

Giant Magnetoresistance

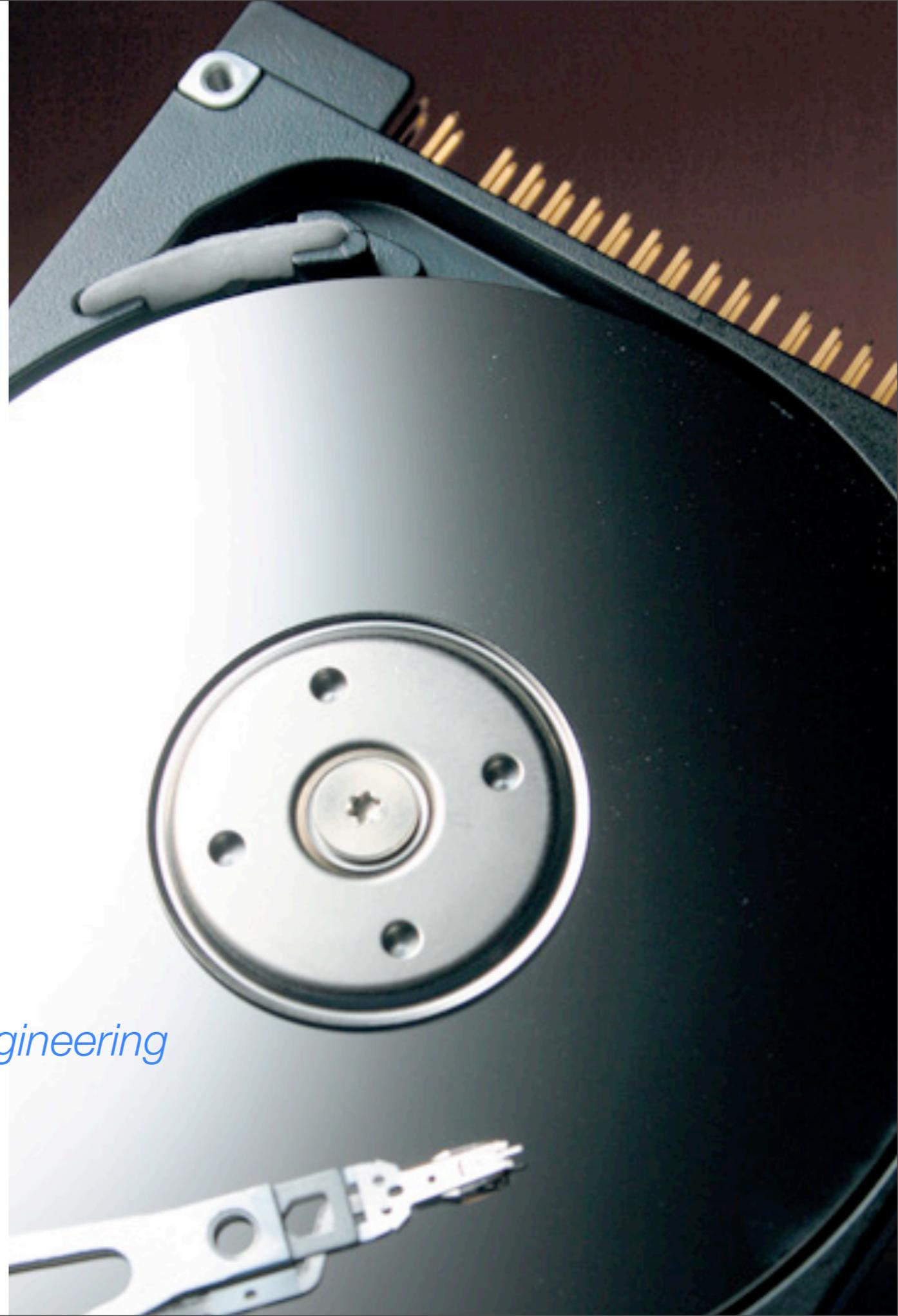
03/18/2010

Instructor: Dr. Elbio R. Dagotto

Class: Solid State Physics 2

Nozomi Shirato

Department of Materials Science and Engineering



