Giant Magnetoresistance-GMR
The Nobel Prize in Physics
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David R. McKenzie
Professor, Materials Physics
The Nobel Prize in Physics

• In 1895 the inventor and businessman Alfred Nobel stated in his will that the Nobel Prize in Physics was to be awarded for inventions as well as discoveries. Only eight inventions have been awarded in the field of physics.

• International critics made the Royal Swedish Academy of Sciences make an informal decision to avoid these kinds of awards after 1912. One argument was that the inventors might be able to earn money patenting the invention.

• The Nobel Committee for Physics later reconsidered its decision and in 1956 another invention was rewarded.
Some inventions awarded the Nobel Prize

Lippman 1908 "for his method of reproducing colours photographically based on the phenomenon of interference"

Marconi, Braun 1909 "in recognition of their contributions to the development of wireless telegraphy"

Dalen, 1912 for his invention of automatic regulators for use in conjunction with gas accumulators for illuminating lighthouses and buoys"
Some of the More Recent Inventions

1956 Shockley, Bardeen, Brattain "for their researches on semiconductors and their discovery of the transistor effect"

1964 Townes, Basov, Prokhorov "for fundamental work in the field of quantum electronics, which has led to the construction of oscillators and amplifiers based on the maser-laser principle"
Magnetic Information Storage
Albert Fert

Peter Grunberg

- Peter Grünberg, German citizen. Born 1939 in Pilsen. PhD in 1969 at Technische Universität Darmstadt, Germany. Professor at Institut für Festkörperforschung, Forschungszentrum Jülich, Germany, since 1972.
Themes of the Talk

• First application of nanotechnology
• The rules for small things are different—quantum physics restricts the values physical quantities can have.
• Experimental investigations make major discoveries
• Our thirst for information storage
Electron Spin and its connection to magnetism

In the classical picture the electron is a spinning ball of charge and the spin gives rise to a tiny magnetic dipole.

Electrons are leptons—very light particles with apparently no internal structure and one of the best known but most mysterious particles in Nature.

In the Quantum physics the electron spin has the quantum number of $\frac{1}{2}$ - and when it interacts, the dipole is only up or down.
Electron spins-only parallel or antiparallel is allowed

- In the quantum world of electron spin, the orientation of the spin along a given direction can only take on two values, parallel or antiparallel.
- For example, the spins of two interacting electrons are either parallel or antiparallel.
The Stern Gerlach experiment

- We have seen that an angular can take only a fixed number of directions with respect to a reference direction and so it is for spin angular momentum. The crucial experiment was done by Stern and Gerlach in 1922 when a beam of neutral atoms is passed through the magnetic field region, two spots were formed.
Spin Dependent Scattering

weak scattering

strong scattering
Antiferromagnets

• Nature prefers to make magnetic fields small and likes to have dipoles cancelling each other

• Antiferromagnetism is:
Ferromagnets

- Nature prefers to make magnetic fields small and likes to have dipoles cancelling each other

- Ferromagnetism is:
  
  ![Diagram of magnetic dipoles aligning]
In 1857, the British physicist Lord Kelvin published an article showing that the resistance diminishes along the lines of magnetization when a magnetic field is applied to a magnetic conductor. If the magnetic field is applied across the conductor, the resistance increases (Magnetoresistance, MR). This is a relatively small effect.

A prerequisite for the discovery of the GMR-effect was provided by new possibilities of producing fine layers of metals on the nanometre scale which started to develop in the 1970s (nanotechnology).

Albert Fert and his colleagues created some thirty alternating layers of iron and chromium – composed of just a few strata of atoms each. They worked at near vacuum and used very low pressure gases of iron and chromium to create crystal layers (Molecular Beam Epitaxy, MBE).

Peter Grünberg’s group created a simpler system with two or three layers of iron with a layer of chromium sandwiched in between.

The French group saw a magnetization-dependent change of resistance of up to 50 per cent, whereas the German group saw a 10 per cent difference.
Giant Magnetoresistance

- Relies on the fact that electrons scatter differently from each other depending on whether their spins are parallel or antiparallel.

