Spintronics: past, present & future!

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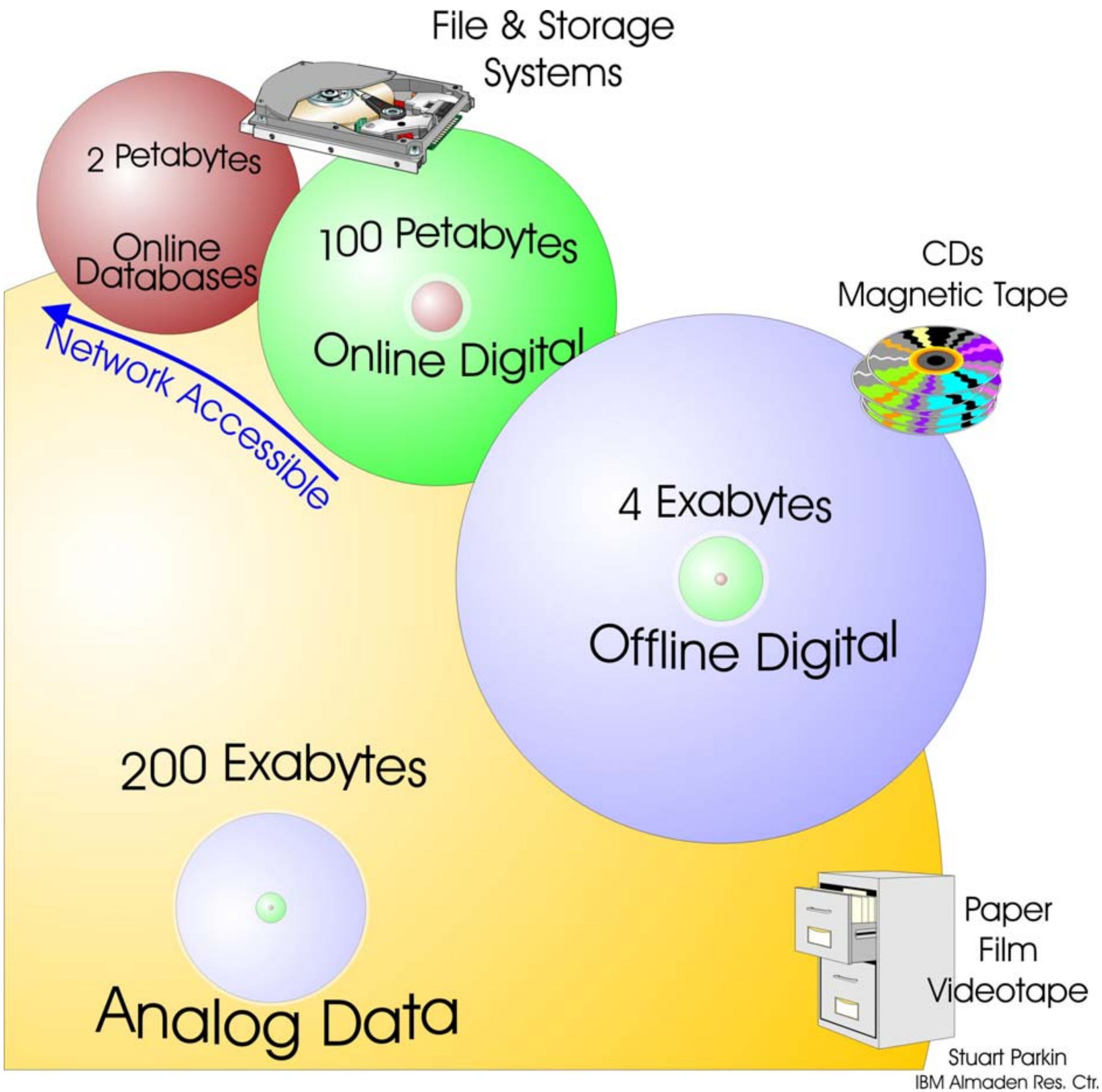
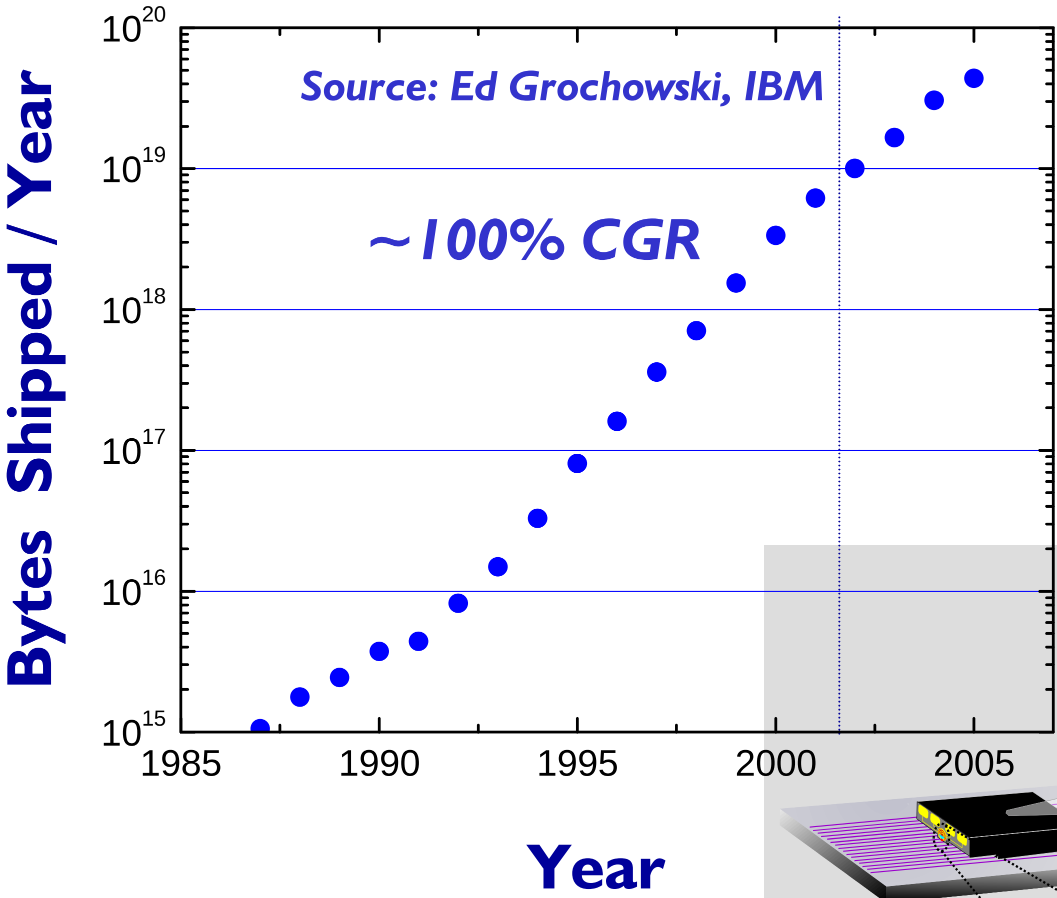
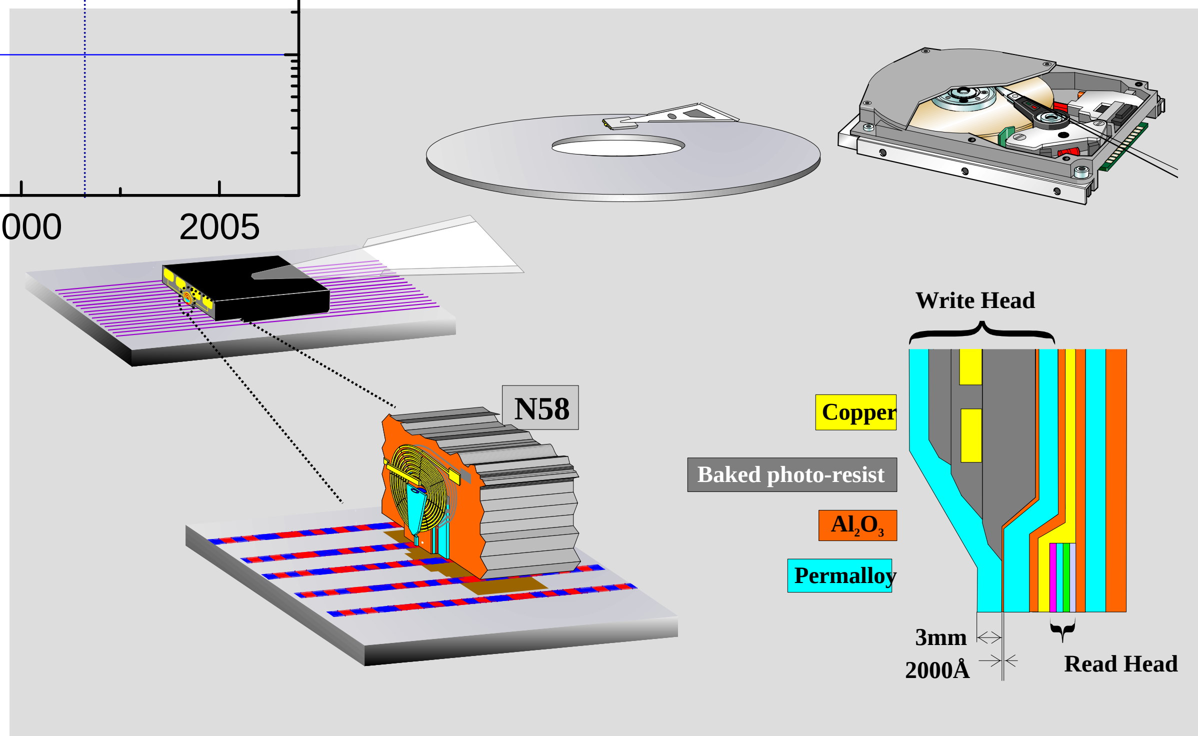
How Much Data is There?



