# Observing Spin-Hall Effect at Optical Frequency

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## What is our question?

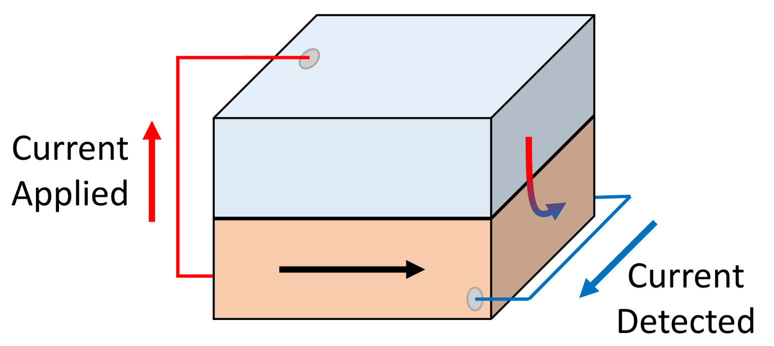
**Is there a Spin-Hall Effect at the optical frequency in NM/FM bilayers**?

- Kerr rotation can be considered the optical equivalence of the Anomalous Hall Effect [1], which of course happens only in the FM component of FM/NM bilayers
- Energy at optical frequency is much higher, which can excite complicated inter-band transitions
- Distances traveled by excited electrons at the optical frequency are significantly shorter

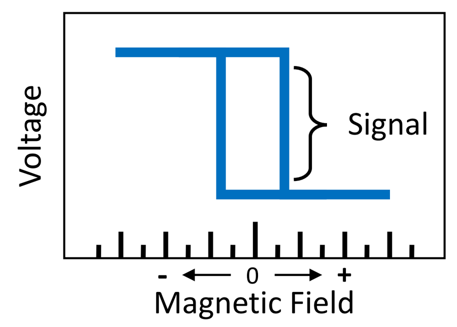
## Why are we curious?

### Hypothetical Measurement

- Inject perpendicular current, observe resultant in plane current from the Anomalous Hall Effect (**AHE**) in FM
- Spin polarized current injected into NM also bends due to Spin-Hall Effect (**SHE**), shifts detected current amount



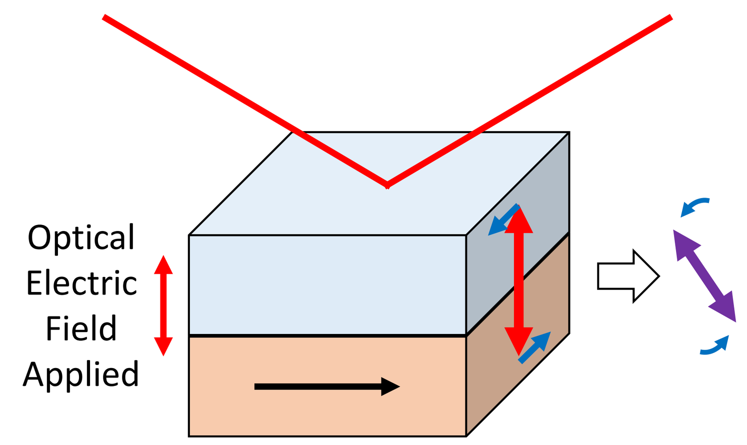

- Switch magnetization direction to observe opposite current, and account for misalignment in the system:



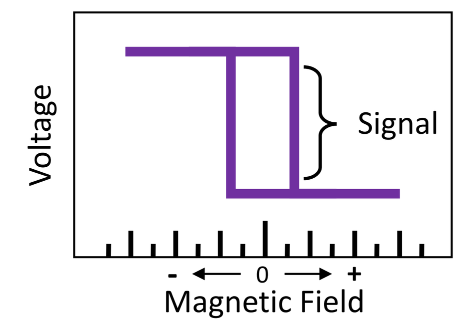

- From this experiment we could study spin-Hall angles for all sorts of bilayer materials, however it's difficult to apply perpendicular current in metallic films

### MOKE Measurement

- Linearly polarized light excites electrons along the electric field direction *at optical frequency*
- Oscillating electrons curve in FM due to **AHE**; they emit a slightly rotated polarization (**Kerr rotation**)
- We think spin polarized electrons ejected into the NM curve due to **SHE**, again shifting the rotation amount




- Again, we switch magnetization direction to observe the opposite rotation




- This measurement suits the same applications as the hypothetical one!