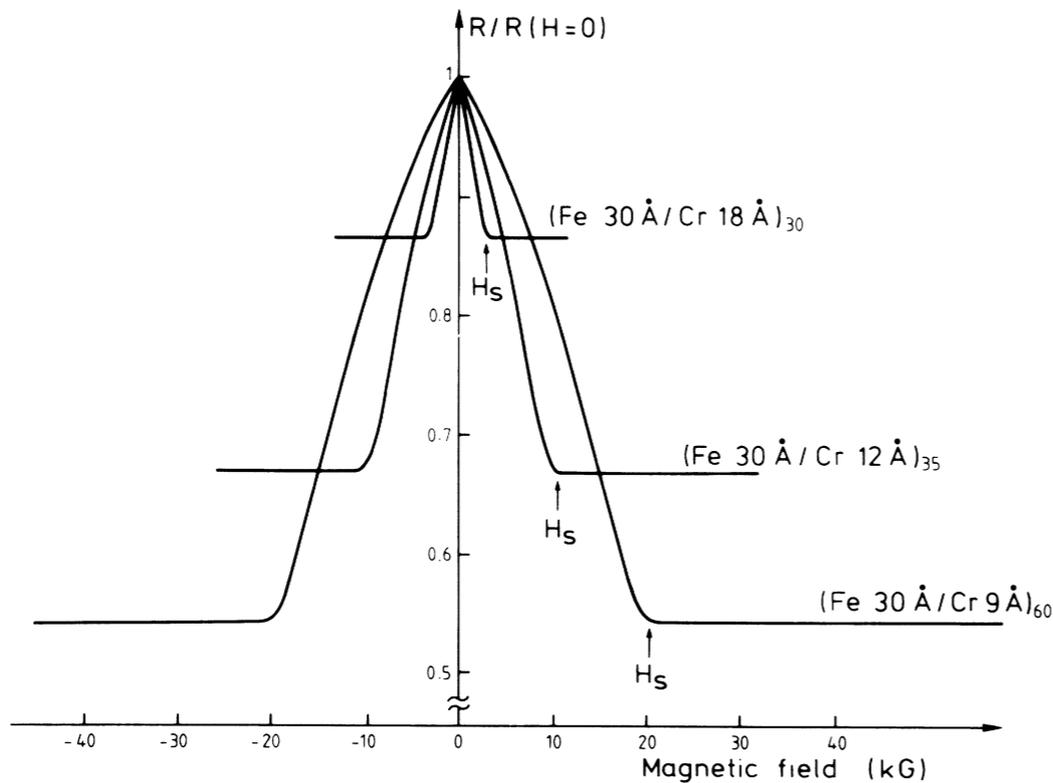
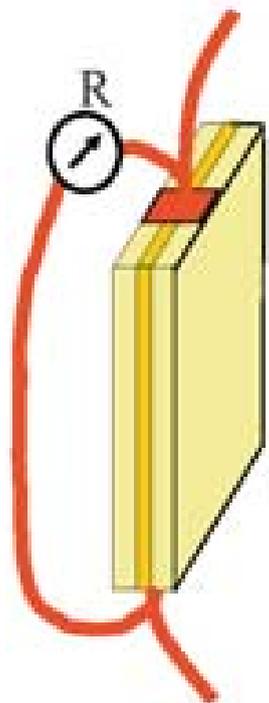
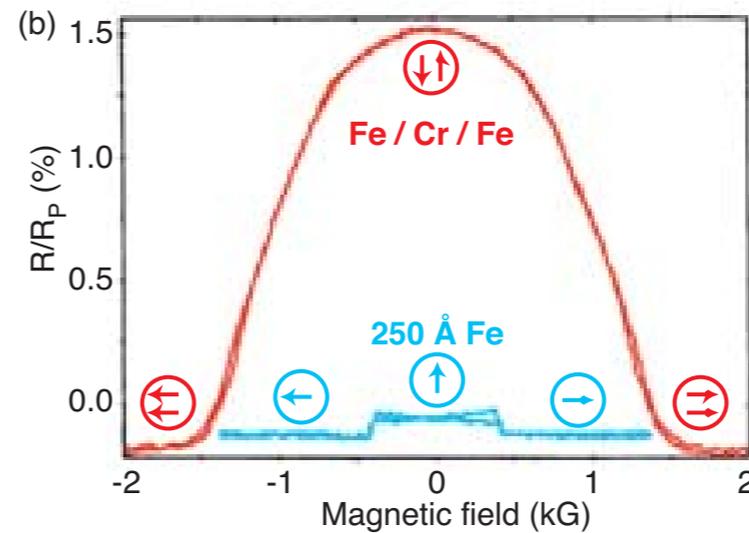
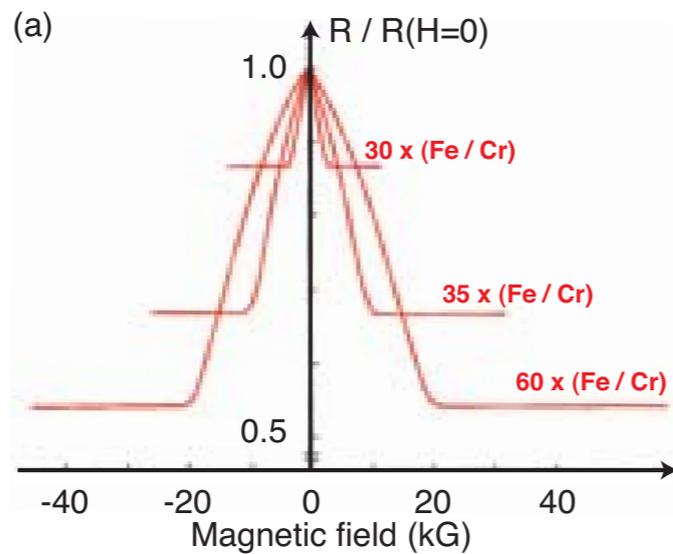
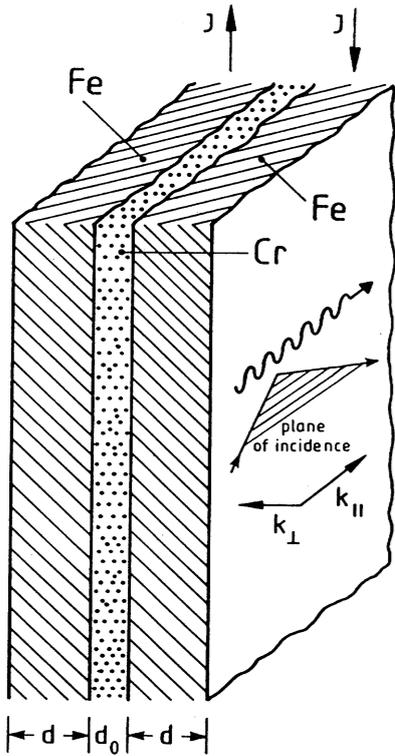
Contents: Giant Magnetoresistance (GMR)

