



# Giant Magnetoresistance

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# Outline

- Introduction
- Science of GMR
  - Anisotropic magnetoresistance
  - Giant magnetoresistance
- Discovery of GMR
  - research by IBM
- Application of GMR
  - GMR-based spin valves in hard drives
- Impact of GMR on the storage media industry



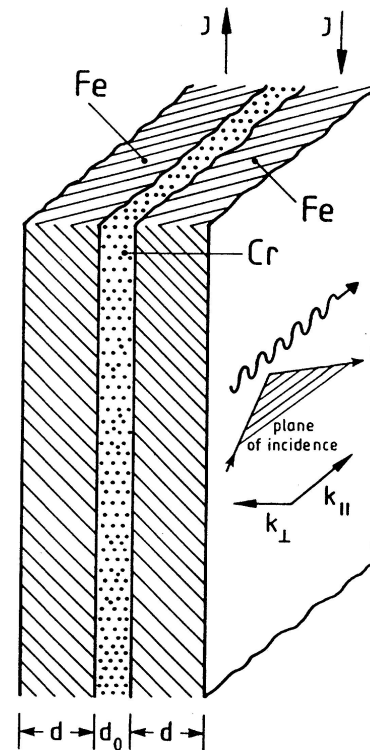
# GMR – why is it useful?

- Discovery and application of the GMR phenomenon is responsible for the ubiquitous availability of economical, high density information storage in our society.
- Compact 160 GB Mp3 players and 1 TB hard drives, now widely available, owe their existence to GMR and subsequent related advances.

# Science of GMR

## Giant magnetoresistance

- System:
  - a thin layer of nonmagnetic material sandwiched between two layers of magnetic material.
- Right: a Fe-Cr-Fe trilayer used in Grünberg's original experiment.





# Science of GMR

## Mott Model

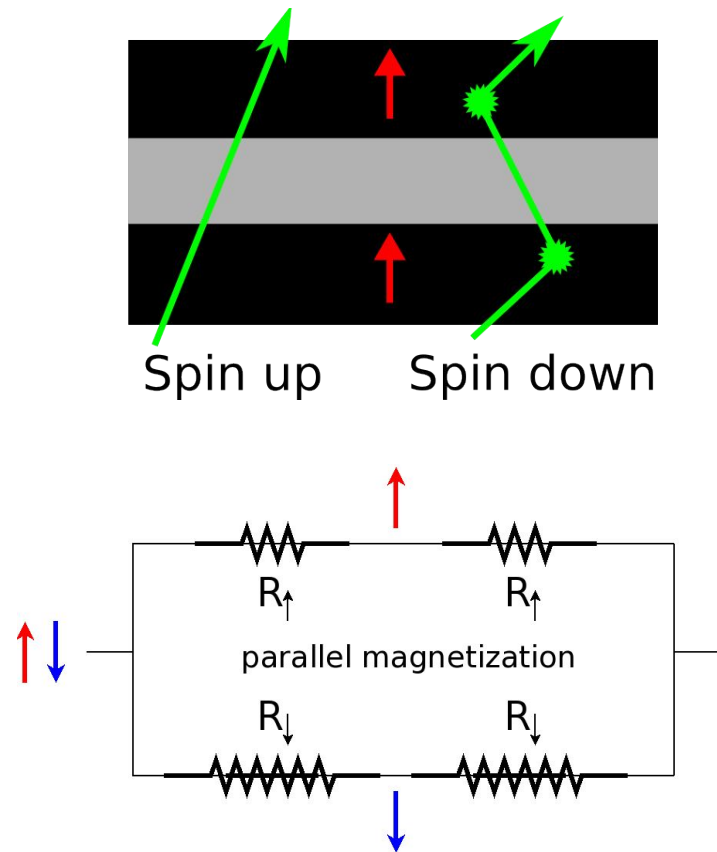
- The electrical conductivity in metals can be described in terms of two largely independent conducting channels, corresponding to the up-spin and down-spin electrons, and electrical conduction occurs in parallel for the two channels.
- In ferromagnetic metals the scattering rates of the up-spin and down-spin electrons are different.
- ❖ (We will assume that the scattering is strong for electrons with spin antiparallel to the magnetization direction and weak for electrons with spin parallel to the magnetization direction.)

# Science of GMR

## Giant magnetoresistance

- Parallel magnetization
- Up-spin electrons experience small resistance, down-spin electrons experience large resistance.
- Total resistance is

