Putting the Electron’s Spin to Work
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Projects in Ralph Group

- Single-Molecule Electronics (with Abruña, Chan)
- Molecular Interfacing with Graphene (with Park, McEuen, Abruña)
- Nano Opto-Electronics (with McEuen, Gaeta) done in KIC Photon Facility
- Manipulating Nanomagnets with Spin Torque (with Muller, Buhrman)
- Spin Manipulation Using Topological Insulators (with Muller, Kim)
An electron can maintain its spin direction over 100’s of nm in a metal like Cu.

In nanoscale devices is possible to generate spin currents and control their dynamics in ways that are impossible in larger devices: new opportunities for science and applications.

I will highlight two projects today:

• Controlling dynamics in nanoscale magnetic tunnel junctions using spin transfer torque

• Learning to measure and manipulate spin in single molecules
Thin magnetic layers act like filters for spins

unpolarized incident electrons
(e.g. sp-like states in Cu)

Magnetic Layer
Putting Spin Filters in Series: Giant Magnetoresistance

discovered 1988

Parallel layers: low resistance

Antiparallel layers: high resistance

Disk drive read heads
Spin Transfer -- An Efficient Way to Apply Torques to Magnets

(proposed by Slonczewski, Berger 1996)

A magnetic layer can absorb the transverse component of incoming spin angular momentum, and therefore receives a torque.

**Cartoon Picture, for a Perfect Spin Filter**

Spin-polarized Current

Magnetic Layer

Torque
Spin-Transfer-Driven Magnetic Switching

70 nm view from above

CoFeB MgO (~1 nm) CoFeB

130 nm

Single-shot time resolved measurements of magnetic dynamics

Huai et al., APL 84, 3118 (2004).
Fuchs et al., APL 85, 1205 (2004).

Low-Resistance Tunnel Junctions for Spin-Torque Studies

- Pt
- Ta
- Cu
- CoFeB
- CoFeB
- Tunnel Barrier

view from above

31yrMTJ-4
Nanopillar
ORTEM0641027-001
J.Brandt & X.Lin

100 nm
40 nm

20 nm
STEM EELS Spectra: Composition Maps Reveal Nanoscale Variations in Chemistry

(with Muller, Buhrman)

Composite RGB Map
(O, B, Fe)

EELS Spectrum Imaging Reveals:
→ Nanoscale inclusions of B and other materials in the bottom electrode
→ Areas of Fe diffusion into the MgO
→ Mn diffusion into the MgO/CoFeB interfaces

all in an excellent junction
~180% TMR
Spin-Transfer-Driven Magnetic Precession

Dephasing time \( \geq 50 \) nsec, hundreds of oscillations can be observed

\(~1\) nsec required to establish a steady precession state (\(~4\) oscillation periods)

New Experiments to be Enabled by the Tools in the Kavli Institute at Cornell Photon Facility

Probing the limits of magnetic dynamics with ultrashort pulses

Testing predictions that strong spin torque can be generated by heat flow
Studying Spin in Single Molecules Using Mechanically-Controllable Break Junctions

- The electrode spacing can be varied by bending the substrate.
- Junctions exhibit excellent stability.
For a purely octahedral bonding environment, the 3 levels in the ground state $S = 1$ multiplet are degenerate. If the molecule is stretched axially, this degeneracy is broken due to spin-orbit coupling.

Spin state for Co$^{1+}$ is $S = 1$

Splitting of the Kondo peak illustrates mechanical control of the spin states (only possible for spins with $S = 1$ or greater)

- The temperature dependence exhibits for the first time underscreened Kondo scaling predicted for high-spin systems
- The breaking of spin degeneracy is confirmed by magnetic field studies.

Kavli Instrumentation Project:
Optical Manipulation and Read-Out of Electron and Spin Dynamics

Initial Projects:
- Nanoscale electronic domain structure in ruthenates (with Davis, Kim)
- Optical spin control in single molecules (with Gaeta)
Conclusion

Advances in understanding how to generate and control spins on the nanoscale is enabling a revolution in the science of magnetic devices.

New instrumentation for atomic scale characterization and dynamical measurements is the key to progress in this field.