- Discovery of **GMR**
- Physics of **GMR**
- Applications and Impacts of **GMR**
- Summary



Discovery of **GMR**: Grunberg & Fert

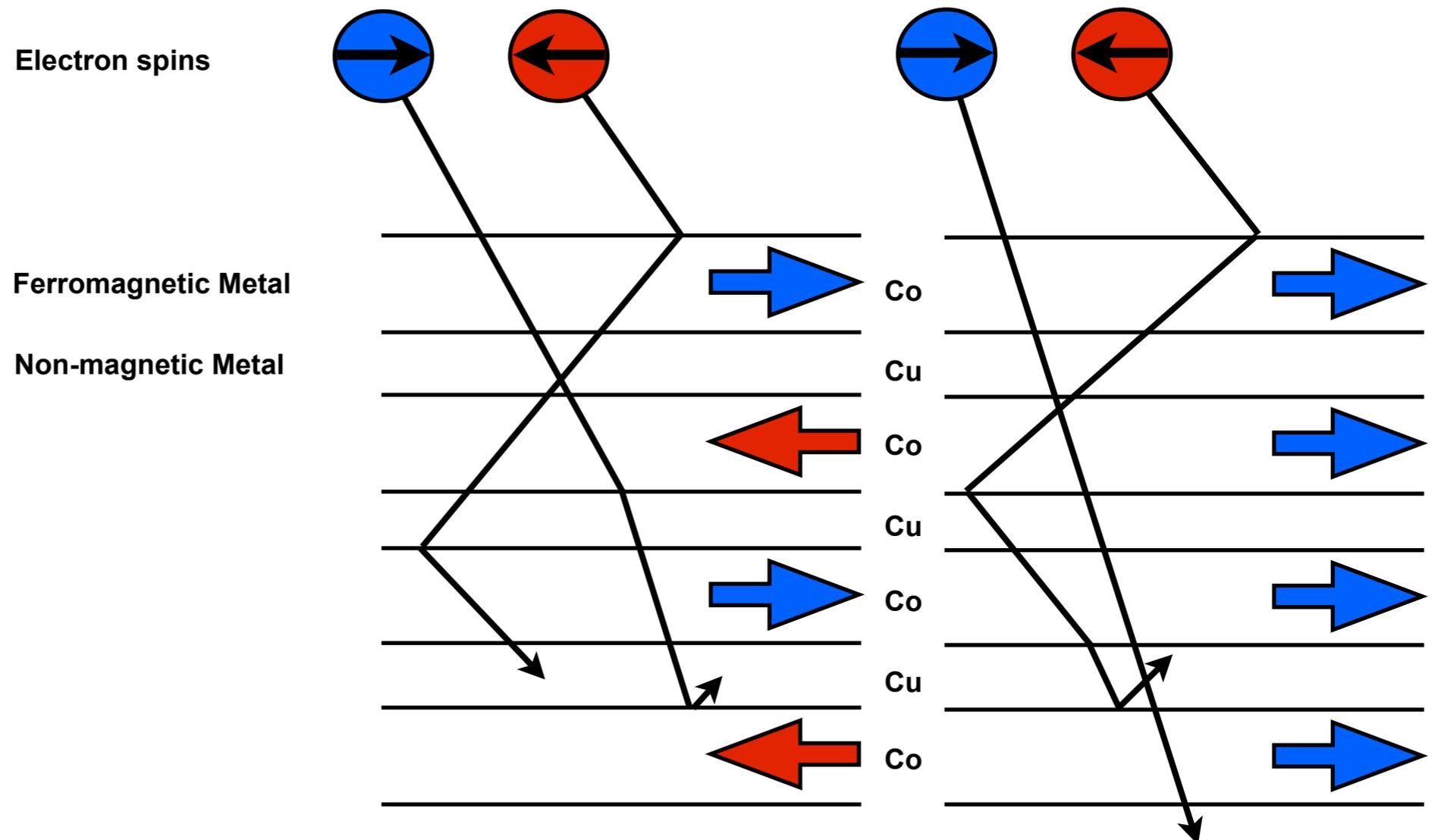
The Nobel Prize of Physics in 2007
"for the discovery of Giant Magnetoresistance"