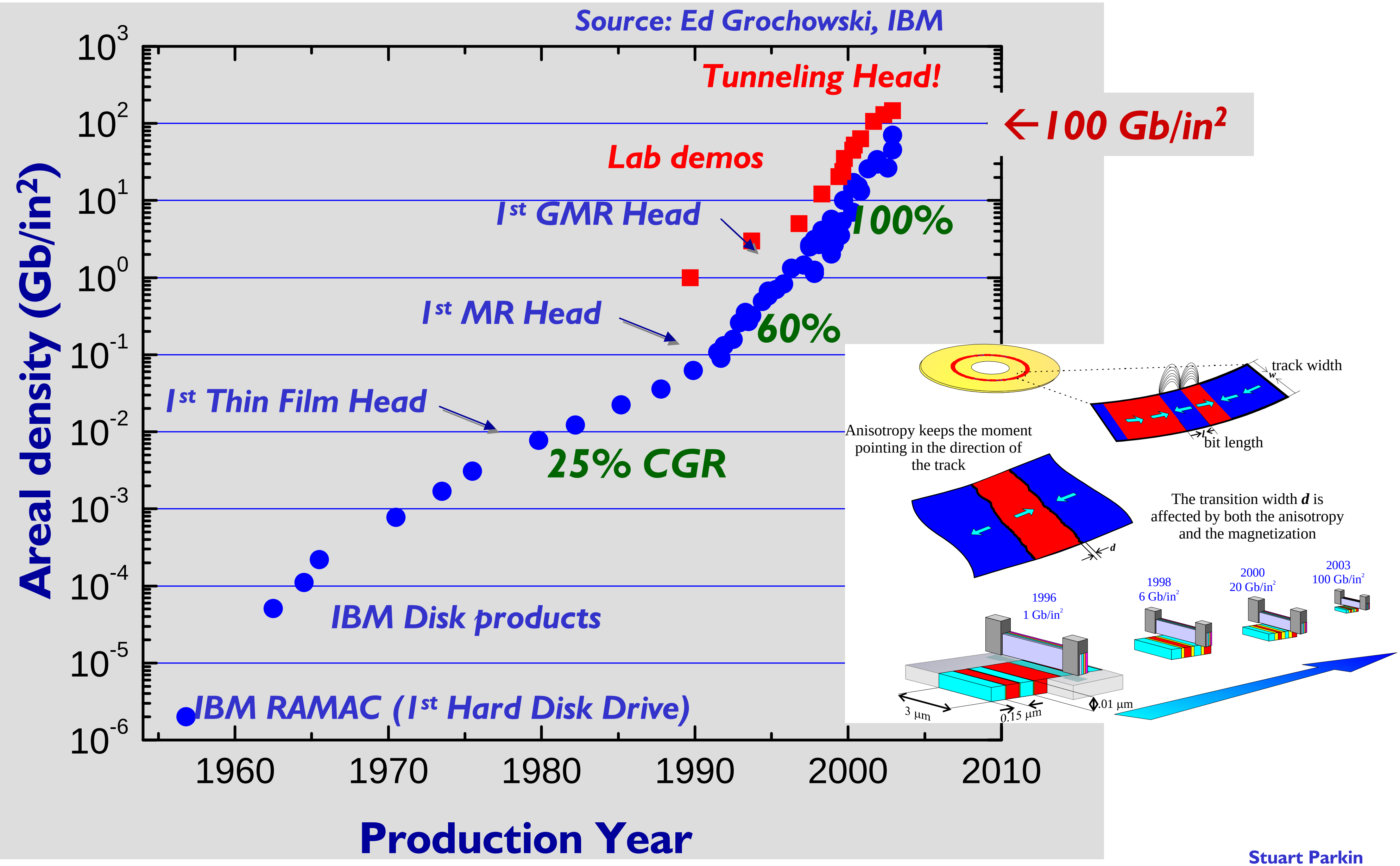
Hard Disk Drive Capacity Shipped Per Year



