# Measuring Spin Diffusion in Platinum using the Spin Galvanic Effect with Spin Rotation Symmetry

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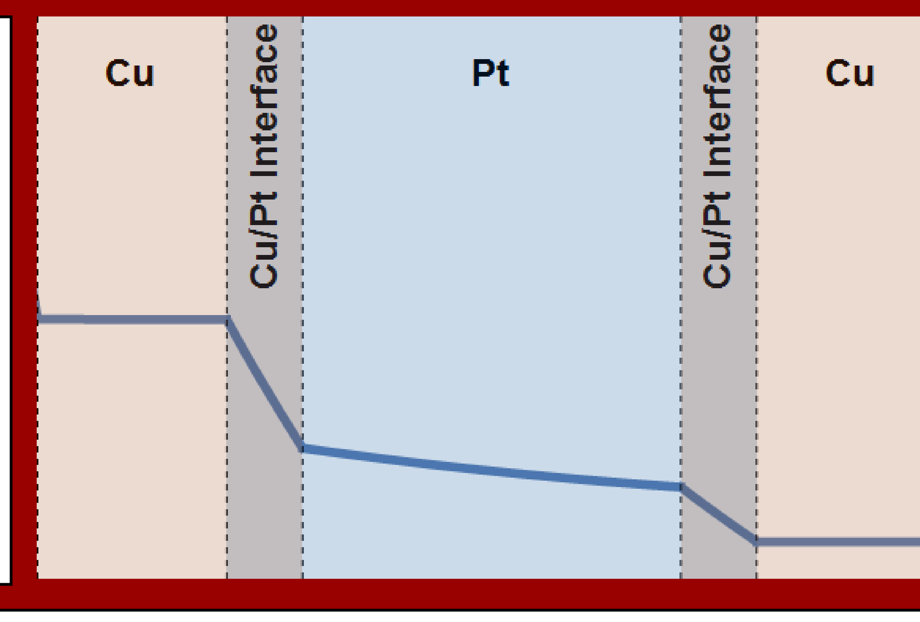
## Research Objective:

- Spin diffusion length ($\lambda_{sd}$ ) is critical for spintronics applications, but there were significant discrepancies in previously reported values for Pt (sometimes an order of magnitude apart)
- We think the discrepancy is due to different treatments of interfacial spin memory loss (SML, $\delta$)
- We aim to quantify the SML and to determine Pt's $\lambda_{sd}$ using our newly found spin galvanic effect with spin rotation symmetry [1].

## Interface Spin Memory Loss:

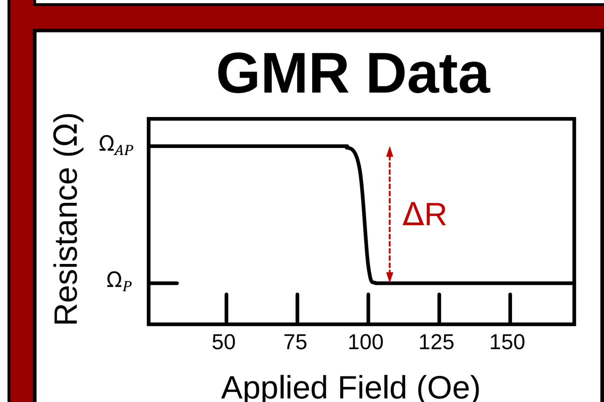
- Besides bulk spin absorption, spin current is subject to additional loss when it penetrates an interface, e.g. Cu/Pt interface.
- We model Cu/Pt bilayer as Cu/(Cu/Pt interface)/Pt trilayer



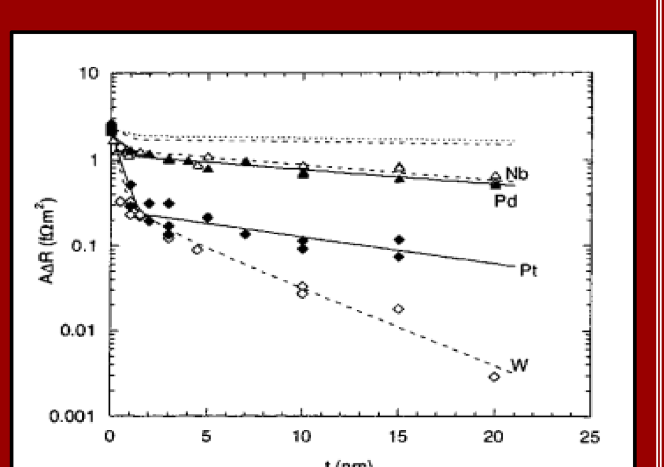

## Giant Magnetoresistance [2]:

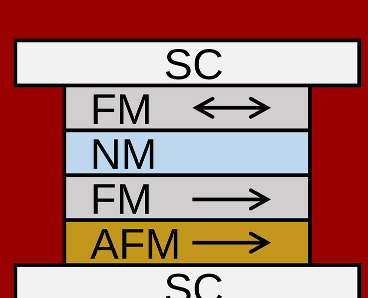
**Pros:**
- Very high dynamic range
- Only two fit values