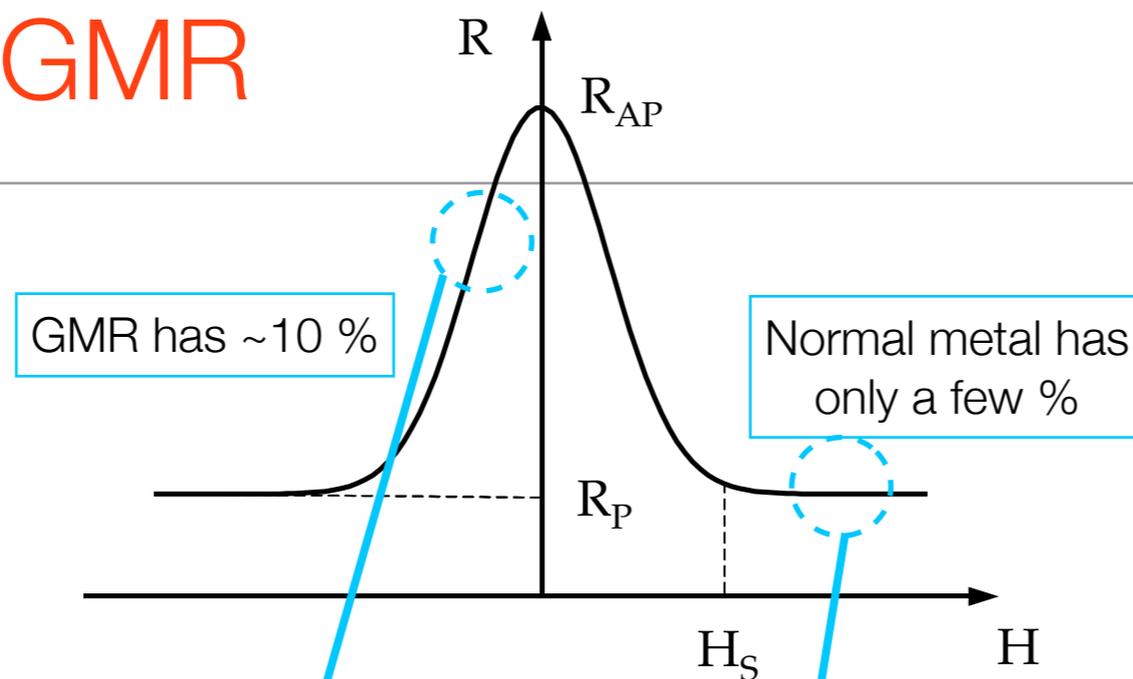
- Magnetoresistance
- **MR: ~0.1 %**
- **GMR: 3~50 %**

Physics of GMR

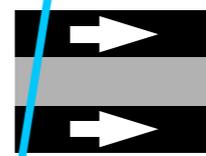
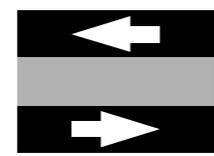
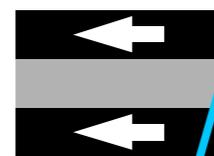
- The splitting between the energies of the “majority spin” [spin up] and “minority spin” [spin down] directions are in different states for opposite spin directions and exhibit different conduction properties. Introduced by Mott in 1936.



Physics of GMR



Tsymbal and Pettifor, Academic Press (2001)