![Diagram showing ferromagnetic and antiferromagnetic alignments with corresponding resistance values.](image)
How big is the effect?

It’s a big effect
Stuart Parkin at IBM

- Stuart Parkin and two groups of colleagues at IBM's Almaden Research Center, San Jose, Calif, quickly recognized its potential.
- Parkin but did not want to wait to use an expensive MBE machine that could make multilayers in the same slow-and-perfect way that Gruenberg and Fert had.
- Parkin and his colleague, Kevin P. Roche, tried a process common in disk-drive manufacturing: sputtering.
- To their astonishment and delight, it worked! Parkin’s team saw GMR in the first multilayers they made.
Bruce Gurney at IBM

• Searching for a useful disk-drive sensor design that would operate at low magnetic fields, Bruce Gurney used two magnetic layers separated by a spacer layer.
• The spacer was chosen to ensure that the coupling between magnetic layers was weak.
• He "pinned" in one direction the magnetic orientation of one layer by adding a fourth layer: a strong antiferromagnet.
• When a weak magnetic field, such as that from a bit on a hard disk, passes beneath such a structure, the magnetic orientation of the unpinned magnetic layer rotates relative to that of the pinned layer.
• This structure was named the spin valve.
Spin Valve

Why is vertical alignment “smaller” in space than horizontal alignment

Analogy with magnetic tape
There is a doubling of semiconductor processing power every 18 months.
Fast Readouts Needed!

The readout task is analogous to an A380 flying at full speed over grass at an altitude of 1 metre and counting every blade.
Kryder’s Law

- Another law is at least as powerful, Kryder's Law: yearly doubling of disk-memory, ever cheaper and smaller hard-drives.
- Mark Kryder is founder and director of Carnegie Mellon's Data Storage Systems Center and now the CTO of Seagate Technology.
- Kryder believes the average person may own some 10-20 drives, tucked away in various appliances.
Advances in hard disc drive technology – perpendicular recording

Old technology-low density

New technology-high density

But-needs more sensitive readout heads!
Spintronics

- Electrons have charge and spin.
- MOSFET operates using charges on a gate, the spin is entirely neglected.
- Spintronics aims to exploit electron spins for logic operation.
- Possibility for quantum computing?
Magnetic Random Access Memory (MRAM)

- This combines the best features of magnetic memory (nonvolatile, inexpensive) with those of conventional RAM (fast access)

Read step: measure resistance between chosen bit and word line
Write step: pass current along chosen bit and word line to create a strong local magnetic field

The tunnel barrier is a GMR spin valve
Tetrahedral Amorphous carbon as a protective layer for magnetic memory

- The GMR head flies over the surface at high speed and lands on the surface when the drive is off.
- A new form of amorphous carbon, tetrahedral amorphous carbon ("amorphous diamond"), first identified in the School of Physics in 1990 (McKenzie et al.), is now being used as the protective layer on hard disc drives.
How safe is your family album?

- Flash v magnetic v optical v silver particle
The Silver Nanoparticle in Photography

- Louis-Jacques-Mandé Daguerre announced his copper/silver process to the public on August 19, 1839 at a meeting of the French Academy of Sciences. American photographers quickly capitalized on this new invention. Daguerreotypists in major cities invited celebrities and political figures to their studios in the hopes of obtaining a likeness for display in their windows. Unlike film and paper photography, a properly sealed daguerreotype can last indefinitely.
“New” Technologies for image and data storage

- Magnetic storage-information is at risk from magnetic events and medium failure
- Optical storage (CD, DVD etc) information is at risk from mechanical failure (disc breakage, fractures etc).
- Solid state (flash etc) information is at risk from loss of charge from the memory element
Discussion Points

• Is the new storage better than the old?
• Do we really need all this storage anyway?
• Theory V Experiment
• Value of basic research
• Nobel prize policy- inventions V discoveries