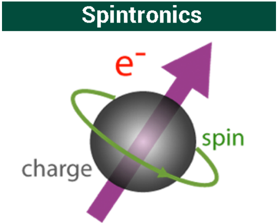
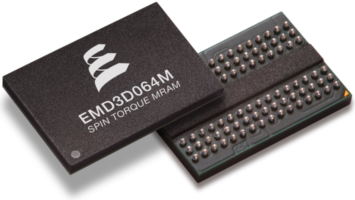
Low frequency magnetization dynamics in thin films

Logan Bishop-Van Horn, CCMR REU, Ralph Group

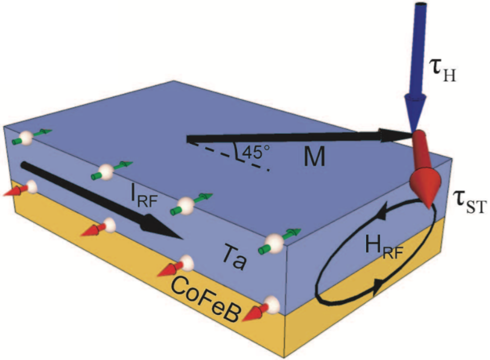
- Electronics
  - Charge used to manipulate electrons
  - Charge current → heat dissipation
- Spintronics
  - Spin used to manipulate electrons
  - Non-volatile
  - Higher speed, lower dissipation (efficient)
- Objectives in spintronics
  - Generate/transport spin currents
  - Manipulate spins/magnetization
  - Detect spins





Spin Orbit Torques

- Spin Hall Effect:
  - Conversion of charge current to transverse spin current
  - Figure of merit: spin Hall angle, $\Theta_{\mathrm{SH}} = J_s / J_c$
- Spin Transfer Torque:
  - Injection of spin polarized current into magnetic material $\rightarrow$ transfer of (spin) angular momentum $\rightarrow$ spin transfer torque $\boldsymbol{\tau}_{\mathrm{ST}}$ applied to magnetization vector
- Additional torque $\boldsymbol{\tau}_{\mathrm{H}}$ caused by Oersted field H_{RF} due to rf current[1]
- Landau-Lifshitz-Gilbert-Slonczewski (LLGS) equation
- **Macrospin approximation**

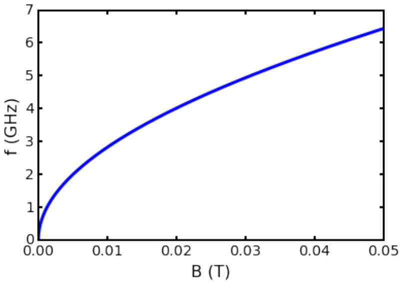


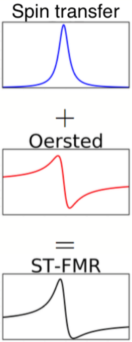
[1] Image ref: Spin-Torque Switching with the Giant Spin Hall Effect of Tantalum. *Science.* **336** *(2012)*.

ST-FMR

Spin transfer torque-driven ferromagnetic resonance

- Inject rf spin current into magnetic layer using spin Hall metal layer
- Excite resonant precession of the magnetization due to τ_{ST} and τ_H
- Kittel resonance condition



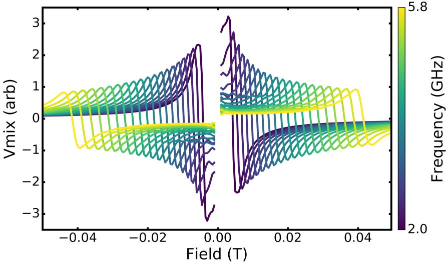


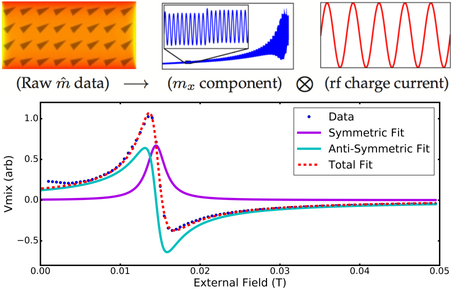
- I_{RF} mixes with rf resistance oscillation due to AMR $\rightarrow$ dc voltage V_{mix}
- V_{mix}: Theory predicts symmetric part from τ_{ST} and anti-symmetric part from τ_H
- Extract Θ_{SH}, α, M_{eff} from Lorentzian fits

Simulations

MuMax3: GPU-accelerated micromagnetics

- **Goal**: understand low frequency ($< 5GHz$) ST-FMR behavior
- **Model**: thin magnetic film with in-plane rf charge current, Oersted field, in-plane external field, and injected transverse spin current
- **Implementation**: MuMax3 micromagnetics[2] + MuCloud (MuMax3 on GPUs in the cloud)[3]
- **Analysis**: Calculate dc mixing signal and perform Lorentzian fitting





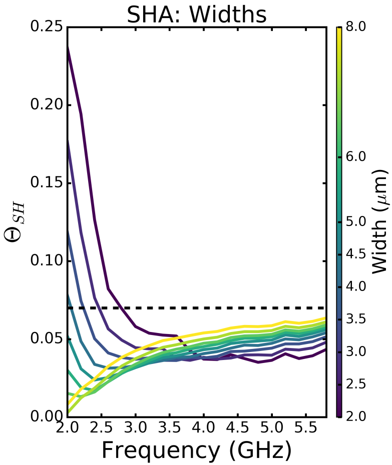
[2] The design and verification of MuMax3. *AIP Advances*, **4** 107133 (2014).

