Center for Energy Efficient Electronics Science
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Second Harmonic Generation and Magnetic Contrast versus Laser Intensity for Materials of Interest in Spin Hall Effect Spin Current Generation

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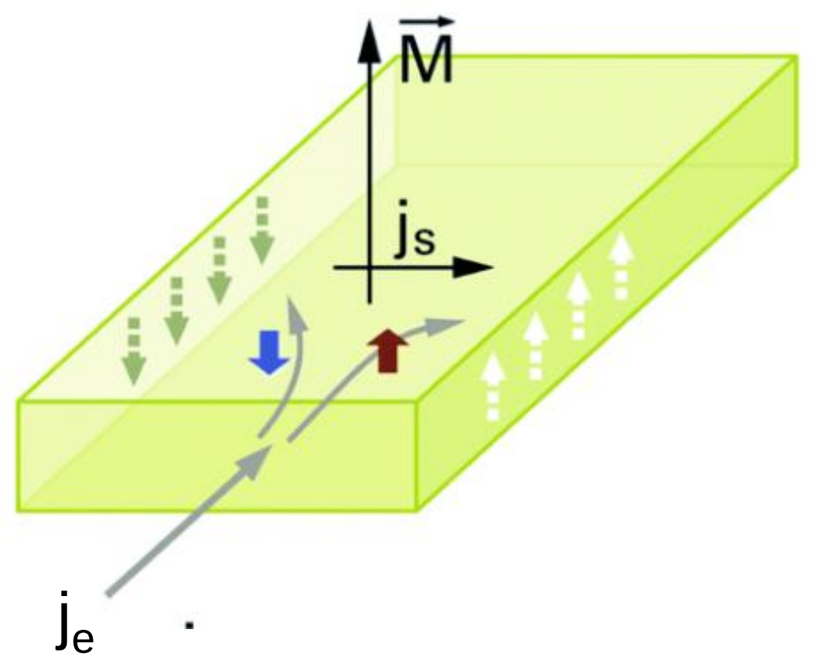
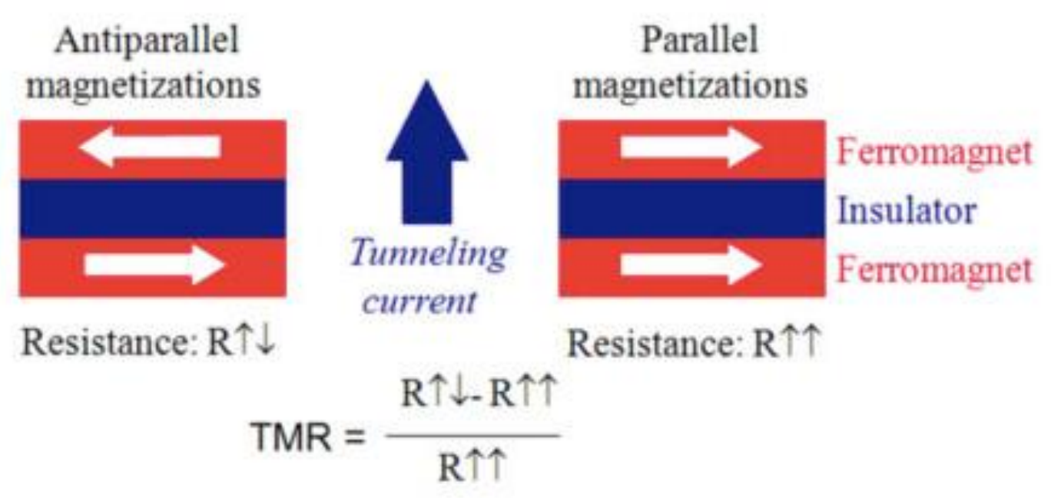
Abstract The spin-Hall effect (SHE) is the generation of a spin current transverse to an applied charge current in materials with high spin-orbit coupling. This could potentially be used to exert useful magnetic torques in magnetic devices. Magnetization-induced second harmonic generation (MSHG) offers a direct method for examining spin accumulation due to the SHE at the surfaces and interfaces of normal metals. This project examines second harmonic intensity as a function of laser intensity for different spin-Hall metals like Au, Pt, Ta, and a Ta/Pt bilayer. The magnetic asymmetry signal, indicative of the magnitude of spin accumulation, is also investigated as a function of laser intensity in 10 nm Pt.

