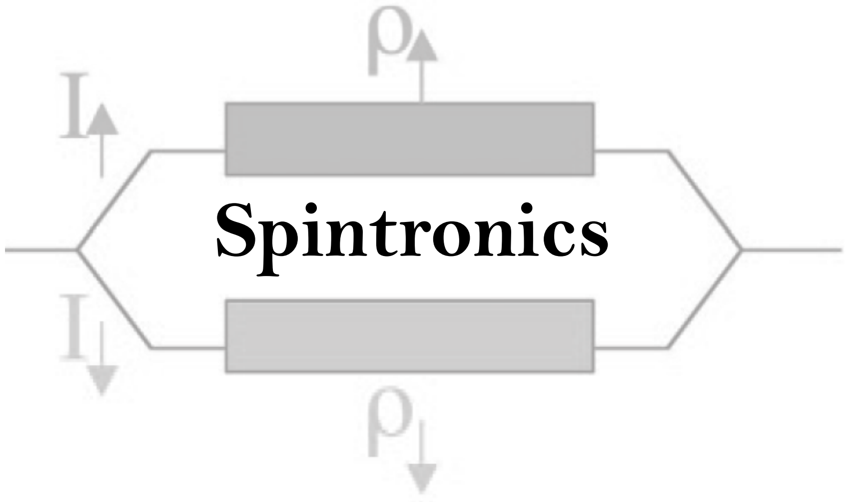
Spintronics



by

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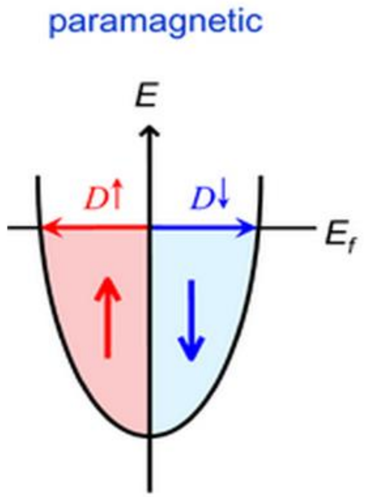
What is spintronics?

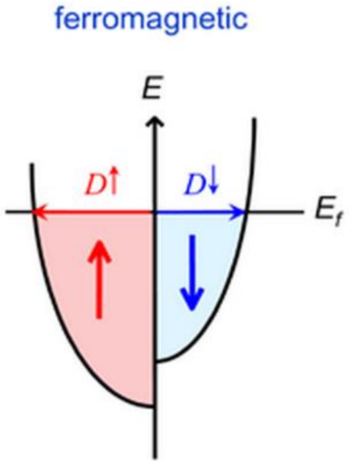
- In conventional electronics, motion of electrons is controlled through interaction between its charge and an external electric field and spin is almost completely ignored in the process.
- In spintronics, we pay attention to the details of electronic structure of a material determined by quantum mechanics and take into consideration the effect of spin on motion of electrons.
- Since spin states of electrons are susceptible to external magnetic fields, it becomes possible to manipulate conduction of charges in materials by applications of electric as well as magnetic fields!
- This extra degree of control on electron mobility has revolutionized the field of electronics, especially magnetic sensors leading to high density memories.

How it began…

In 1936, Mott tried to take into account the role of spin in his calculations of resistivity of ferromagnetic metals near Curie temperature.

- Unlike non-magnetic metals, the band structures of ferromagnets are asymmetric for up-spin and down-spin electrons.
- As a result, mobilities of up- and down-spin electrons, which are functions of electronic states, in such material are different.
- This implies that up- and down-spin electrons behave differently under the application of identical electric fields. Thus, exhibiting disparate resistivities.
- Since spins can be manipulated by magnetic fields, dependence of resistivity on spin allows for the possibility of control and measurement of electric currents through magnetic fields.





Fast forward to 1966…

- The discovery, however, remained dormant and unexplored for three decades partly due to lack of technology to prepare suitable samples and partly due to the lack of interest.