## How are we answering it?

**We already know:**

- Tantalum and Platinum have opposite spin-Hall angles at low frequency [2]
- Tantalum and Platinum influence the signal over a short length scale, the SHE component of the signal can be considered an interface effect

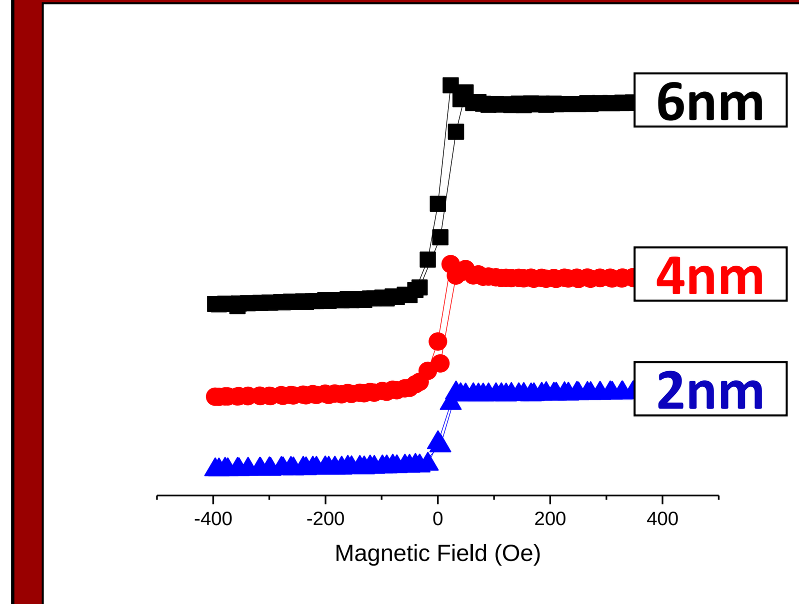
**We don't know:**

- Whether or not the oscillating electrons travel a long enough path have any effect in the normal metal/at the interface
- If their behavior is the same as it is at lower frequencies

Our samples for this experiment are CoFeB wedges (1nm-6nm), capped with SiO2, Tantalum, and Platinum. Each wedge was cut into 6 pieces, and each piece was tested with longitudinal MOKE. From CoFeB, we expect a positive linear relation between thickness and rotation amount. Furthermore, we expect the line to shift in opposite directions, depending on whether the magnetic layer is capped with Platinum or Tantalum.

## Tantalum

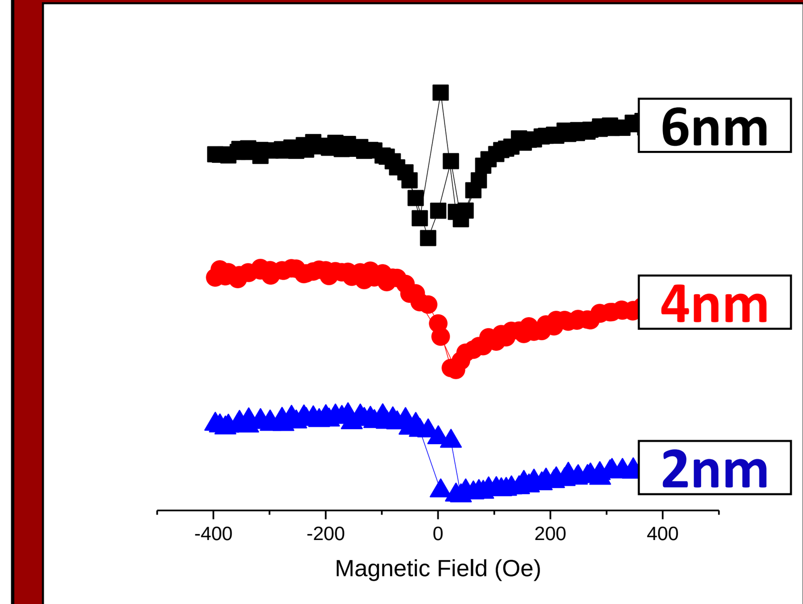
**Pos Spin-Hall Angle**




Signal trends **away from** zero as FM thickness increases, suggesting SHE contribution from Ta is **in line with** AHE contribution from CoFeB