**Cons:**
- Requires nanolithography and cryogenic measurement




$$\Delta\Omega \propto \delta^2 * \exp\left[\frac{-t}{\lambda_{sd}}\right]$$



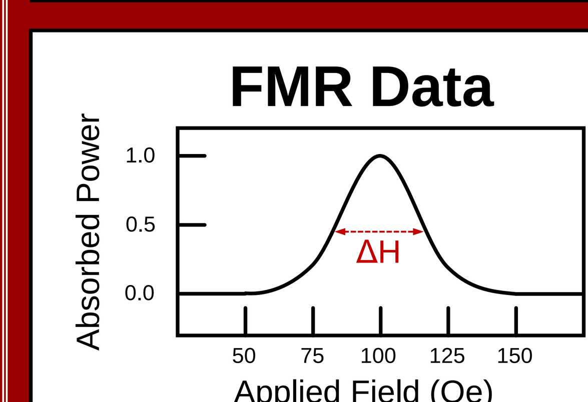



Fitting Result: $\lambda_{Pt} = 14 \pm 6$ nm

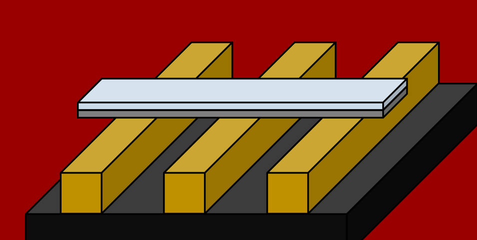
## Spin Pumping, Damping Enhancement [3]:

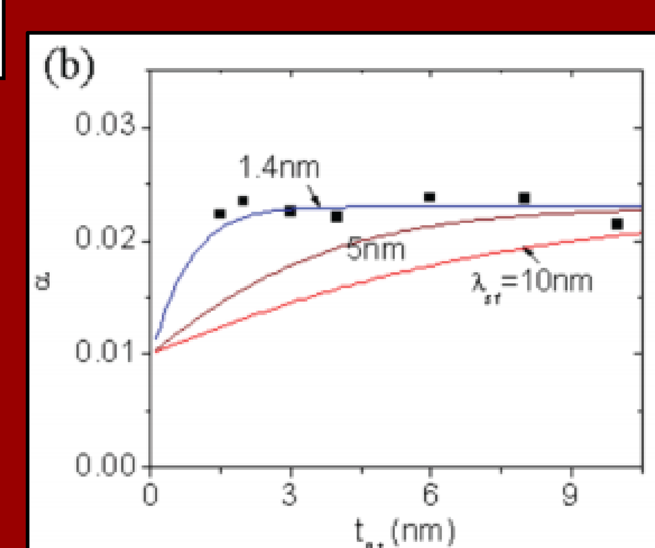
**Pros:**
- Simple to set up
- No patterning required

**Cons:**
- Non-zero background limits the dynamic range
- Many fit values




$$\alpha = \alpha_0 + \Delta\alpha$$
$$\Delta\alpha \propto \delta + (1-\delta)^2 * \left(\exp\left[\frac{-2t}{\lambda_{sd}}\right]\right)$$