←10 ExaBytes
In 2002



Hard Disk Drive Areal Density Evolution



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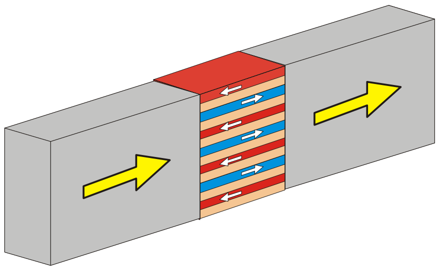
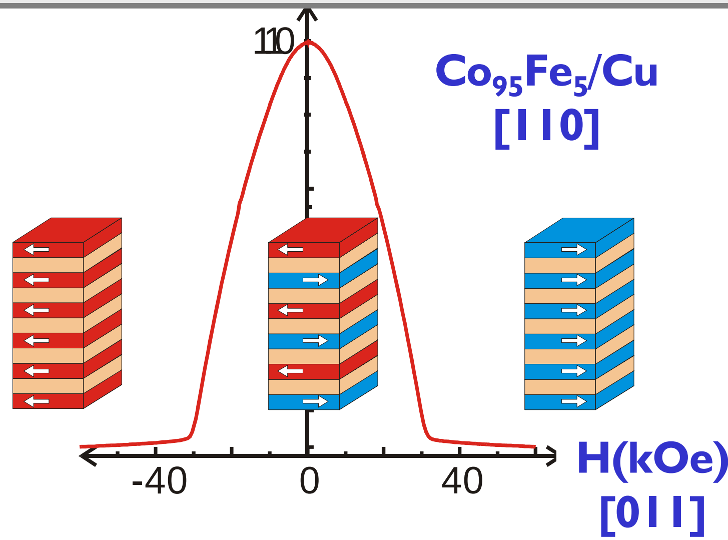
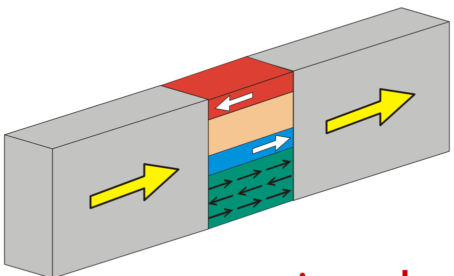
Giant Magnetoresistance (GMR) in Multilayers and Spin-Valve Sandwiches



