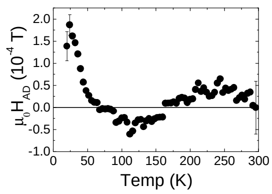
$R_{xy}^{2\omega}$ at 5K cannot be changed by magnetic field

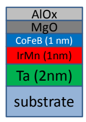
sample Ta/IrMn:

-SSE should not be present

-SHE from Ta absorbed by AFM moments

Part B Compared with Part A





H_{AD} measured as a function of temperature. Increase of H_{AD} when crossing T_{neel}.

References

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[2] Marti, PRL 1, 108 (2012)
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[8] Miron, Nat. Mat. 9, 230-234 (2010)
[9] arXiv:1503.03729

Summary

Angular dependencies of Second Harmonic Contributions summarized.

SSE contribution from CoFeB does not vary with temperature.

Above T_N torque from IrMn and Ta canceled. Below T_N toque from IrMn dominates, from Ta suppressed.

Torque appears below T_N in sample without CoFeB.

All above could be explained by **current induced torque absorbed by AFM moments in IrMn**.