$$R_{para} = \frac{2R_{\uparrow}R_{\downarrow}}{R_{\uparrow} + R_{\downarrow}}$$

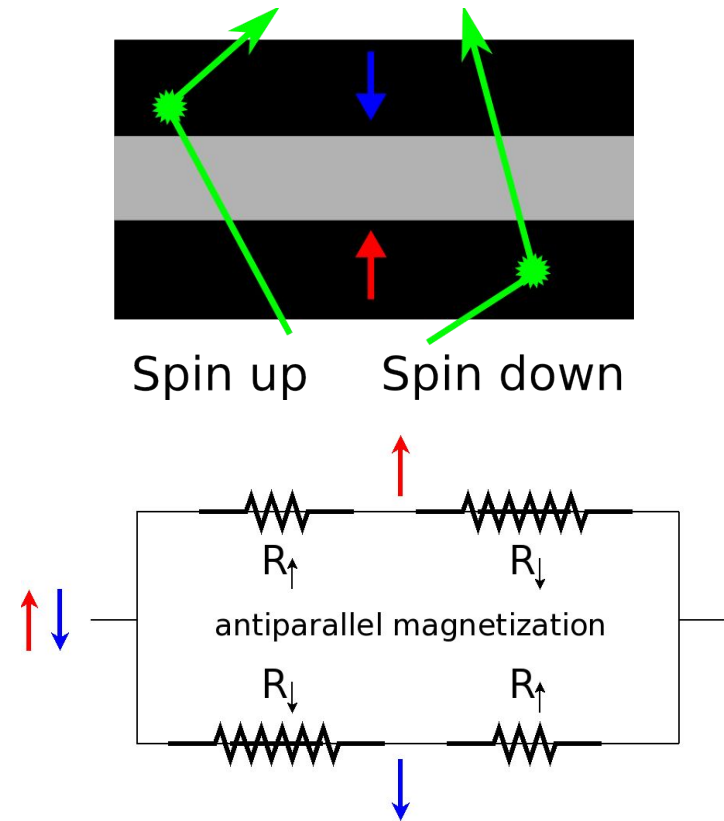


# Science of GMR

## Giant magnetoresistance

- Antiparallel magnetization
- Both electron spins experience small resistance in one layer and large resistance in the other.
- Total resistance is

$$R_{antpara} = \frac{1}{2} (R_{\uparrow} + R_{\downarrow})$$





# Discovery of GMR

## Fert and Grünberg

- Discovered by independently by Professor Albert Fert of Université Paris-Sud in France and Professor Peter Grünberg of Forschungszentrum in Jülich, Germany.
- Both groups submitted papers to *Physical Review* in the summer of 1988.





# Discovery of GMR

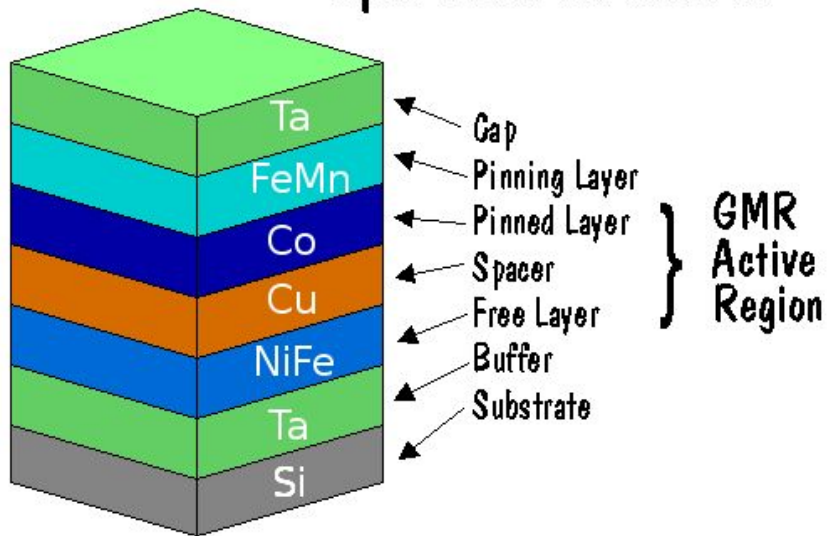
## IBM

- Stuart Parkin of IBM attempted to reproduce the effect using the sputtering technique
- Fert and Grünberg used molecular beam epitaxy, a more precise but slower and more expensive method.
- Parkin's group succeeded, observing GMR in the first multilayer sample's produced.
- Parkin's group began experimenting with various sample compositions and layer thicknesses to better understand GMR and how to integrate it into magnetic storage.

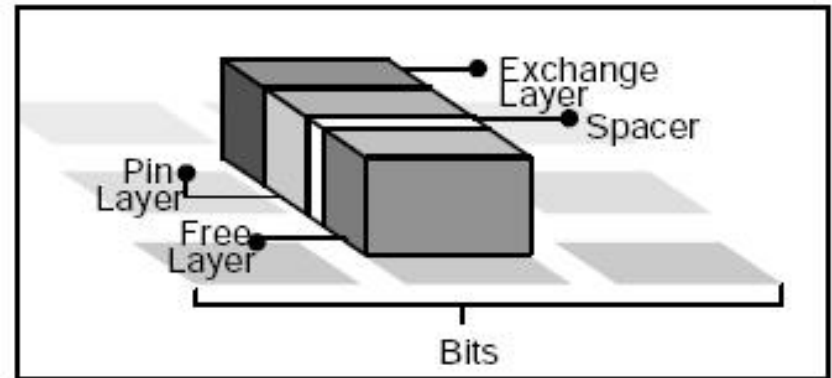
# GMR in practice

## Spin Valve

Spin-valve structure.



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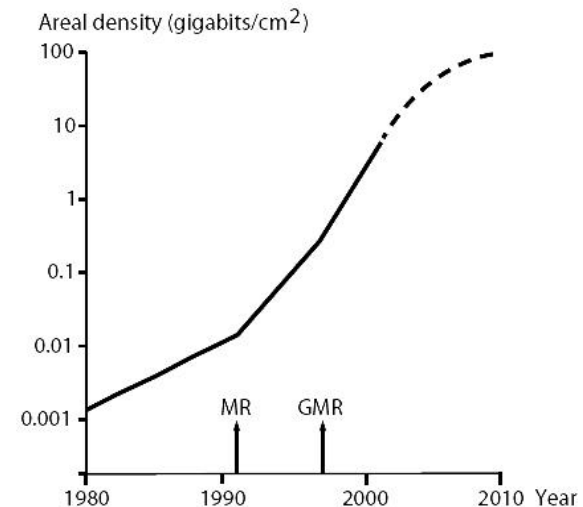
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# Read/Write Head



# GMR's effect on hard drive industry

- First GMR hard drive deployed:
  - Deskstar 16 GP by IBM
  - Date: 1997
  - Storage: 16.8 GB
  - 2.7 billion bits per square inch.
- Current largest hard drive:
  - Deskstar 7K1000 by Seagate
  - Date: 2014
  - Storage: 8 TB



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