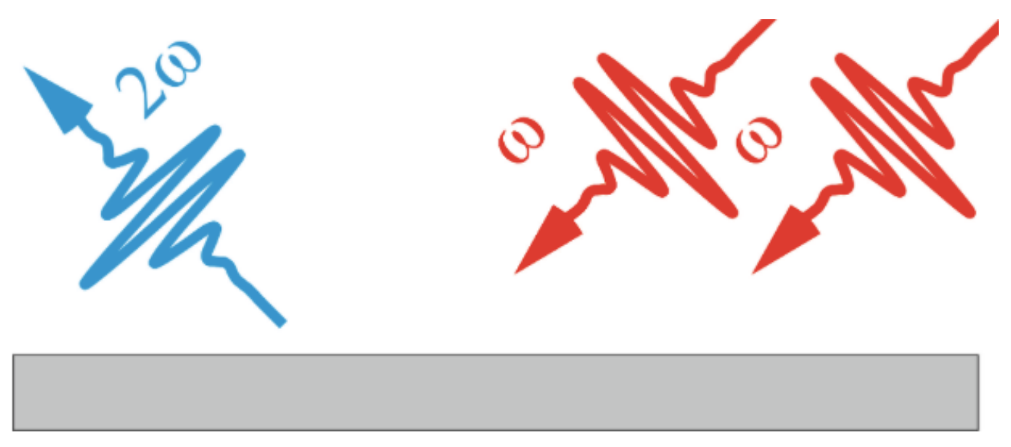
Spin-Hall Effect and Magnetization Induced Second Harmonic Generation



- Spin-Hall Effect: causes spin accumulation at the surfaces of a sample when a charge current is run through the sample. Ratio of spin current generated per unit charge current in a particular material is represented by the spin Hall angle, θ_{SH} [1], [2]

- Motivation for investigation: SHE can generate spin current, which could possibly be used for more efficient switching of magnetic tunnel junctions (MTJs) [1], [3]