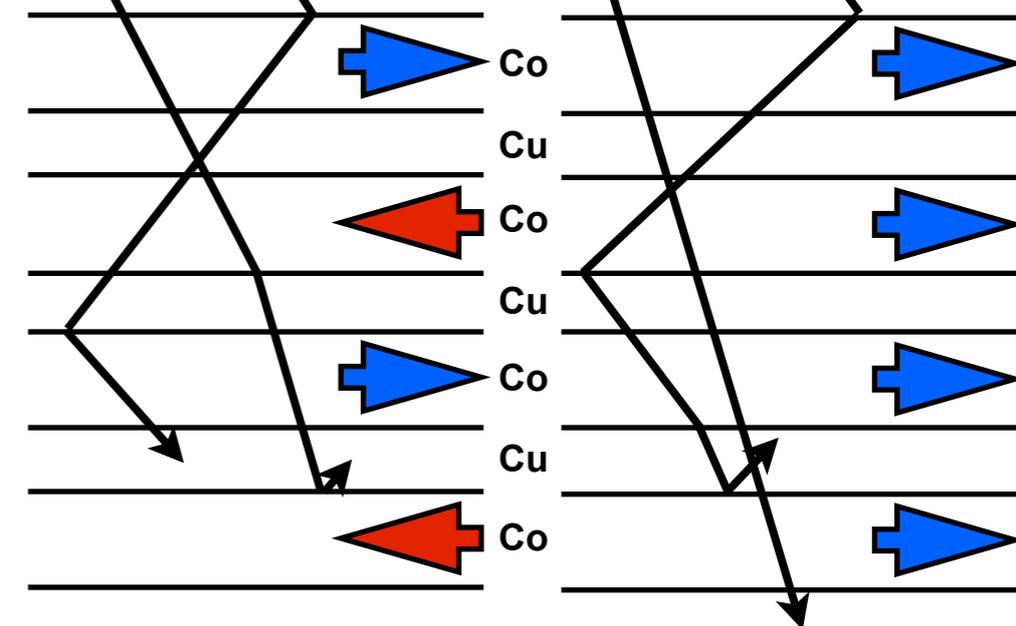


Electron

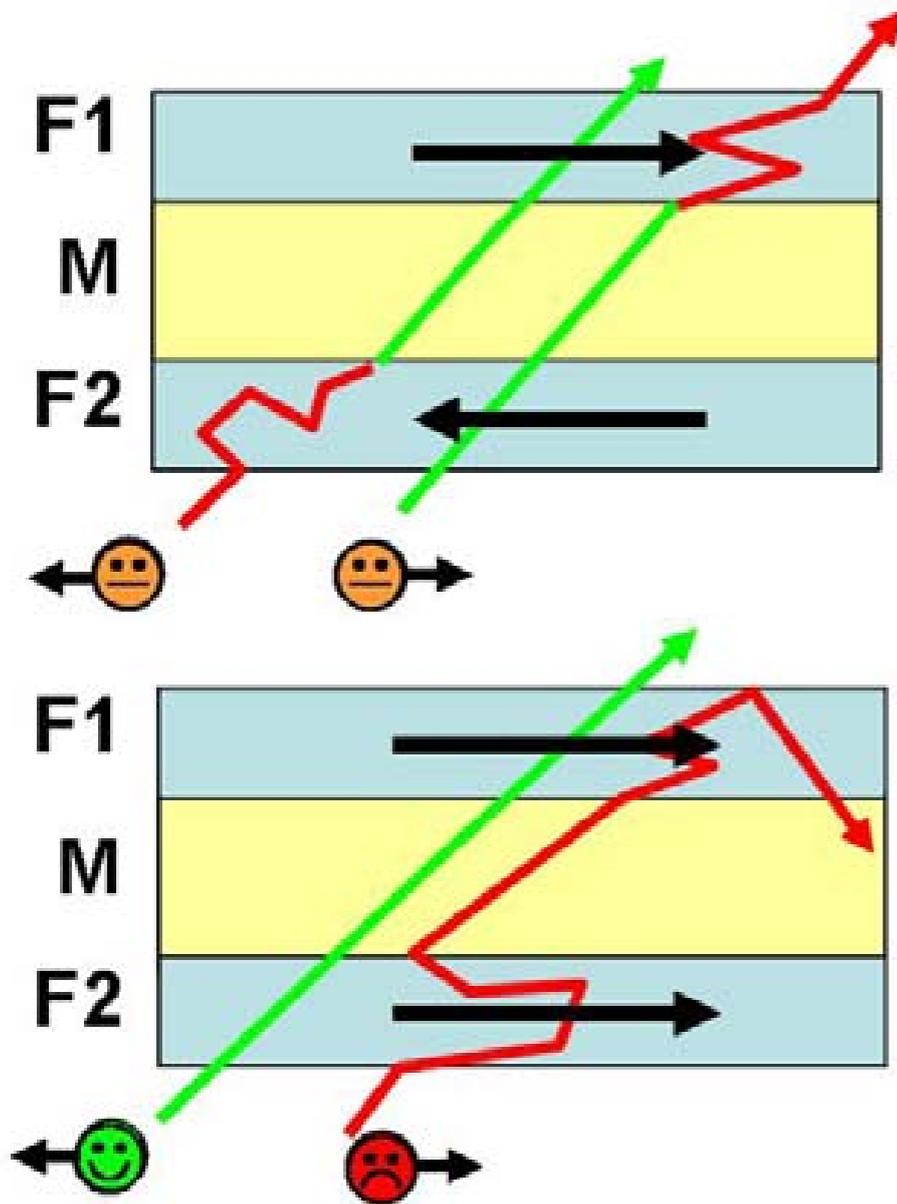


Ferromagnetic Metal

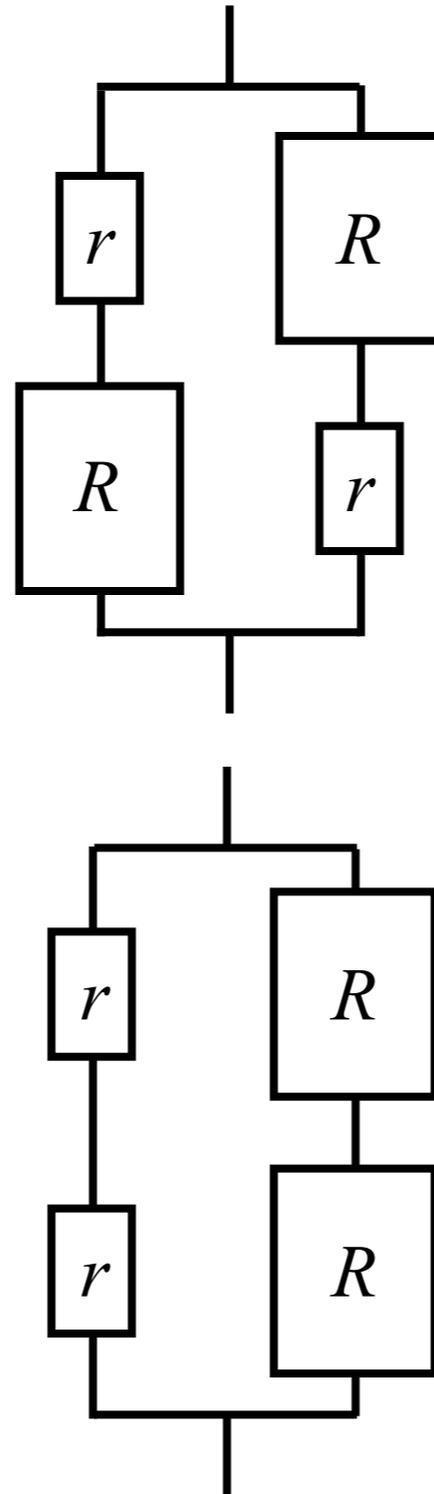
Non-magnetic Metal



Physics of GMR



Chappert et al., Nature Mat. (2007)