Spin dependent resistivity is very weak compared to normal resistivity and hence difficult to measure.

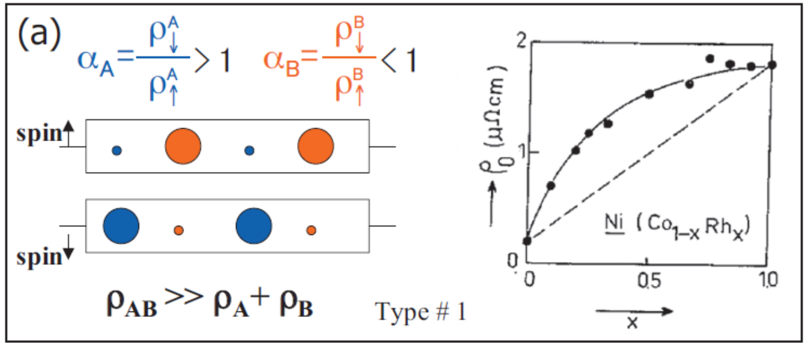
- In 1966, following Mott's work, a graduate student Albert Fert and his supervisor Ian Campbell started investigating the problem of spin dependent conductivity.

- They designed a series of experiments to determine the nature of influence of spin on conductivity and also contributed to the current theoretical framework in the form of ***two-current model***.

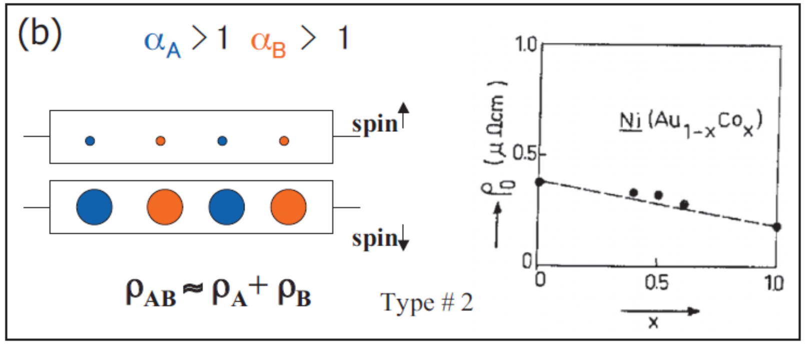
Recipients of 2008 Nobel prize in *Spintronics*

Albert’s experiments

To study spin dependent electron scattering, Albert measured resistivities of Nickel doped with impurities such as Cobalt and Chromium which present scattering cross-section strongly dependent on spin.

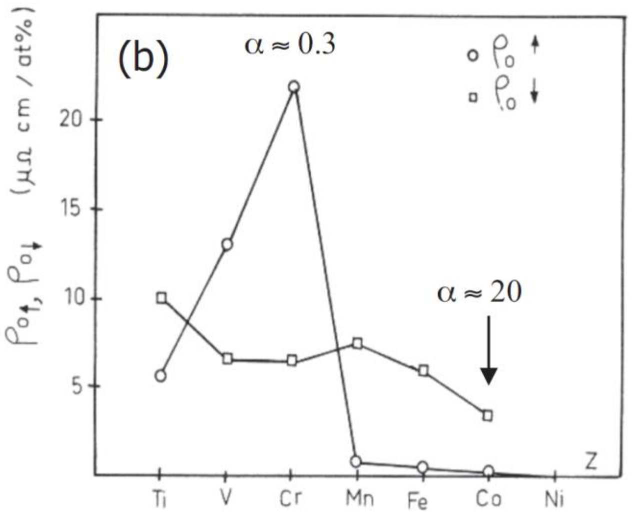


Nickel doped with impurities of opposite scattering spin asymmetries *Ni(Co$_{1-x}$Rh$_x$)*



Nickel doped with impurities *Ni(Au$_{1-x}$Co$_x$)* having strong scattering cross-section for only one type of spin.