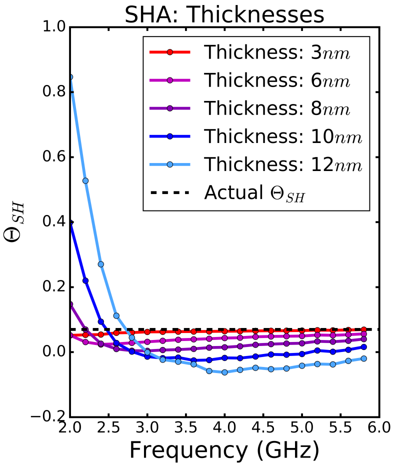
[3] GPU-accelerated micromagnetic simulations using cloud computing. *J. Magn. Magn. Mater.*, **401** (2016).

Simulation Results

Low frequency trends in Θ_{SH}

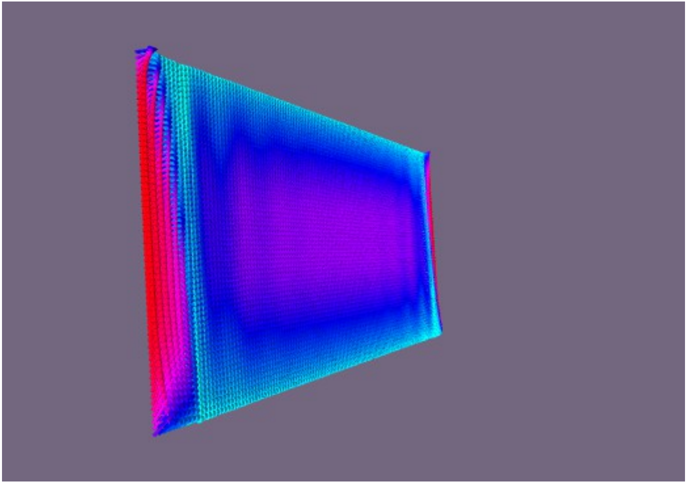
- Sample dimensions play an important role
  - Competing effects?
  - Θ_{SH} is suppressed and then diverges in thick samples





Simulation Results

Spatial variation in magnetization[4]: $10\mu m \times 1\mu m \times 6nm$ Py, $2.4GHz$

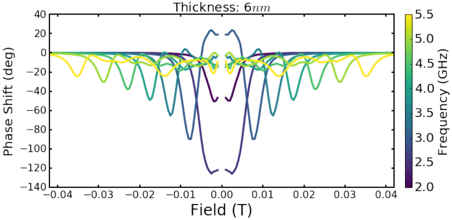


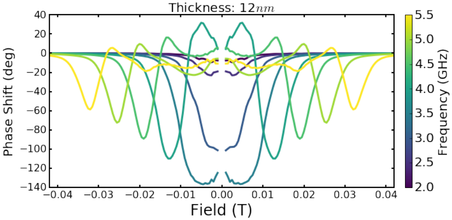
▸ MuMax3 ST-FMR

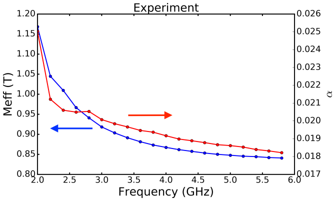
[4] Visualization created using MuView2: http://grahamrow.github.io/Muview2/

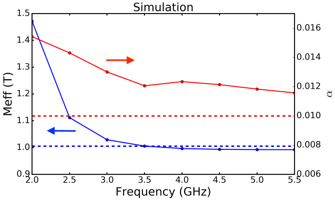
Simulation Results

Spatial variation in magnetization







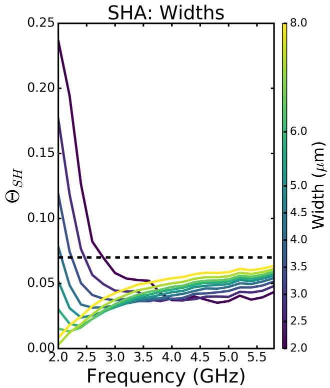


$$\Theta_{\mathrm{SH}} \propto M_{\mathrm{eff}}$$

Conclusion/Future Work

Conclusion:

- Simulation tools:
  - ST-FMR analysis
  - Phase/amplitude relative to rf current
  - Phase/amplitude between regions
  - Phase/amplitude between regions and samples
  - Visualization of results
- Clarify ST-FMR results
- Link to results from spatially-resolved measurement methods



Future Work:

- Compare to other experimental tehcniques
- Further explore effects of sample dimensions

Acknowledgments

and Questions

- **Ralph group:**
  - Neal Reynolds
  - Samuel Brantley
  - Dr. Ralph
- **CCMR**
- **CNF**
- **NSF MRSEC & REU Programs**