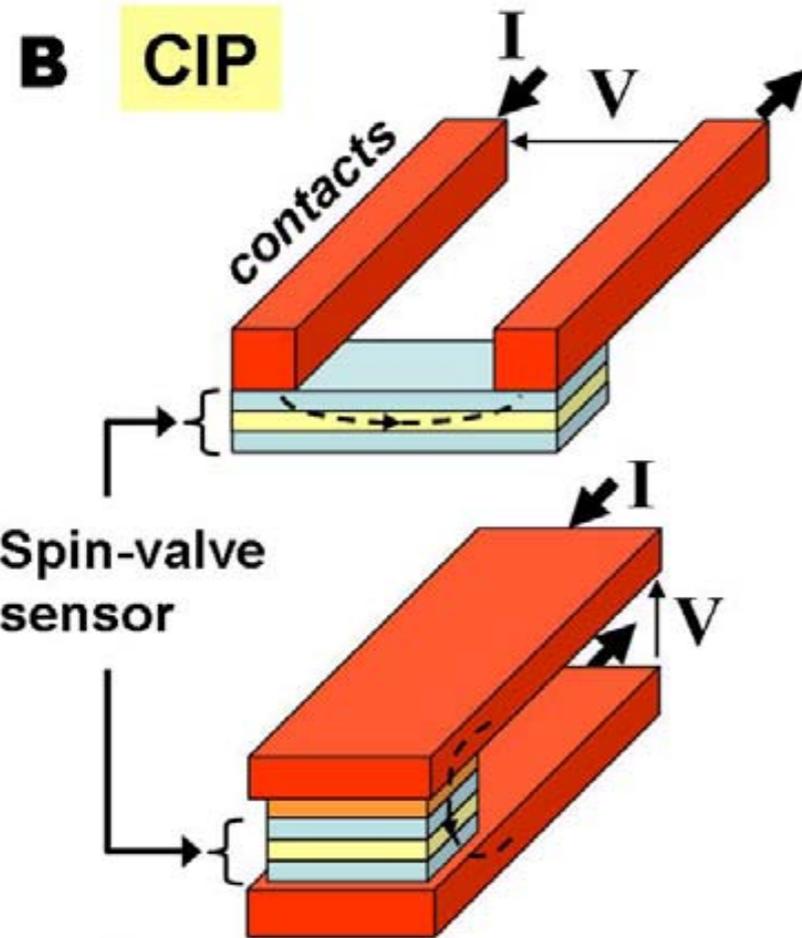
$$R_{AP} = N \frac{r+R}{2}$$

$$\frac{\Delta R}{R} = \frac{R_{AP} - R_P}{R_P} = \frac{(r - R)^2}{4rR}$$

Relative magnetoresistance

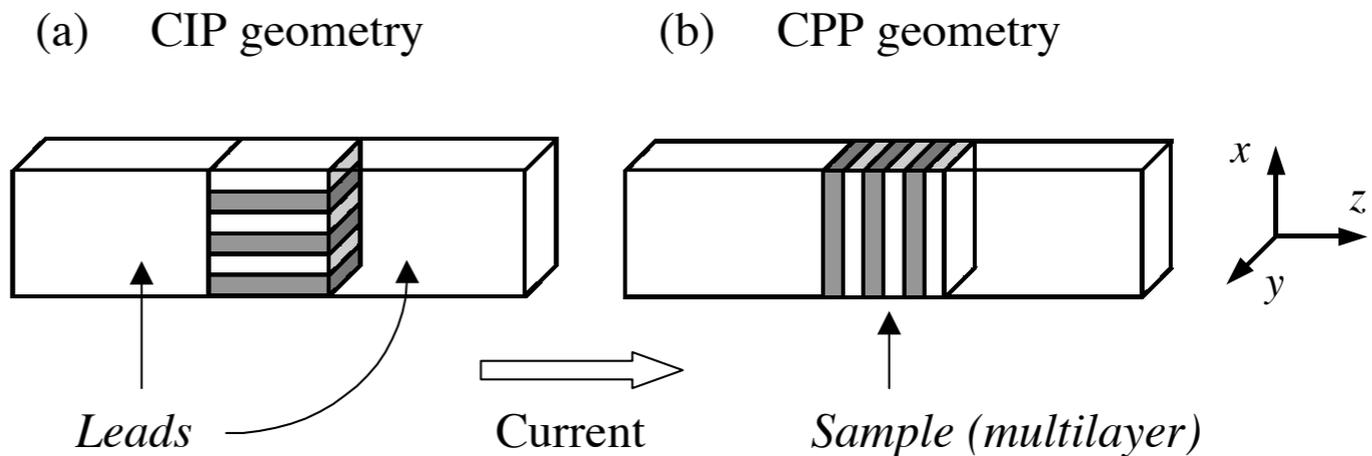
$$R_P = N \frac{rR}{r+R}$$

Geometry of GMR



C CPP

Chappert et al., Nature Mat. (2007)