Here Au does not exhibit spin dependent scattering



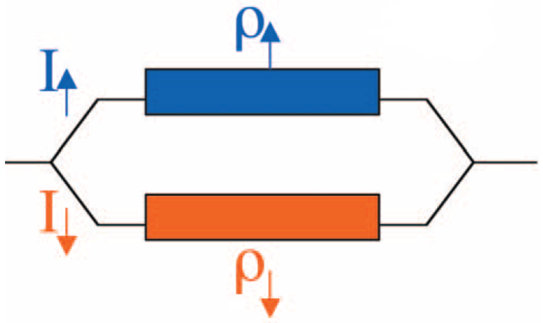
Spin-dependent resistivities of some materials

This phenomenon of spin dependent resistivity was referred to as ***Magnetoresistance***.

The two-current model

To explain their observations of spin-dependent electron scattering, Albert and Ian proposed the *two-current model* where they treat the conduction as a two-channel process.

- Up- and down-spin electron currents are assigned separate channels.
- Contributions to resistivities of the two-channels are different for the same impurity depending on it spin scattering cross-section.
- Albert also took into account the spin-mixing between the two channels whereby the net spin-polarization of a ferromagnetic material decreases.
- In the model, this spin-mixing or spin-relaxation is due to spin-orbit coupling as the electrons near Fermi level move at relativistic speeds.



1980s…

- During 70s, solid foundations of spin-dependent conduction had been laid but physicists were still limited in their ability to grow structured materials and so could not exploit the thin newly discovered phenomena to the full extent.

- 80s was an era of innovation. With the advent of *sputtering technique*, started the new and very important branch of material science – ***thin films technology***.

- Sputtering technique allowed physicists to grow epitaxial thin films and enabled them to exercise an unprecedented degree of control on physical properties of materials.

- Several groups started working on thin films simultaneously. Among them were the groups of *Baibich* (1988) and *Binash* (1989) who studied magnetoresistance in multilayered films.

- During their study they discovered something remarkable – ***Giant Magnetoresistance*** (GMR).

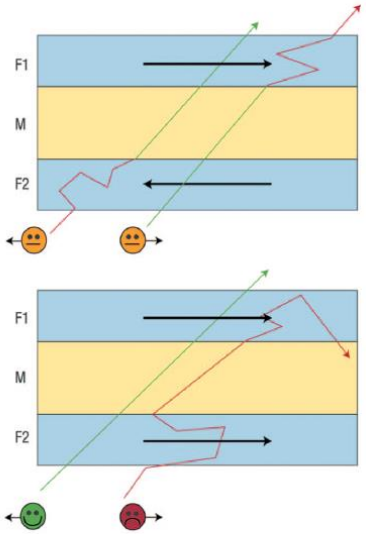
- GMR allowed for much more efficient control of motion of electrons through magnetization which rapidly crystalized into a new field of research and technology, which we now refer to as ***Spintronics***.

What is GMR?

Next time…

Small changes in magnetic fields ⟶ Huge changes in resistance.

In other words, something that makes iPod possible.



From 2008 Nobel lecture of Albert Fert.

References

1. *Nobel lecture: Origin, development and future of spintronics* by Albert Fert, *Reviews of Modern Physics, Vol 80, Oct-Dec 2008*
2. *Nobel lecture: From spin waves to giant magnetoresistance and beyond* by Peter Grunberg, *Reviews of Modern Physics, Vol 80, Oct-Dec 2008*
3. *Giant magnetoresistance in organic spin valves* Z. H. Xiong, Di Wu, Z. Valy Vardeny & Jing Shi, *Letters to Nature Vol 427*
4. *Giant Magnetoresistance in Organic Spin Valves* Dali Sun, Lifeng Yin, Chengjun Sun, Hangwen Guo, Zheng Gai, X. G. Zhang, T. Z. Ward, Zhaohua Cheng, and Jian Shen **PRL 104, 236602 (2010)**
5. *Boundary Resistance at FM/NM interface* http://xiaoshanxu.blogspot.com/
6. http://firstlook.pnas.org/giant-magnetoresistance/