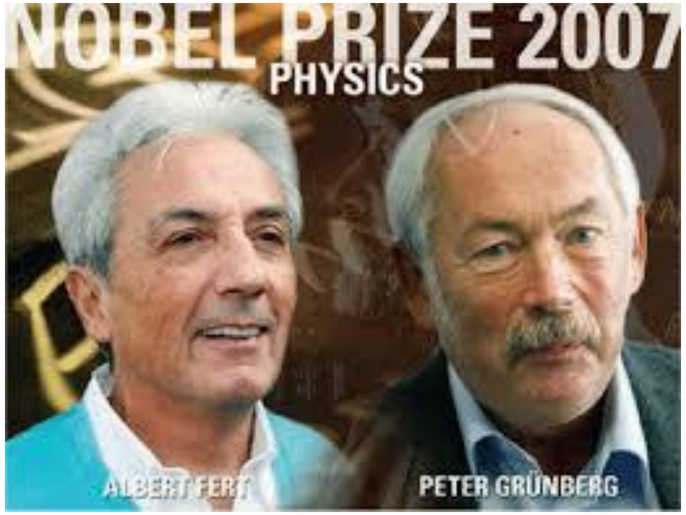
Engineered Materials
(SC221)

The "giant magnetoresistive" (GMR) effect was discovered in the late 1980s by two European scientists working independently: Peter Gruenberg and Albert Fert. This won them a Nobel prize in Physics, in 2007.

They saw very large resistance changes in the materials comprised of alternating very thin layers of various metallic elements.



- GMR is a quantum mechanical effect

- It is observed in multilayers composed of alternating ferromagnetic and non-magnetic conductive layers (Fe/Cr layers)

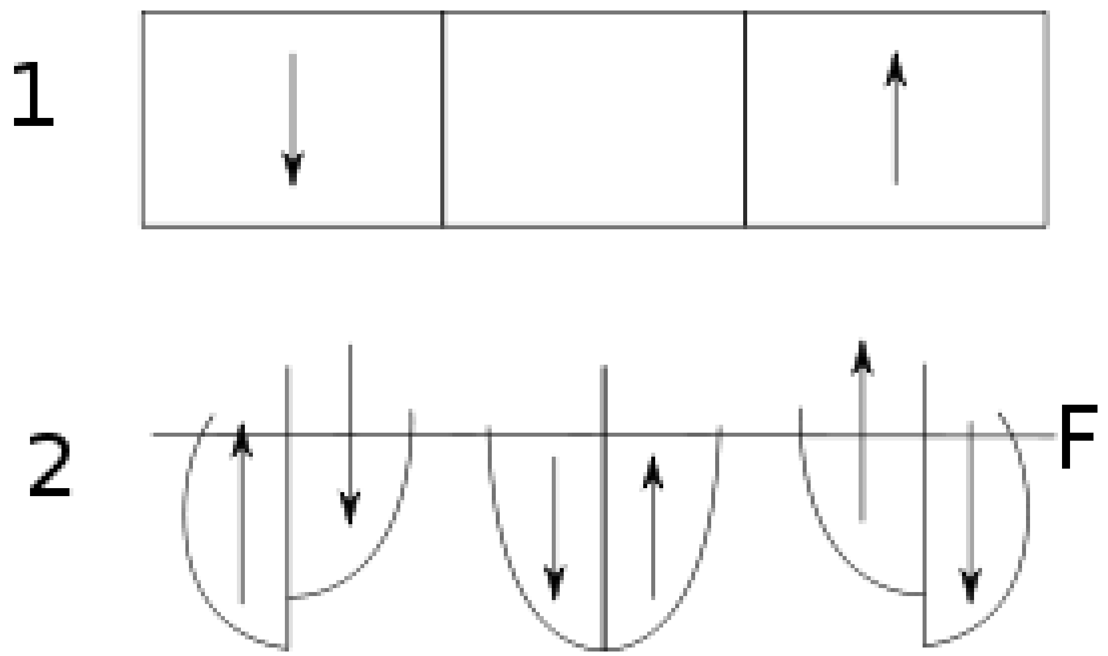
- a significant change in the electrical resistance of such multilayered material is observed depending on whether the magnetization of adjacent ferromagnetic layers are in a parallel or an antiparallel alignment.

Multilayer GMR

In a multilayer GMR two or more ferromagnetic layers are separated by a very thin (about 1 nm) non-ferromagnetic spacer (e.g., Fe/Cr/Fe).

At certain thicknesses, the coupling between adjacent ferromagnetic layers becomes antiferromagnetic, making it energetically preferable for the magnetizations of adjacent layers to align in anti-parallel.

Resistance is reported to change by 50% and more if coupling spacing goes above 3 nm.



Electronic density of states (DOS) in magnetic and non-magnetic metals. 1: the structure of two ferromagnetic and one non-magnetic layers (arrows indicate the direction of magnetization). 2: splitting of DOS for electrons with different spin directions for each layer (arrows indicate the spin direction). F: Fermi level. The magnetic moment is antiparallel to the direction of total spin at the Fermi level.

- The overall resistance is relatively low for parallel alignment and relatively high for antiparallel alignment.

- The magnetization direction can be controlled, for example, by applying an external magnetic field.

- The GMR effect is based on the dependence of electron scattering on the spin orientation.

- A new term has emerged with the invent of GMR and that is “spin current” instead of “charge current”.

- Spintronics is a new area.

The GMR material changes its electrical resistance in response to an applied magnetic field.

The electron scattering depends on the relative orientations of the electron spins and those magnetic moments: it is weakest when they are parallel and strongest when they are antiparallel.

Numerically GMR is characterized as

$$\delta H = [R(H) - R(0)]/R(0)$$

where R(H) is the resistance of the sample in a magnetic field H, and R(0) corresponds to H = 0.

The term "giant magnetoresistance" indicates that the value δ for multilayer structures significantly exceeds the anisotropic magnetoresistance, which has a typical value within a few percent.

The enhancement of δ_H became possible with the advent of sample preparation techniques such as molecular beam epitaxy (MBE), which allows manufacturing multilayer thin films with a thickness of several nanometers.

Applications of GMR:

The main application is magnetic field sensors and hence it is used for the following:

- Read data in hard disk drives, biosensors, microelectromechanical systems (MEMS) and other devices
- Magnetoresistive random-access memory (MRAM)
- Read data in biosensors

https://www.youtube.com/watch?v=wteUW2sL7bc

Spin Valve GMR

In spin valve GMR two ferromagnetic layers are separated by a thin non-ferromagnetic spacer (around 3 nm).

We increase the distances over which an electron will retain its spin (the spin relaxation length), and enhance the polarization effect on electrons by the ferromagnetic layers and the interface.

This device is sometimes also called a spin valve.

Further Readings

- Kristen Coyne, E.S. "Giant Magnetoresistance: The Really Big Idea Behind a Very Tiny Tool"
- Tsymbal, E.Y. and D. Pettifor, "Perspectives of giant magnetoresistance"
- IBM using GMR to store on hard disk https://www.research.ibm.com/research/demos/gmr/index.html