multi-layer

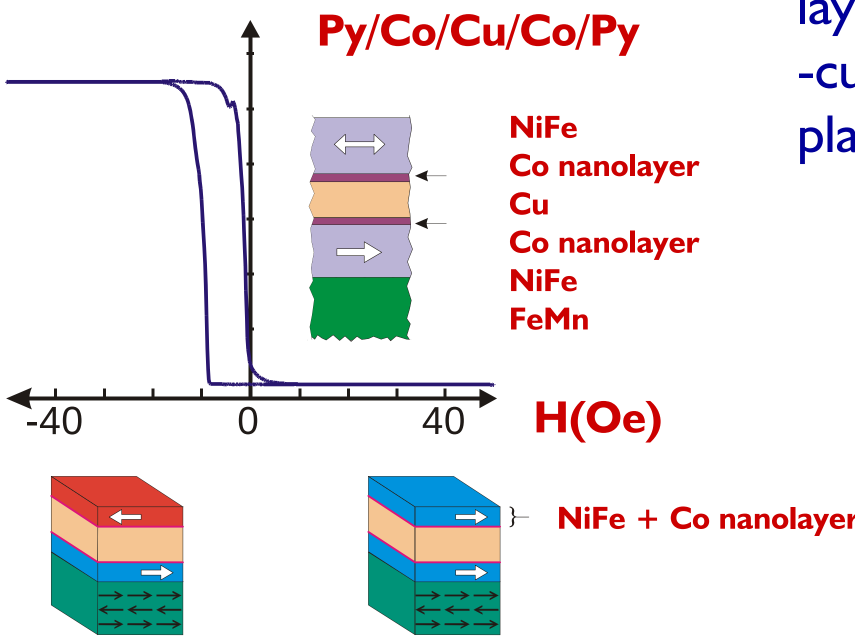
ΔR/R~110% at RT
Field ~10,000 Oe





spin-valve

ΔR/R~8-17% at RT
Field ~1 Oe



GMR
- metallic spacer between magnetic layers
- current flows in-plane of layers

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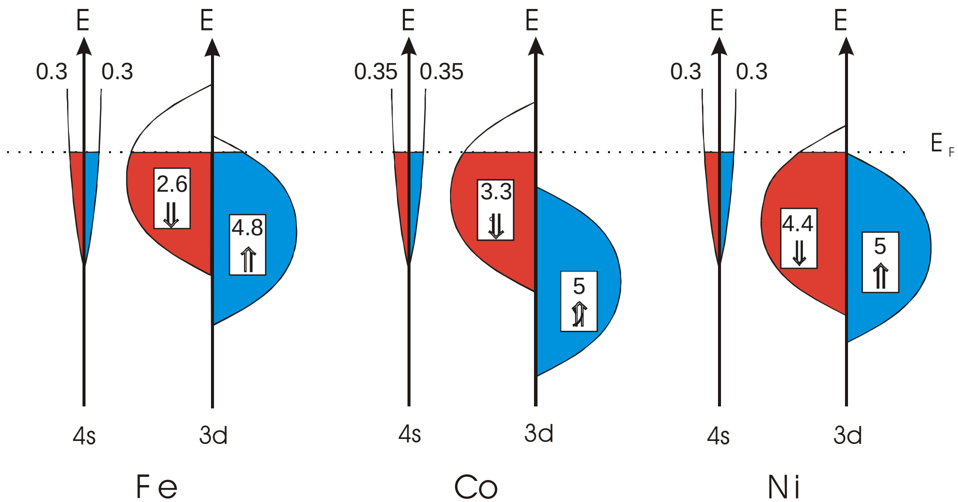
Spin dependent conductivity in ferromagnetic metals



Density of states in the s and d bands of ferromagnetic Ni, Fe and Co.
Total number of electrons in the spin down (left) and spin up (right) bands are also shown.
The bands are filled up to the common Fermi level E_F.