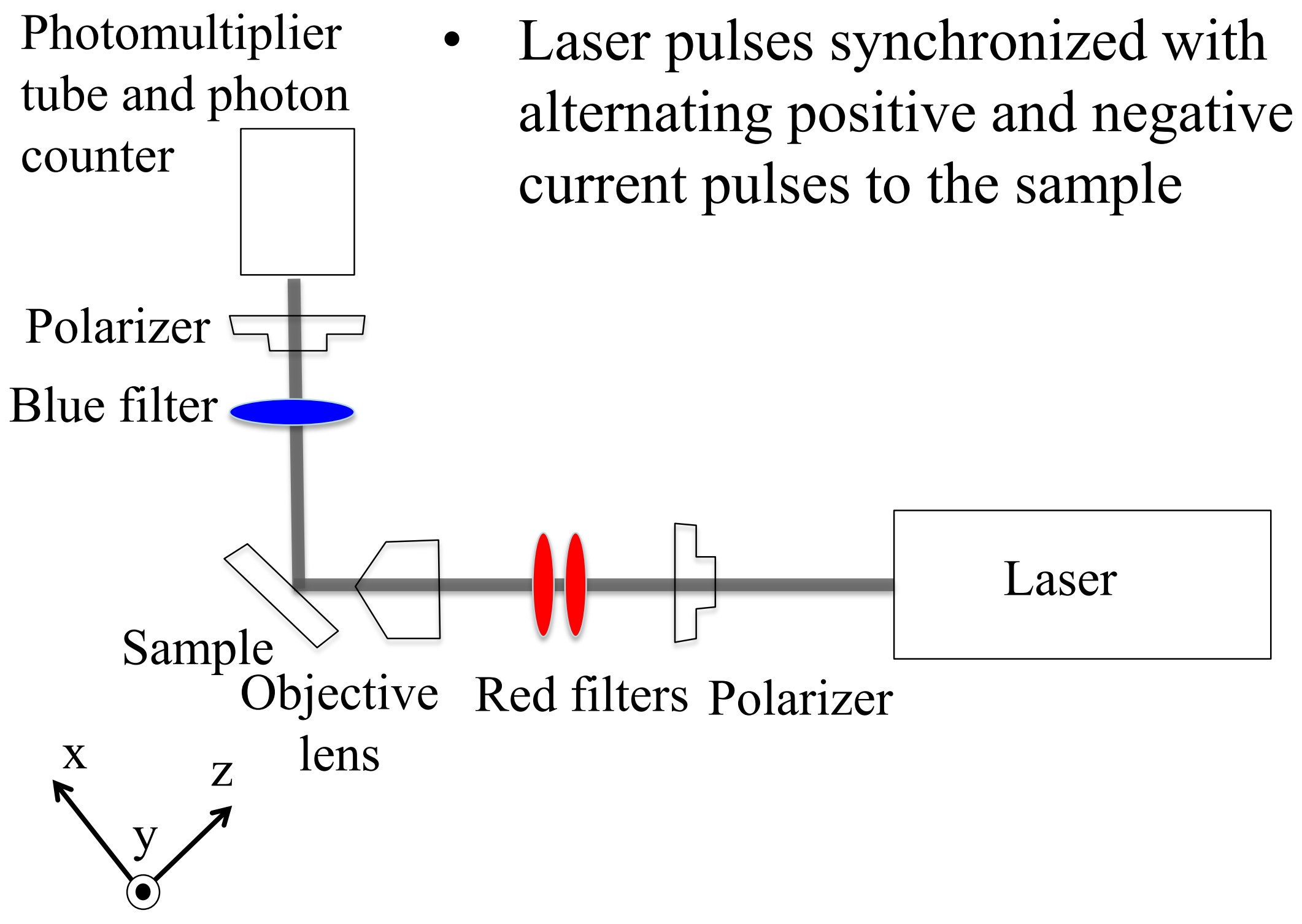


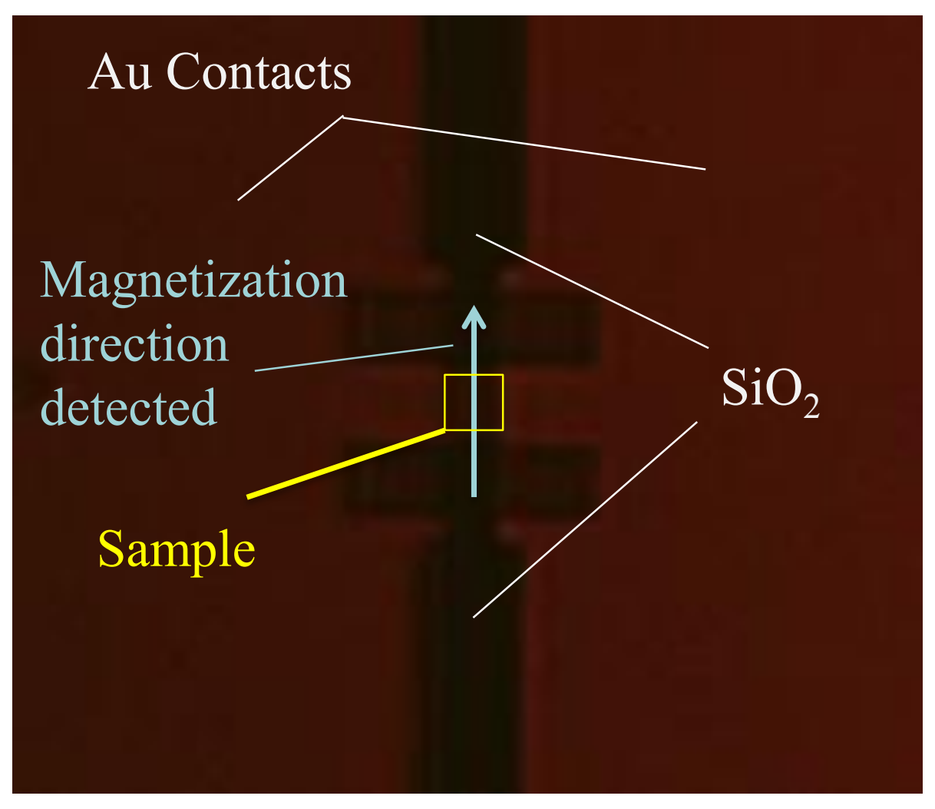
- Second Harmonic Generation: upon reflection, two incident photons may combine to form one photon with twice the frequency. Amount of SHG depends on incident light intensity, reflecting material, and in-plane magnetization of sample (MSHG). The technique is highly surface- and interface-sensitive [4], [5]

