# Spin Currents and Spin Fluctuations in $Fe_xPt_{1-x}$ Alloys and Heterostructures

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**Principal Investigator(s): Robert A. Buhrman**

**User(s): Ryan Tapping**

*Affiliation(s): Applied and Engineering Physics, Cornell University*

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*Contact: buhrman@cornell.edu, rct76@cornell.edu*

*Primary CNF Tools Used: GCA 5x stepper, AJA sputtering tool*

## Abstract:

**The spin Hall effect (SHE) is the conversion of a longitudinal charge current to a transverse spin current, often attributed to spin-orbit coupling. The magnetization of a thin film can be manipulated by spin-orbit torques (SOTs) generated by the SHE in an adjacent metallic layer, which has many promising applications in spintronics. Most research studying SOTs has focused on heavy metals such as Ta, Pt, and β-W, and more recently in alloys with other non-magnetic elements such as PtAu [1]. However, SOTs in systems with magnetic elements is not well understood. Recently it has been shown that the SOTs have a strong temperature dependence in $Fe_xPt_{1-x}$ alloys [2]. The strength of the SHE in these ferromagnetic alloys, as measured through the damping-like spin torque efficiency, are enhanced near the Curie temperature, where there are strong spin fluctuations. We also look at the results of Fe/Pt multilayer heterostructures, where the strength of the magnetism can be adjusted by tuning the thicknesses of the ferromagnetic and heavy metal layers. Additionally, our work is continued to show that the Curie temperature can be tuned to be above room temperature, at working temperatures for possible computing applications.**

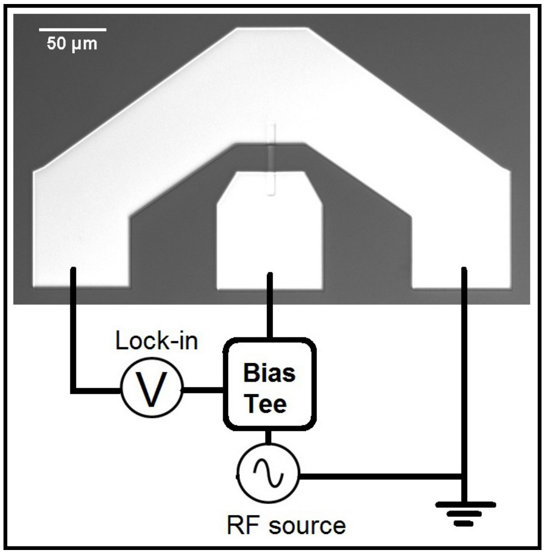

*Figure 1: Microstrip after fabrication with top contacts and a schematic of the ST-FMR measurement.*

## Summary of Research:

Thin film samples were deposited onto 100 mm silicon wafers using our magnetron sputtering system. Structures were composed of, from bottom to top, Ta(1)/$Fe_xPt_{1-x}$(4)/FM(t)/MgO(2)/Ta(1) with numbers in parenthesis representing the thickness of the layer in nanometers and t, the thickness of the ferromagnetic layer (FM). Stacks were then patterned into 60 × 5 $\mu m^2$ microstrips using photolithography with the 5X g-line stepper at CNF and etched using our own ion milling system. The contacts were made using the AJA sputtering system at CNF.

Resistivity measurements, using a four probe method, showed that the FePt resistance increased with Fe concentration. Resistivities ranged from 40 μΩ.cm for pure Pt films to 88 and 101 μΩ.cm for $Fe_xPt_{1-x}$ films with x = 0.23 and 0.35, respectively. This result is in agreement with previous reports and is indicative of the FM scattering impurities in the FePt [2]. Using Co as the FM layer, along with 0.4 nm of Pt spacer between the FePt and Co, the stacks have induced perpendicular magnetic anisotropy (PMA). When using FeCoB as the FM layer, the samples have in-plane anisotropy.

These two structures allow for different, independent measurements of the spin torque efficiency.