Current carried independently in spin-up and spin-down subbands [*Mott, 1936*]

$$\sigma = \sigma_{\Downarrow} + \sigma_{\Uparrow}$$

Assumptions:

- negligible spin-mixing
- $\sigma_{\Uparrow} > \sigma_{\Downarrow}$

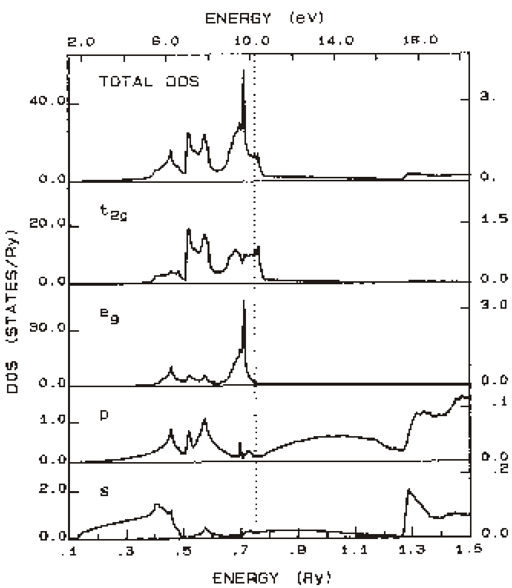
-fundamental property of all ferro and ferri-magnetic systems is that the current is carried independently in two spin-channels

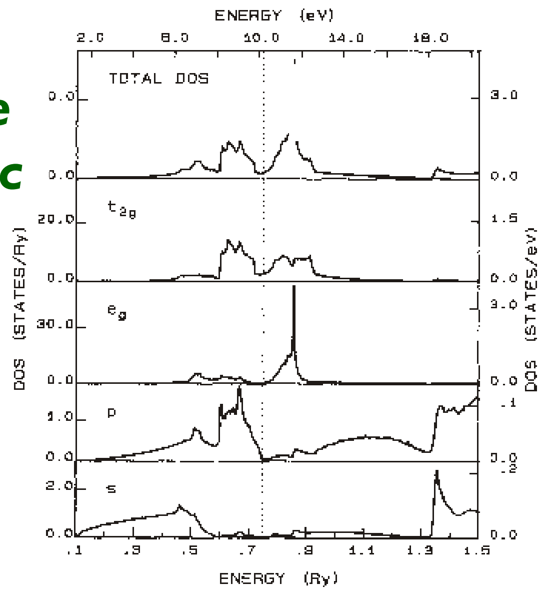
-conductivity in two channels can be very different as described by spin-dependent mean free paths or scattering times

-leads to spin-filtering under certain circumstances

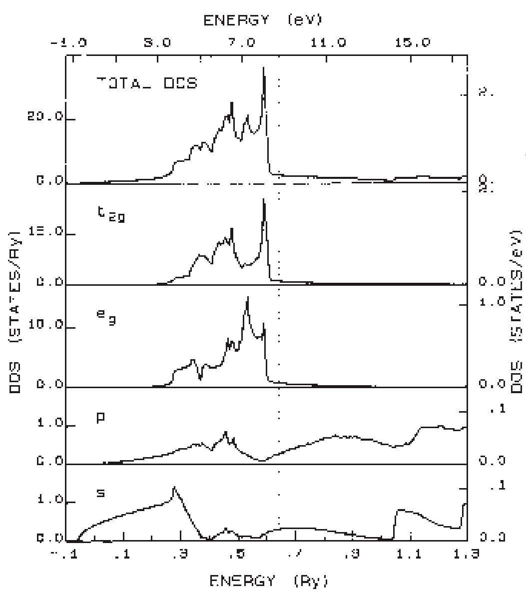
Majority Band vs Minority Band Density of States in 3d Ferromagnets

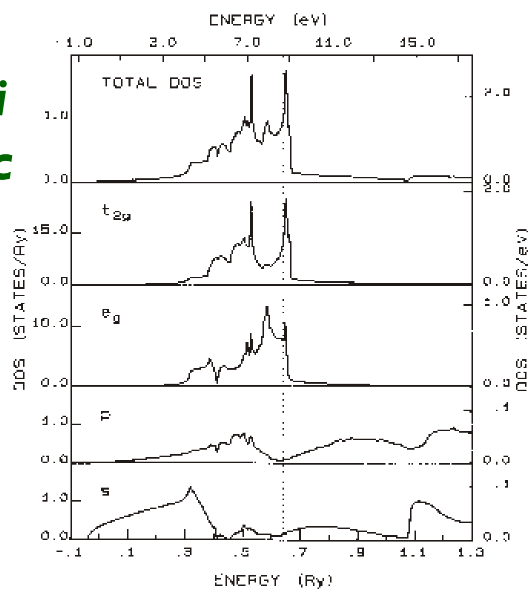
Majority Band N(E)↑   Minority Band N(E)↓





Fe bcc





Ni fcc

$N(E_F)$	↑	↓	↓/↑
Ni(fcc)	2.51	21.28	8.48
Co(hcp)	2.46	9.53	3.87
Fe(bcc)	11.89	3.27	0.28