Tsymbol and Pettifor, Academic Press (2001)

- CIP: In 1988. General GMR geometry. It has been used for HDD head.
- CPP: In 1993. Sandwiching magnetic multilayer between superconducting electrodes. GMR is higher than CIP because of spin accumulation effects at magnetic/non-magnetic

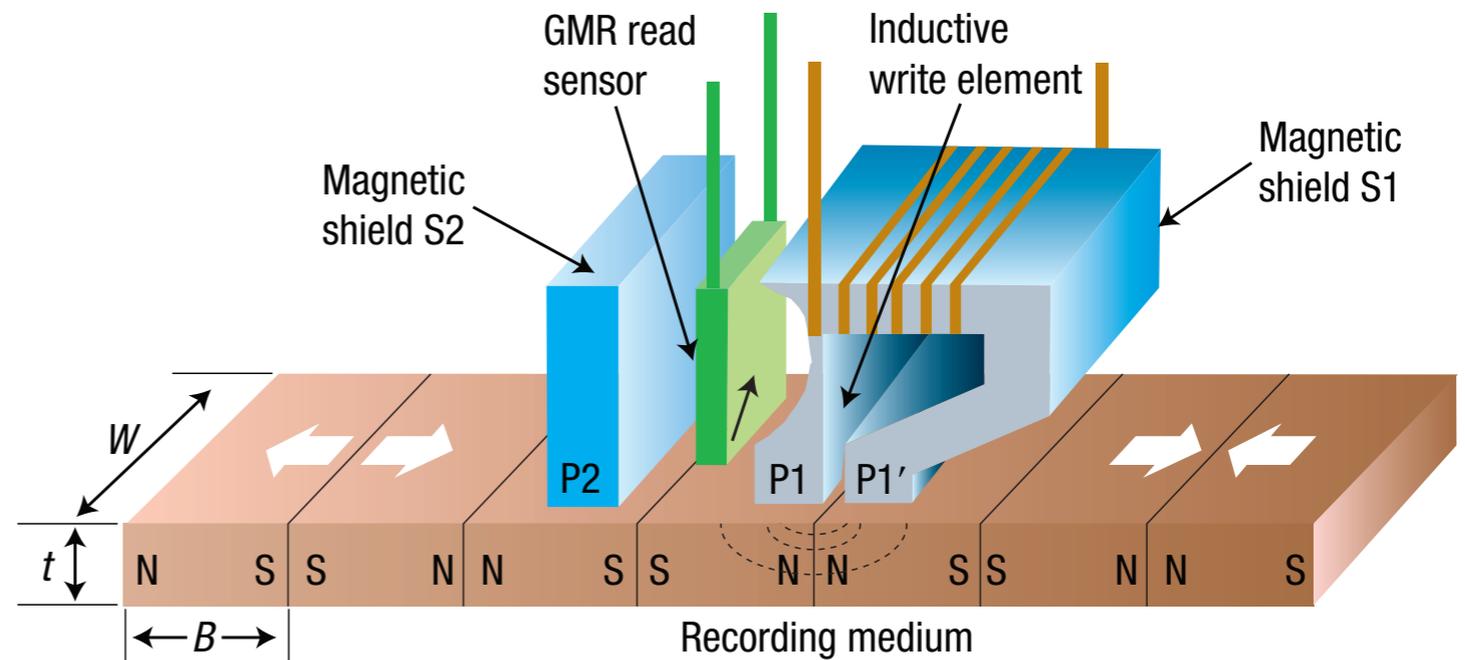
Applications of GMR: HDD Head

~ 1 Gbit/inch² => ~15 Gbit/inch² => ~100 Gbit/inch²
(~1992) (~ 2001) (~ 2003)

↑
GMR

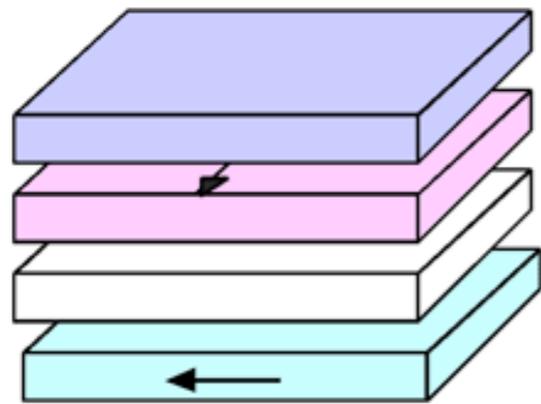
↑
Tunneling magnetoresistance (TMR)
Spin-Valve

- As the raw HDD areal recording density increase, the size and the magnetic strength of each bit gets reduced.
--> The reading head needs to give the large change of the magnetoresistance with the small magnetic moment



