Implications and future of Computers through Giant Magnetoresistance (GMR) and Spintronics

Bryan Chávez
University of South Carolina, Physics and Astronomy Graduate Seminar
September 19, 2014
Outline

- Introduction to 2007s Physics Nobel
- Early Years
- Giant Magnetoresistances (GMR)
- Spintronics
- Applications
- Conclusion
2007 Nobel in Physics

- Awarded: "for the discovery of Giant Magnetoresistance"
- Awarded to: Albert Fert and Peter Grünberg
- Actually discovery was in 1988
Early Years (1970’s)

- Spin wave experiments done by Peter Grünberg
- Done through Raman Light Scattering
Testing a Magnetic Multilayer

- Look at how an electron moves through a magnetic multilayer
- The two magnetic layers are Fe(~12nm) with Cr(~1nm) in between
Camley–Barnas Model

- First Theoretical theory for Giant Magnetoresistance
- Based on Boltzmann’s diffusion equation

\[
\frac{\partial g^{\uparrow(\downarrow)}(z, \mathbf{v})}{\partial z} + \frac{g^{\uparrow(\downarrow)}(z, \mathbf{v})}{\tau^{\uparrow(\downarrow)} v_z} = \frac{eE}{mv_z} \frac{\partial f_0(\mathbf{v})}{\partial v_x} ,
\]

Boltzmann transport equation: Camley-Barnas model
Original Experiment

Magnetizations of Fe layers at zero field in Fe/Cr multilayers

\[ V = RI \]
Giant Magnetoresistance

Orsay

Resistance ratio

$R / R(H=0)$

$\sim + 80\%$

Magnetic field (kGauss)

(B) Double layers

Fe 250 Å

Jülich
Theory vs. Expirement
Current In Plane vs Current Perpendicular to Plane

- Original experiment had the current in plane with the multilayer
- Spintronics is based off of current perpendicular to plane of multilayer
From GMR to Spintronics

- Giant Magnetoresistance leads to spintronics
- Moved away from dealing with charge to deal with electron spin
- Conventional circuit analysis deals with bulk charge through current
- Spintronics attempts to manipulate the spin of an electron
Spintronics

- The barrier between the Fe and the spacer causes an accumulation of spins.
- If you have an anti-parallel B field on the other side it produces a torque.
Spin Transfer

- Similar to Light Polarization

The transverse component of the spin current is absorbed and transferred to the total spin of the layer.

\[
\frac{\text{torque}}{\hbar} = \left( \frac{d S^z}{dt} \right) = \text{absorbed transverse spin current} \propto j M \times (M \times M_0)
\]

Tunneling Magnetic Resistance

- Current Perpendicular to Plane effect with an insulator instead of conductor
- Can be used as switches or to store data
Applications

- Magnetic Sensors
- Tunneling Switches
- Magnetic Random Access Memory
Magnetic Sensors

- Currently used on hard drives and lead to the ability to make 1 terabyte drives
- Used to measuring small magnetic fields
Magnetic Switches

- Tunnel junctions can be used as switches or to store data
- To switch a junction the B field needs to be \(~100 \text{ Oe} = 0.01 \text{ Telsa} = \text{ fridge magnet}\)
Magnetic Random Access Memory

- Uses the Tunnel junction to store data in a matrix
- Possibly to replace all current forms of memory storage
Other Applications

- Ferromagnetic semiconductors
- Spin transfer oscillators
- Phone gaussmeters
- Traffic control sensors
Conclusion

- Giant Magnetoresistance has change the way electronics are thought about
- Giant Magnetoresistance has lead to great advance in our understanding of the manipulation of electron spins
- Spintronics is wide open to many new advances to help us in computing
Bibliography

Grünberg, Peter. *From spinwaves to Giant Magnetoresistance (GMR) and beyond*. 2007.