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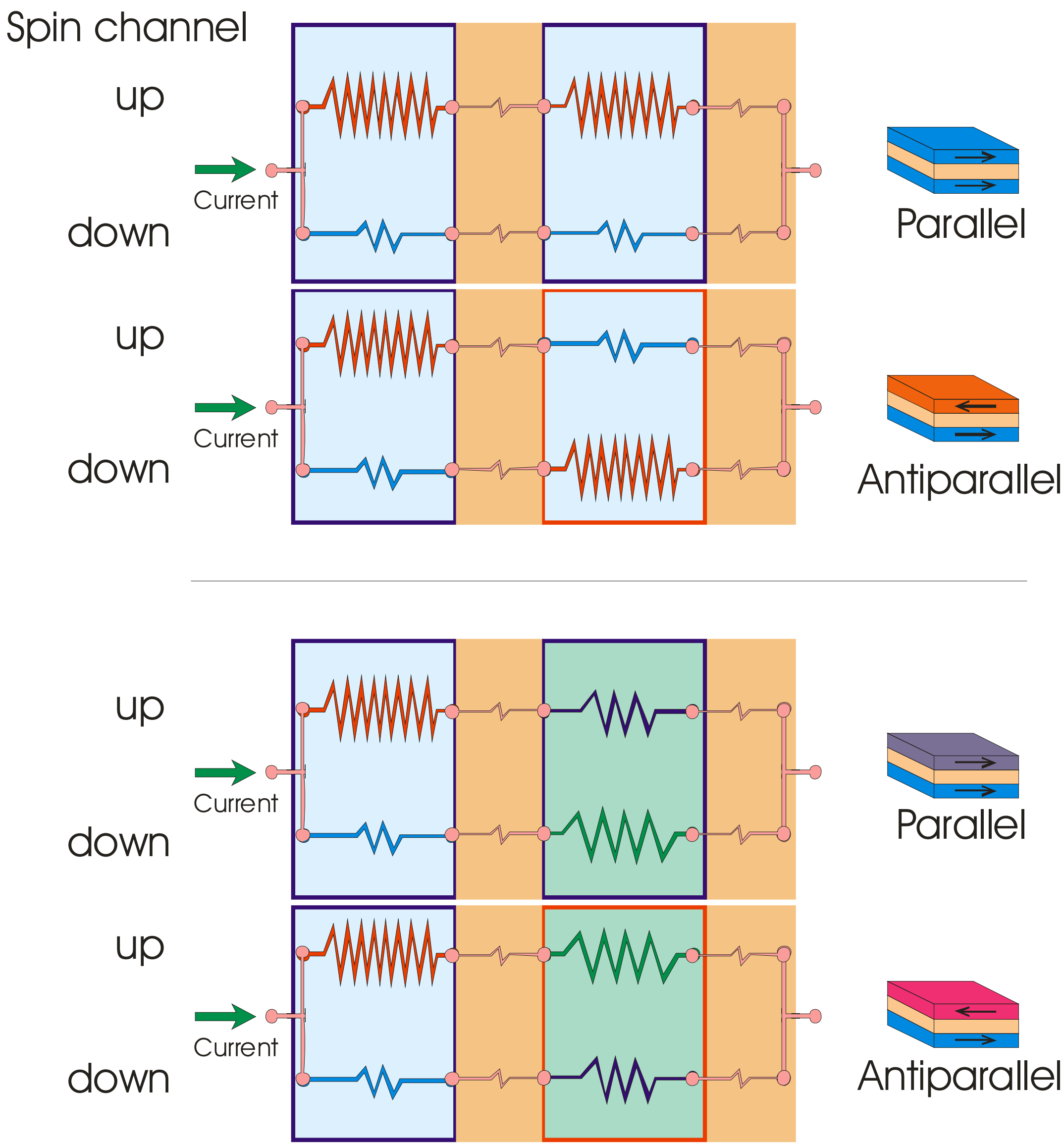
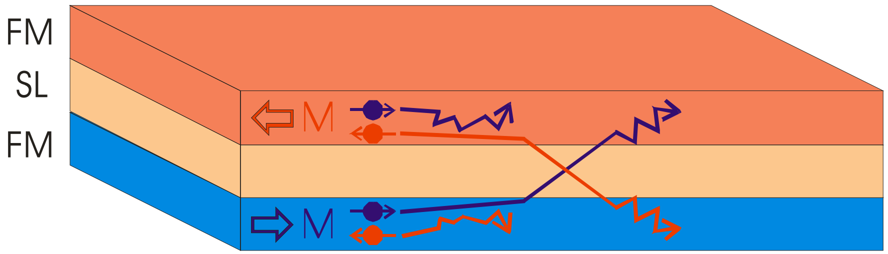
Resistor network model of GMR



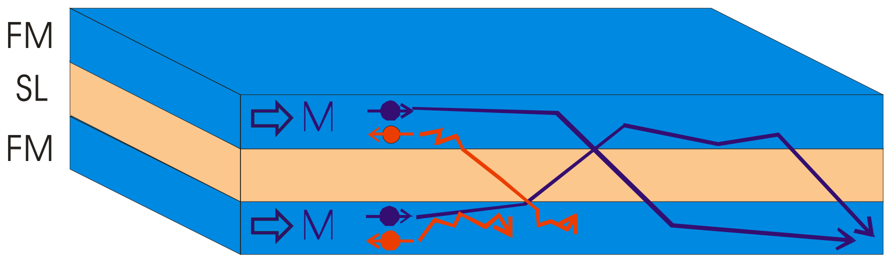
-Basic physics readily understood in two-channel conductivity model