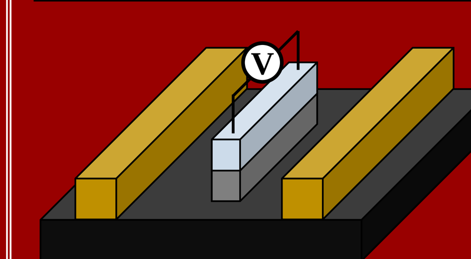





## Spin Pumping, Inverse Spin Hall Effect [4]:

**Pros:**
- Can decouple SML from $\lambda_{sd}$ *if* interface spin conversion is weak

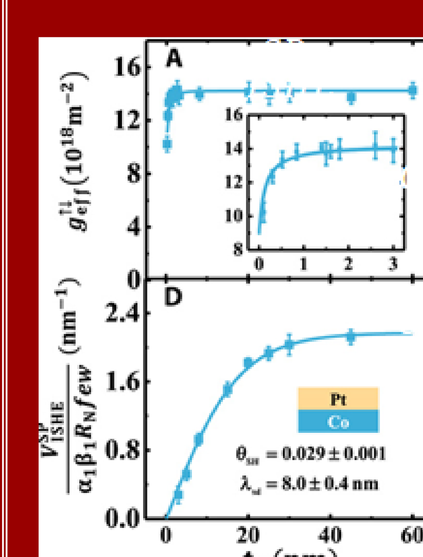
**Cons:**
- Requires patterning and careful alignment
- Many fit values



$$g_{eff}^{\uparrow\downarrow} = G^{\uparrow\downarrow}[1-(1-\delta)^2\varepsilon]\ ;$$

$$\varepsilon = \frac{G^{\uparrow\downarrow}}{G^{\uparrow\downarrow} + \frac{2}{3}k_F^2\frac{l_{mf}}{\lambda_{sd}}\tanh\left(\frac{t}{\lambda_{sd}}\right)};$$

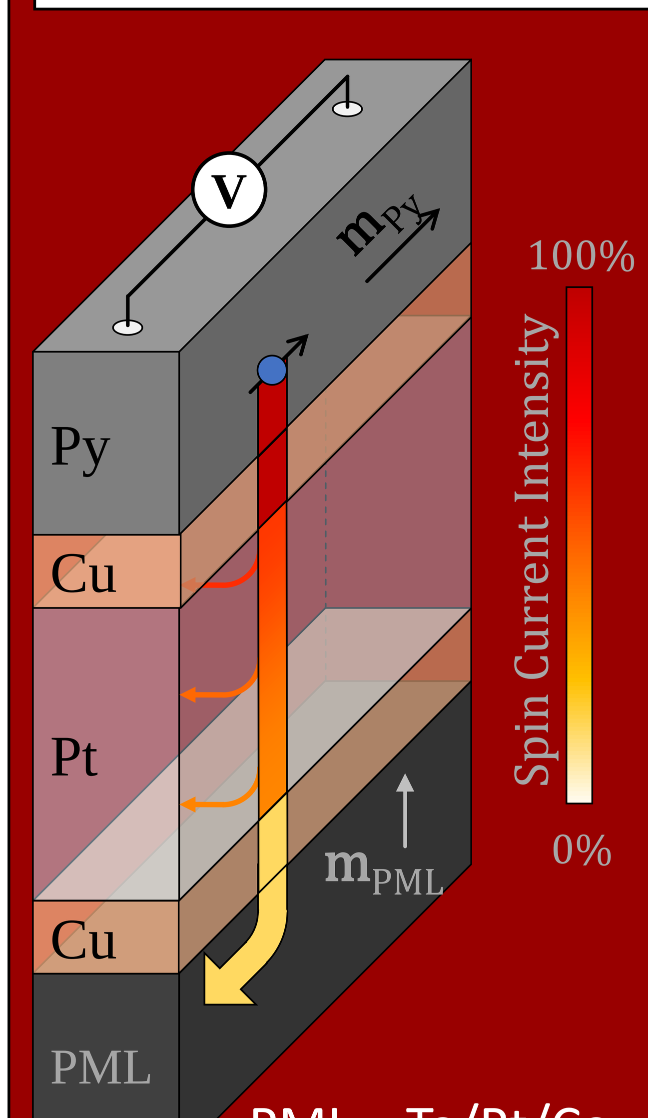
$$V_{ISHE}^{SP} = \alpha_1\beta_1 f R_N e w G^{\uparrow\downarrow}\left[\theta_{SH}(1-\varepsilon)(1-\delta)\lambda_{sd}\tanh\frac{t}{2\lambda_{sd}} + \lambda_{IEE}\delta(1+\varepsilon-\delta\varepsilon)\right];$$