Experimental Methods

- Pulsed 800 nm Ti/Sapphire laser

- Laser pulses synchronized with alternating positive and negative current pulses to the sample





$$\text{Magnetic asymmetry} = \frac{I^{2\omega}(+M_y) - I^{2\omega}(-M_y)}{I^{2\omega}(+M_y) + I^{2\omega}(-M_y)} \propto M_y$$

References

[1] Luqiao Liu et al., *Science* **336**, 555 (2012).
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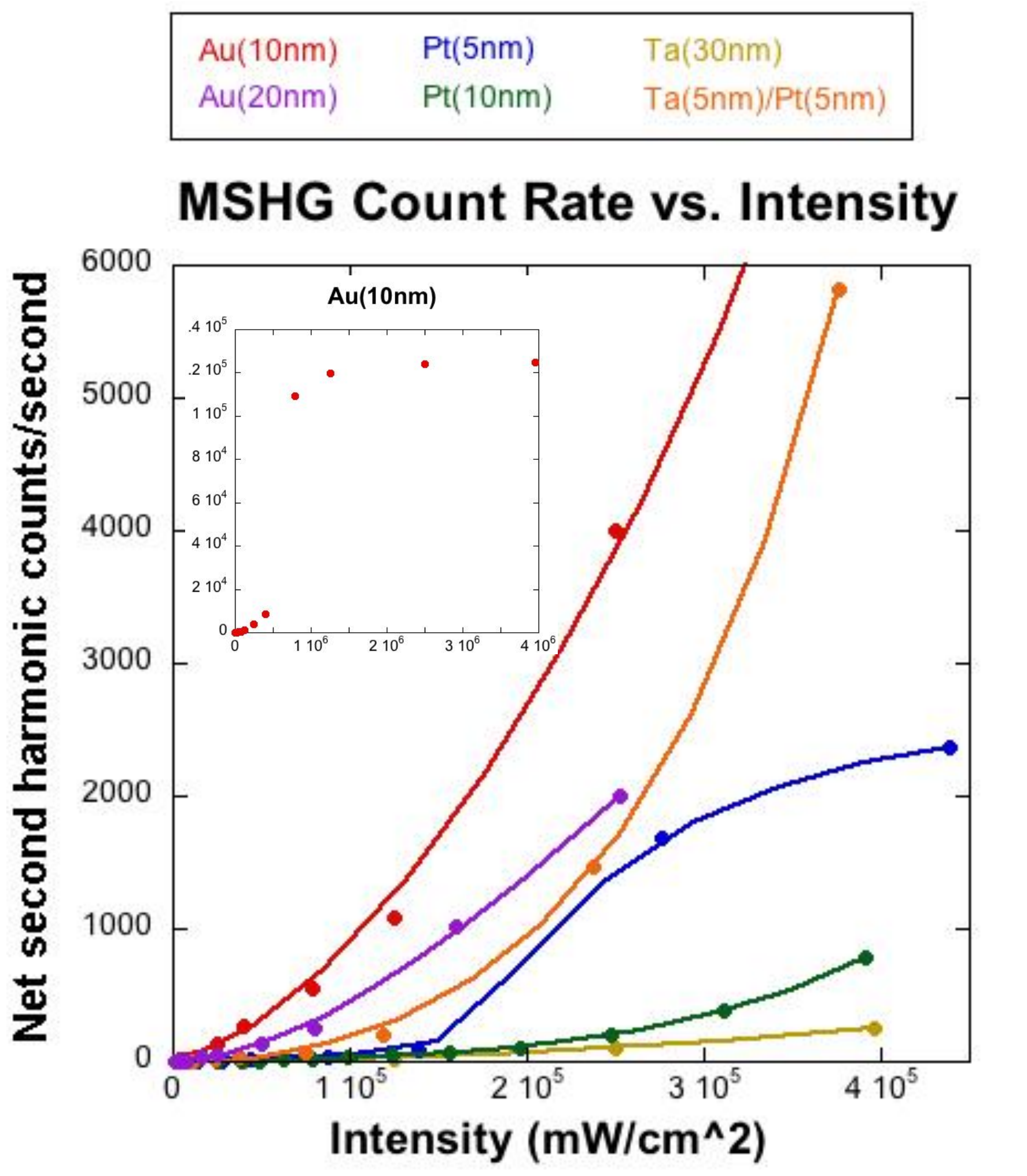
Intensity, Count Rate, and Asymmetry Results