-Many sophisticated models developed but none have much predictive power

Current-in-plane (CIP) GMR



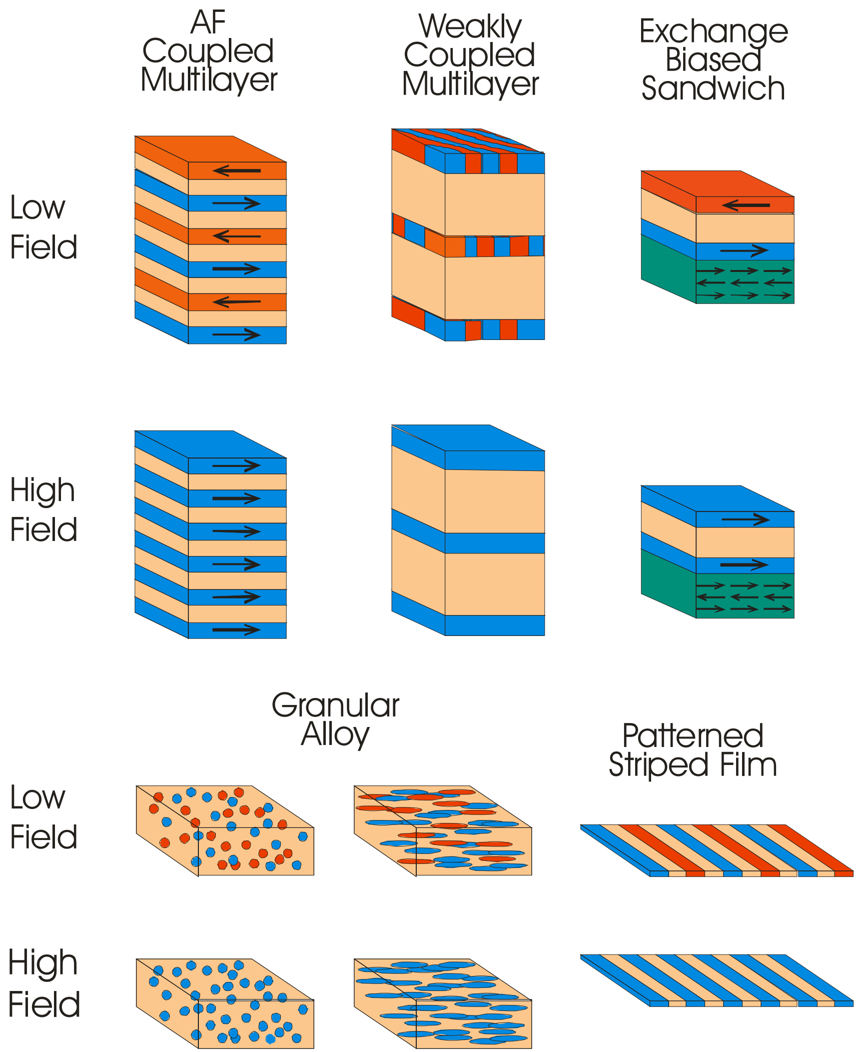
Moments antiparallel: *Higher resistance.*
An electron will have short scattering length in one layer regardless of its spin polarization.



Moments parallel: *Lower resistance.*
One spin polarization of electrons will have have longer scattering length in all layers.

-Short circuit effect in one spin channel
-GMR limited in magnitude by current shunting through non-magnetic layers
-this model assumes bulk spin-dependent scattering but GMR mostly derived from spin-dependent interface scattering