## Platinum

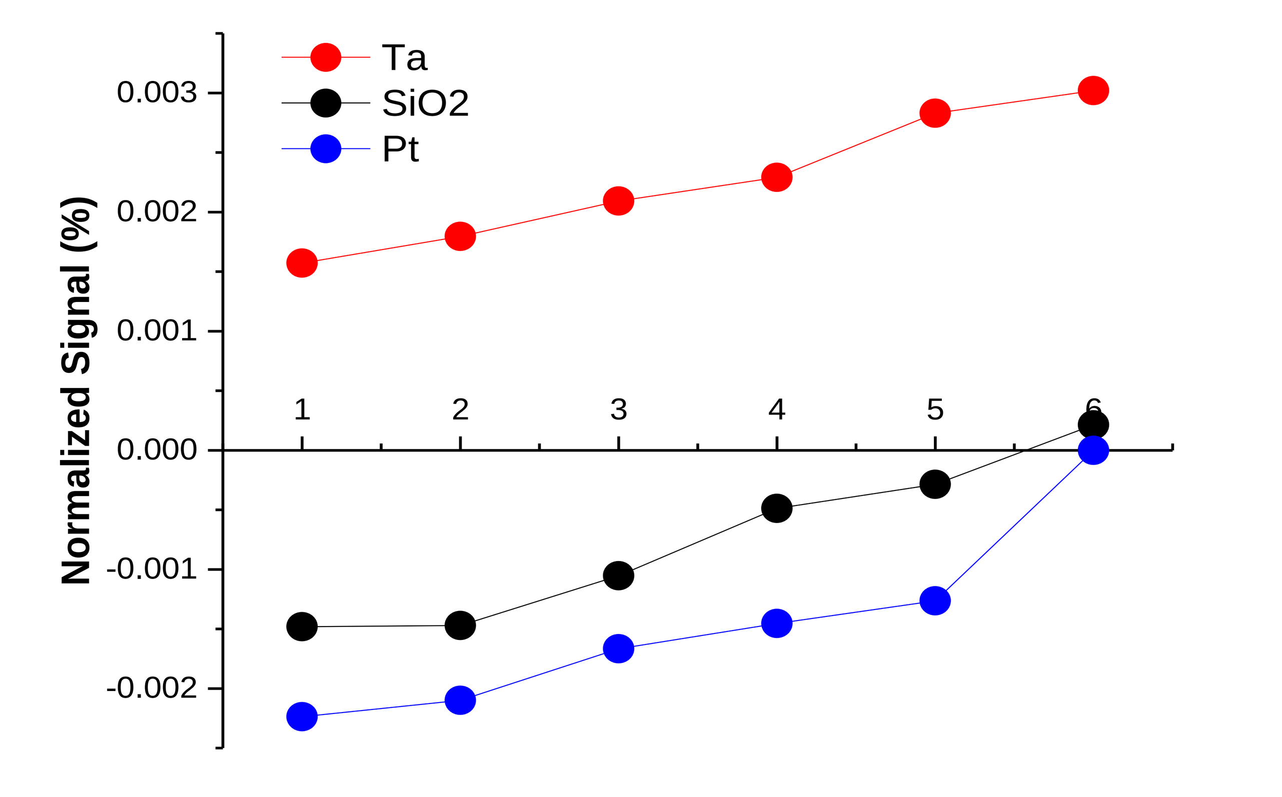
**Neg Spin-Hall Angle**




Signal trends **towards** zero as FM thickness increases, suggesting SHE contribution from Pt is **opposite** AHE contribution from CoFeB

## Analysis

**Normalized Signal vs. CoFeB Thickness**




We did in fact observe the behavior we anticipated – with respect to a sample we expected to have no SHE contribution, the addition of Ta and Pt had opposite effects.

## Possibilities for Future Research:

- Spin currents transmit for more than 100nm in some materials (Copper especially). Do the optically excited electrons travel this complete distance? What's the limit?
- Thickness dependence for Pt and Ta (interface or bulk effect), try different ferromagnetic layers
- polar MOKE (geometry lends to weak capping layer contribution)
- Thick insulator layer as a control experiment

## References and Acknowledgements:

[1] K. Takanashi, M. Watanabe, H Fujimori, "Correlation between magnetooptical Kerr rotation and anomalous Hall effect in FePt/Pt multilayer films," Journal of Magnetism and Magnetic Materials vol. 104-107 (1992)
[2] H. Abdel-Raziq, S. Salahuddin, Jeffery Bokor, "Enhancement of the Spin Hall Effect in Heavy Metal Bilayers," UC Berkley EECS Technical Report UCB/EECS-2016-29 (2016)

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