The spin torque efficiency (ξ) in the in-plane samples was determined using spin-torque ferromagnetic resonance (ST-FMR) [3]. This technique works by driving a microwave frequency (RF) current through the microstrip, which induces magnetic precession in the ferromagnetic layer via the spin transfer torque. A magnetic field is swept at 45° to the microstrip and the voltage is measured by a lock-in amplifier. A lineshape analysis is done by fitting a Lorentzian function with symmetric (S) and antisymmetric (A) components as shown in Figure 2. The ratio of the prefactors S and A yield $\xi_{FMR}$. By fitting $1/\xi_{FMR}$ vs $1/t$, the damping-like ($\xi_{DL}$) and field-like ($\xi_{FL}$) spin torque efficiencies can be extrapolated.

Additionally PMA samples with cobalt as the FM layer were measured using an out-of-plane second harmonic technique [4]. Measurements of the resistance of the microstrips as an in-plane field is swept can yield information about the anisotropy field. Then second harmonic measurements of the resistance and fields are swept parallel and perpendicular to the applied current yield information about $\xi_{DL}$ and $\xi_{FL}$ through effective field determinations.

We observe that $\xi_{DL}$ and $\xi_{FL}$ are in the FePt alloys having a large temperature dependence, specifically near the Curie temperature ($T_c$). As shown in Figure 3 (published [2]), a large increase in the effective fields, $H_{DL}$ and $H_{FL}$ occurs near the ferromagnetic transition and the peak values are measured just above the Curie temperature, for two samples of different Fe concentration.

These results pave the way for future research and potential application of ferromagnetic systems with strong spin-orbit coupling and spin fluctuations.

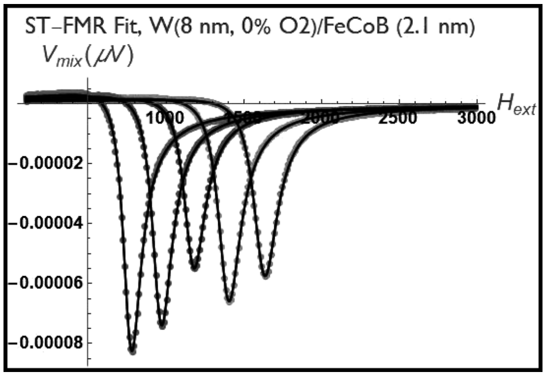

*Figure 2: Example of voltage output from a magnetic field sweep from ST-FMR. Fits are also shown at 8, 9, 10, 11, and 12 GHz frequencies.*

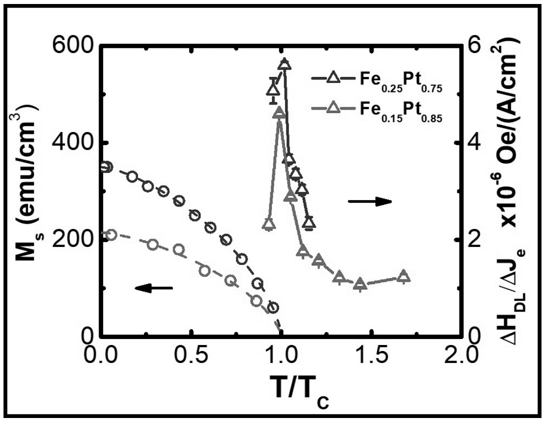

*Figure 3: The temperature dependent magnetizations are plotted on the left for $Fe_{0.15}Pt_{0.85}$ and $Fe_{0.25}Pt_{0.75}$ samples, as a function of normalized temperature to the Curie temperature ($T/T_c$). Damping-like effective fields are plotted on the right as a function of normalized temperature, with a large enhancement observed near $T_c$.*

## References:

[1] L. Zhu, D.C. Ralph, and R.A. Buhrman, Phys. Rev. Applied 10, 031001 (2018).

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[4] M. Hayashi, J. Kim, M. Yamanouchi, and H. Ohno, Phys. Rev. B 89, 144425 (2014).