- Highest count rates in 10 nm Au and Ta/Pt

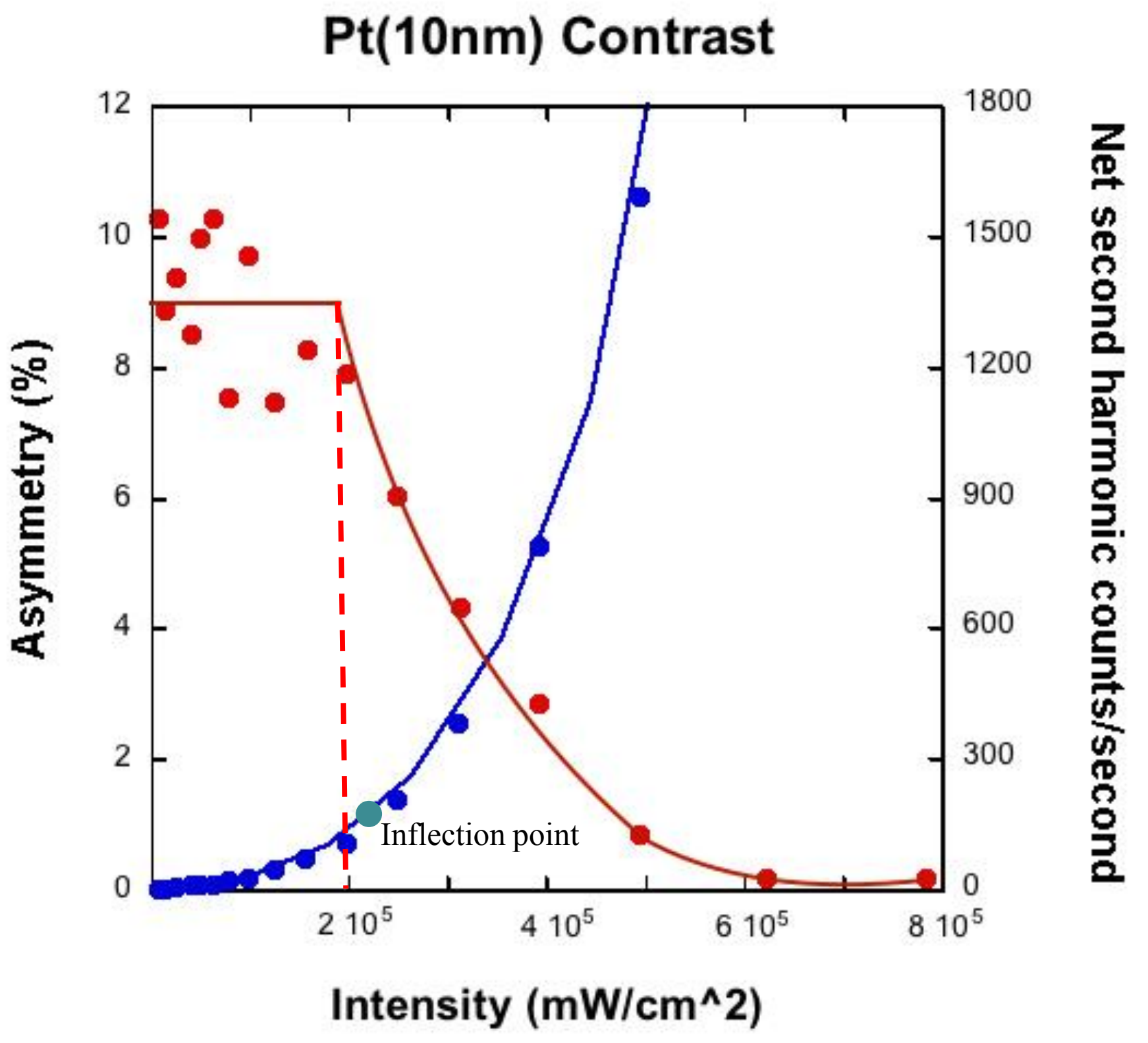
- Second harmonic rates are different for different thicknesses of the same metal