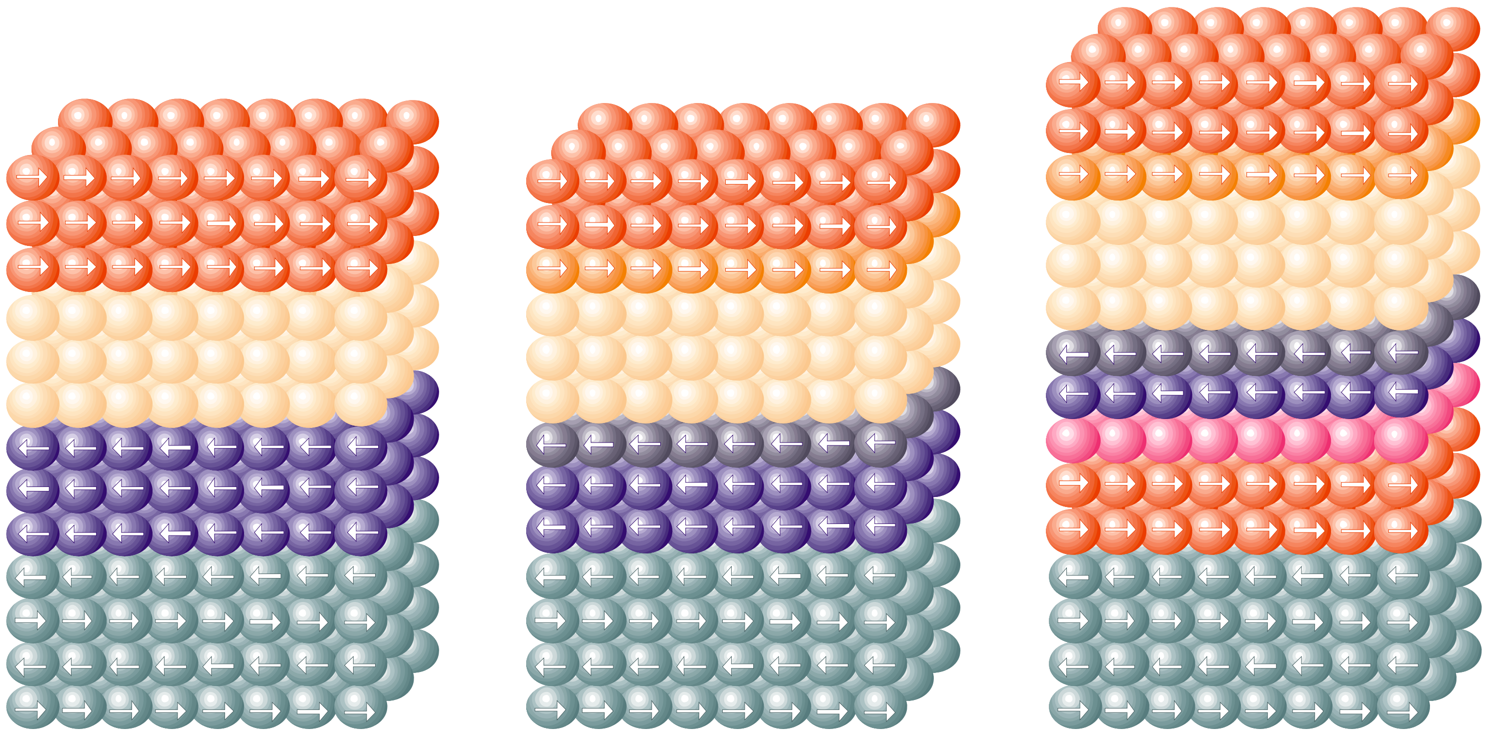
Giant Magnetoresistance in heterogeneous ferromagnets



GMR
-common to almost any heterogeneous ferro or ferri-magnetic system

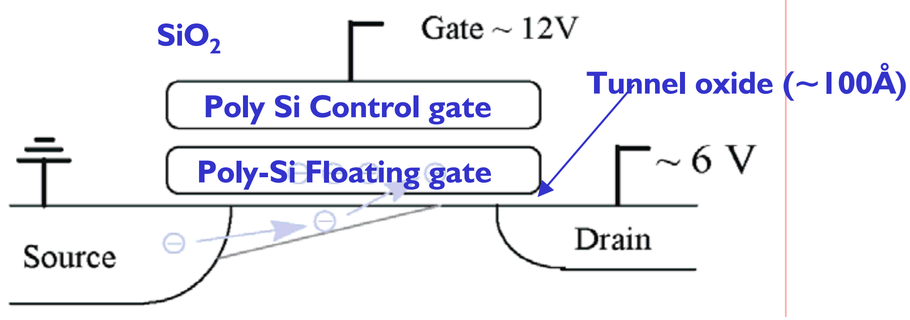
Magnetic Engineering at the Atomic Scale

Spin Valve GMR sensor → **+ interface engineering** → **+ Artificial Antiferromagnet**



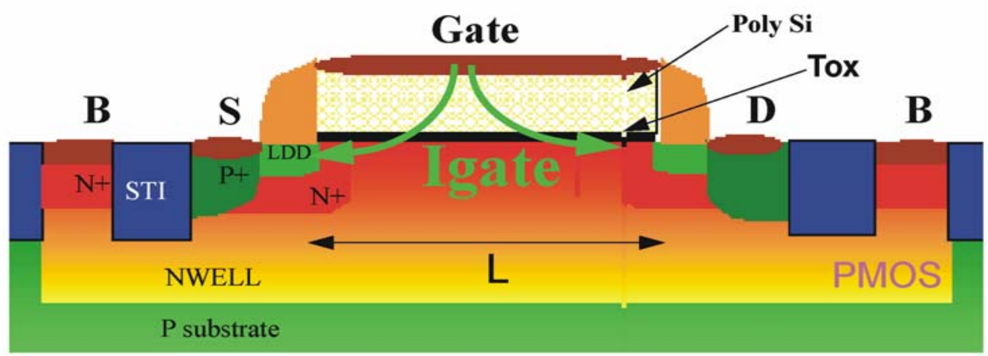
Tunneling today (good and bad)

- Flash
  - Read and write process using tunneling to change state of floating gate.
- Transistors
  - Source of leakage current
  - Significant power consumption in off state
  - Seeking solutions to this problem
- MRAM
  - See lecture 2



Writing a flash bit

Fazio and Bauer, Intel Technology Journal (1997)



Gate leakage in transistor

Rideau, STMicroelectronics