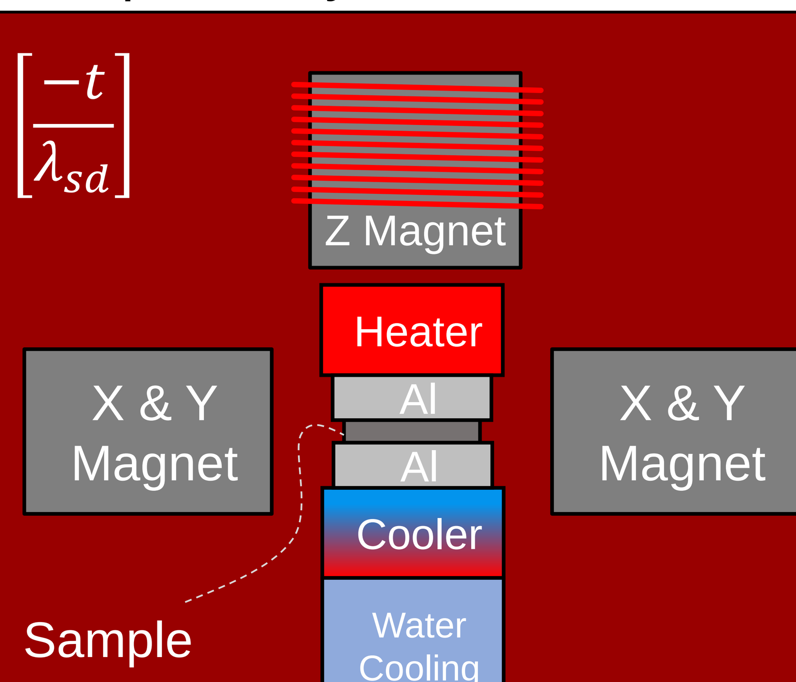

## Spin Galvanic Effect with Spin Rotation Symmetry:

We recently demonstrated a spin galvanic effect with spin rotation symmetry (SGE-SR) in a spin valve [5]:

- Spin current is generated by the Spin Seebeck effect
- This spin current generates a voltage near the other FM interface, in the direction parallel with $\mathbf{m}_{Py}$
- This is different from all other spin galvanic effects in the system, which follow the inverse spin Hall symmetry.
- The SGE-SR signal is proportional to the amount of spin current that transmits unperturbed the Cu/Pt/Cu spacer layers.



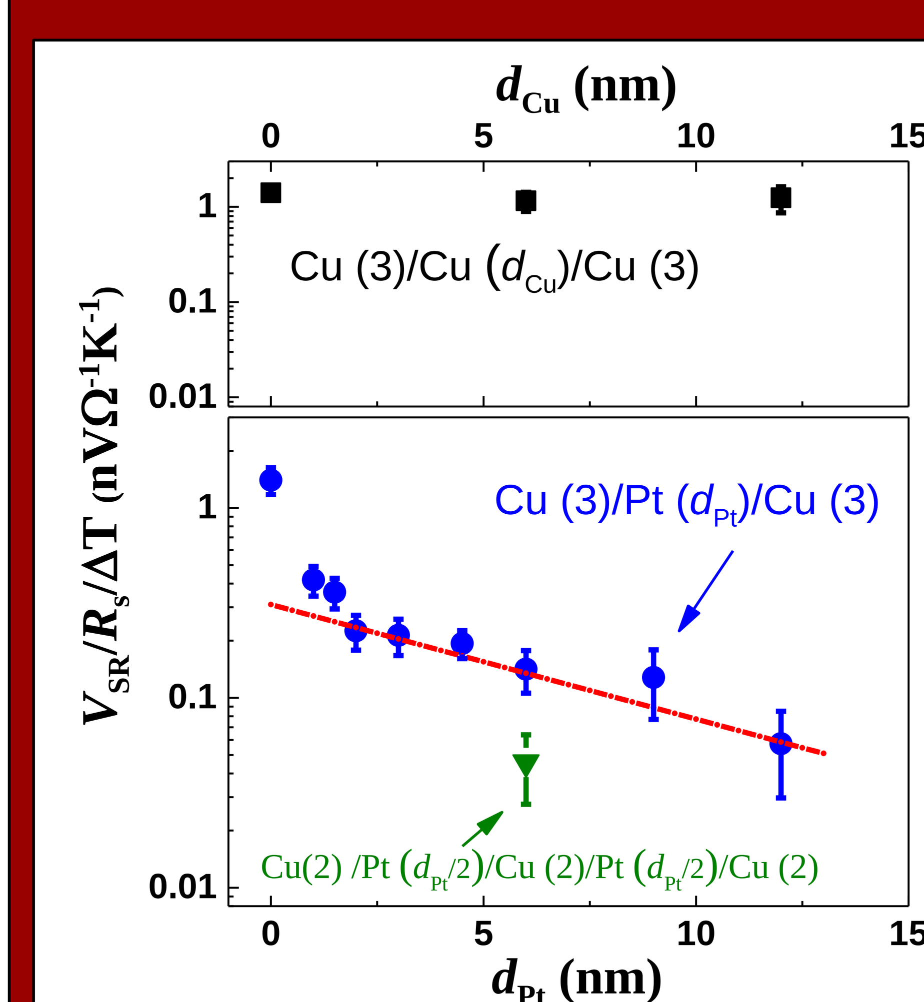

$$\frac{V_{SR}}{R_s\Delta T} \propto \delta^2 * \exp\left[\frac{-t}{\lambda_{sd}}\right]$$