- 20 nm Au, 5 nm Pt, and Ta/Pt curves all deviate from quadratic near 3×10^4 mW/cm^2

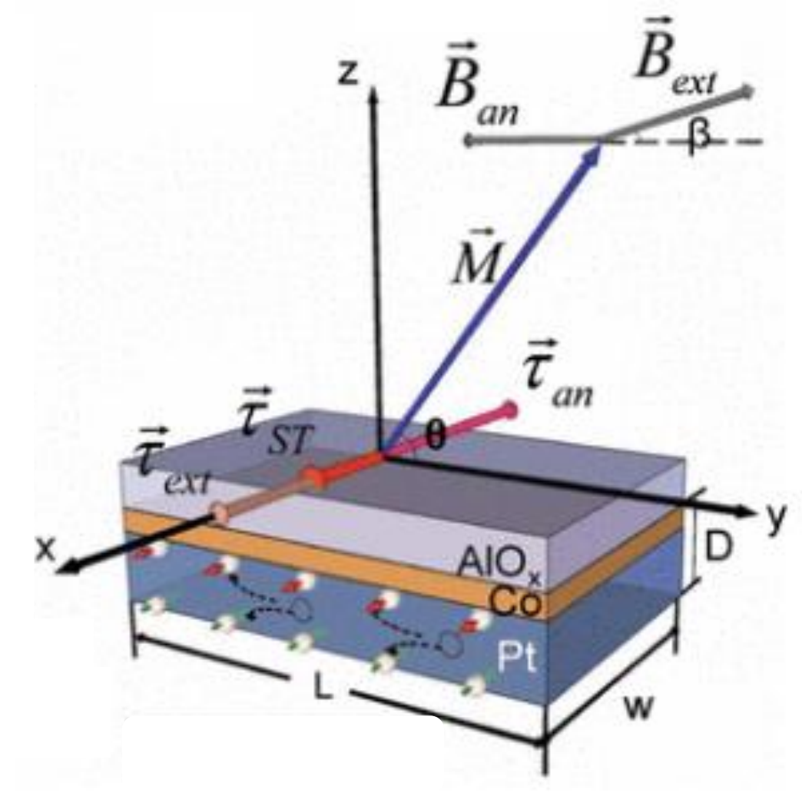
- At higher intensities, asymmetry declines with increasing intensity

- Consistent with heating of coherent spins by higher-power laser pulses

- Intensity where decline begins is near intensity where second harmonic rate leaves the quadratic regime



Calculation of Magnetization Canting Angle [6]



$$\tau_{tot} = \tau_{ST} + \tau_{ext} + \tau_{an}$$
$$= \tau_{ST}{}^{0} + B_{ext}\sin(\theta - \beta) - B_{an}{}^{0}\sin(\theta)\cos(\theta) = 0$$

$$\tau_{ST}{}^{0} = \frac{\hbar\, J_S}{2e\, M_s} = \frac{\hbar\, \theta_{SH}\, J_E}{2e\, M_s}$$

$$\boxed{\theta = 5.5^\circ}$$

Conclusions

As expected, second harmonic count rate increases with increasing laser intensity. Different thicknesses of the same metal showed differences in count rate and in the point at which they left the quadratic regime; the thinner Au and Pt samples showed higher count rates than their thicker counterparts, but there was no such consistency between thickness and the inflection point. Magnetic asymmetry for 10 nm Pt declined at higher powers. The threshold of decline was similar to the inflection point between the quadratic and linear regimes, and modeling of this phenomenon would make interesting future work.

Acknowledgements

I would like to thank my mentor, Akshay Pattabi; Professor Bokor; the Bokor group; and the E^{3}S staff.

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Support Information
This work was funded by
National Science Foundation
Award ECCS-0939514.