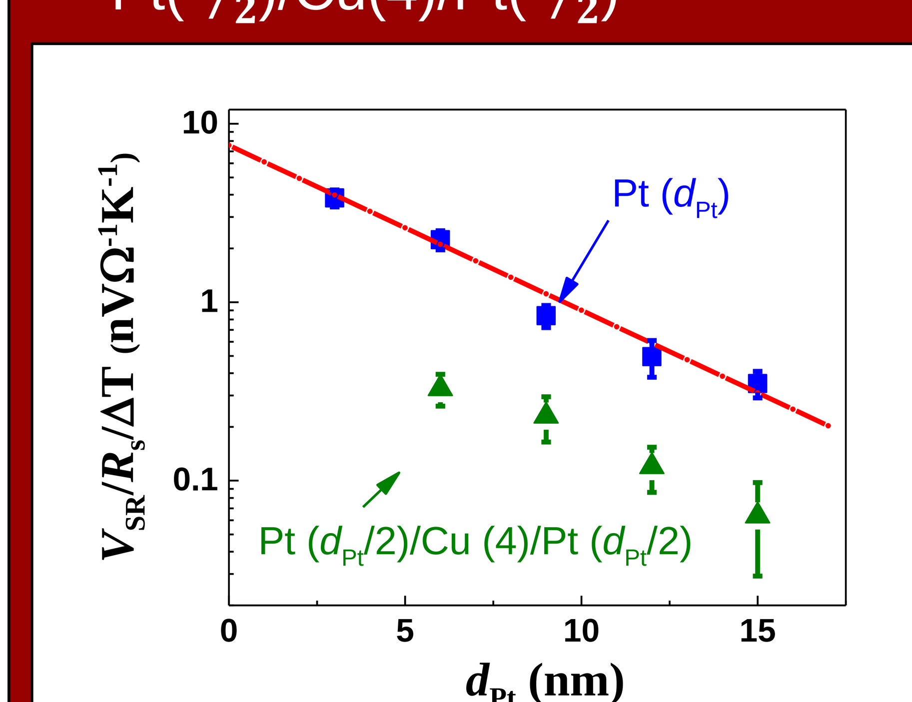

- Zero background signal leads to good dynamic range
- No patterning required
- Room temperature measurement
- Only two fit parameters

## Results and Discussion:

- Cu(3)/Cu(***d***)/Cu(3) (control)
- Cu(3)/Pt(***d***)/Cu(3)
- Cu(2)/Pt($^d/_2$)/Cu(2)/Pt($^d/_2$)/Cu(2)
- Pt(***d***)
- Pt($^d/_2$)/Cu(4)/Pt($^d/_2$)




Fitting Result: $\lambda_{Pt} = 7.7 \pm 1.4$ nm




Fitting Result: $\lambda_{Pt} = 4.7 \pm 0.4$ nm

**Discussion:**
- Interface spin memory loss (SML) of Pt/Cu is large, $\delta$ ~ 70% for our samples
- $\lambda_{sd}$ = 4.7 ~ 7.7 nm for Pt
- Discrepancy between the two fittings may be because we neglect the spin rotation upon reflection at the PML/Pt interface (related to imaginary part of $G^{\uparrow\downarrow}$), which is prominent in the second case where Pt is in direct contact with PML and Py.

## References & Acknowledgements:

[1] A. M. Humphries *et al.*, Nature Communications, 8, 911 (2017)
[2] H. Kurt *et al.*, Appl. Phys. Lett. 81, 4787 (2002).
[3] L. Liu, R. A. Buhrman, and D. C. Ralph, arXiv:1111.3702 (2012).
[4] X. Tao, H. Ding *et al.*, Science Advances 10.1126 (2018).
[5] Aljuaid W.S., Allen, S.R., Davidson A., Fan, X., arXiv: 1807.04918 (2018)
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