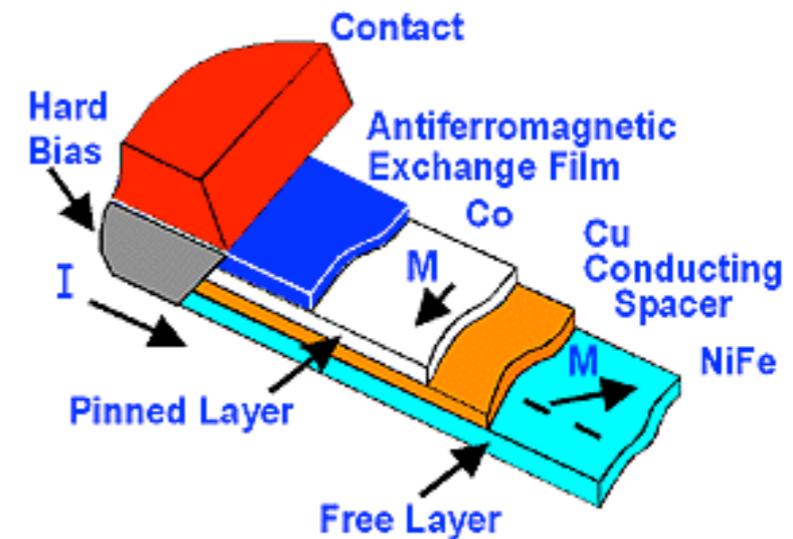
Chappert et al., Nature Mat. (2007)

Spin-Valve Head



Anti-ferromagnetic Exchange Layer
Pinned Ferromagnetic Layer
Conducting Spacer Layer
Free Layer

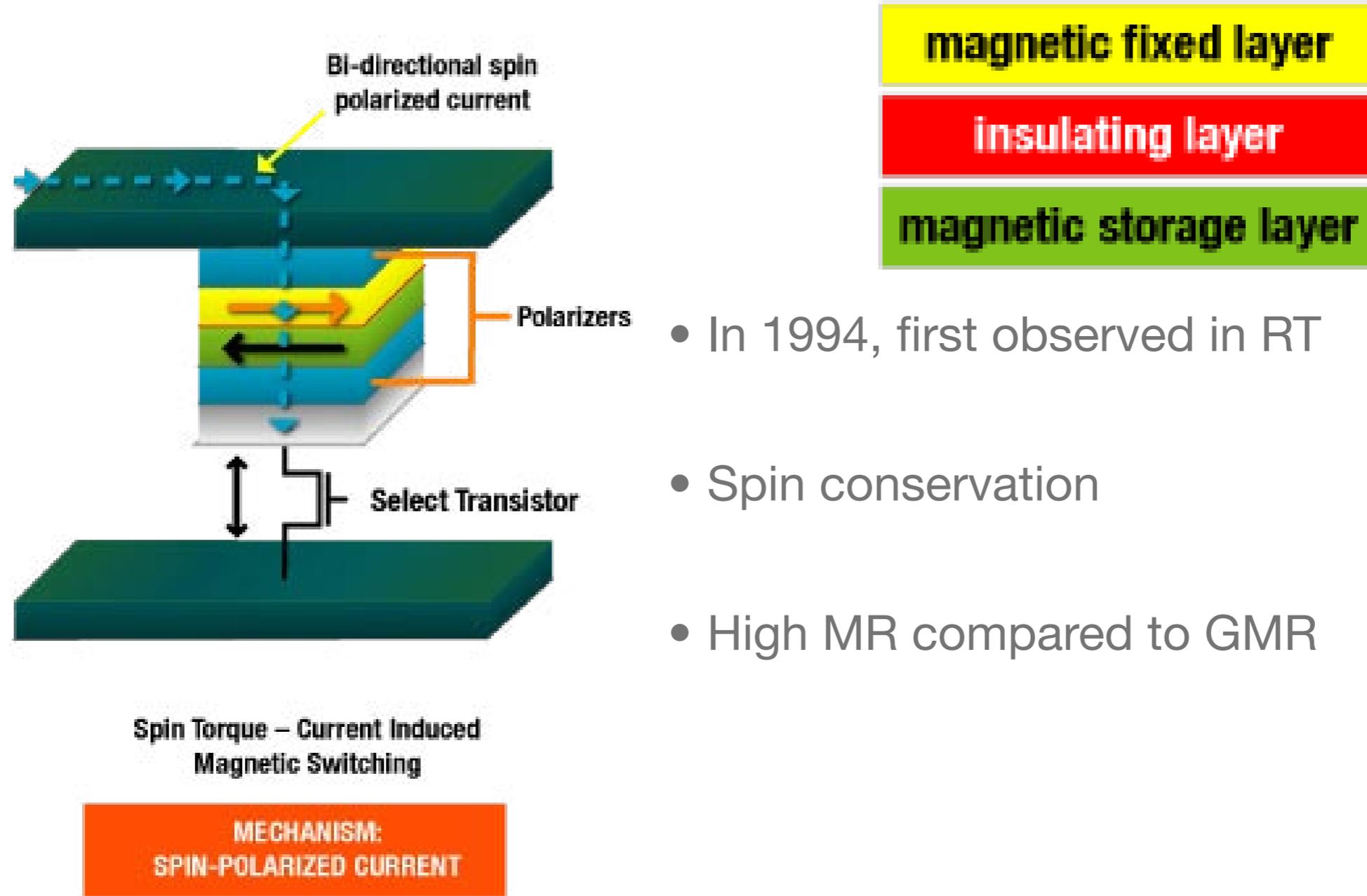
S \longleftrightarrow N



Hitachi, Corp.

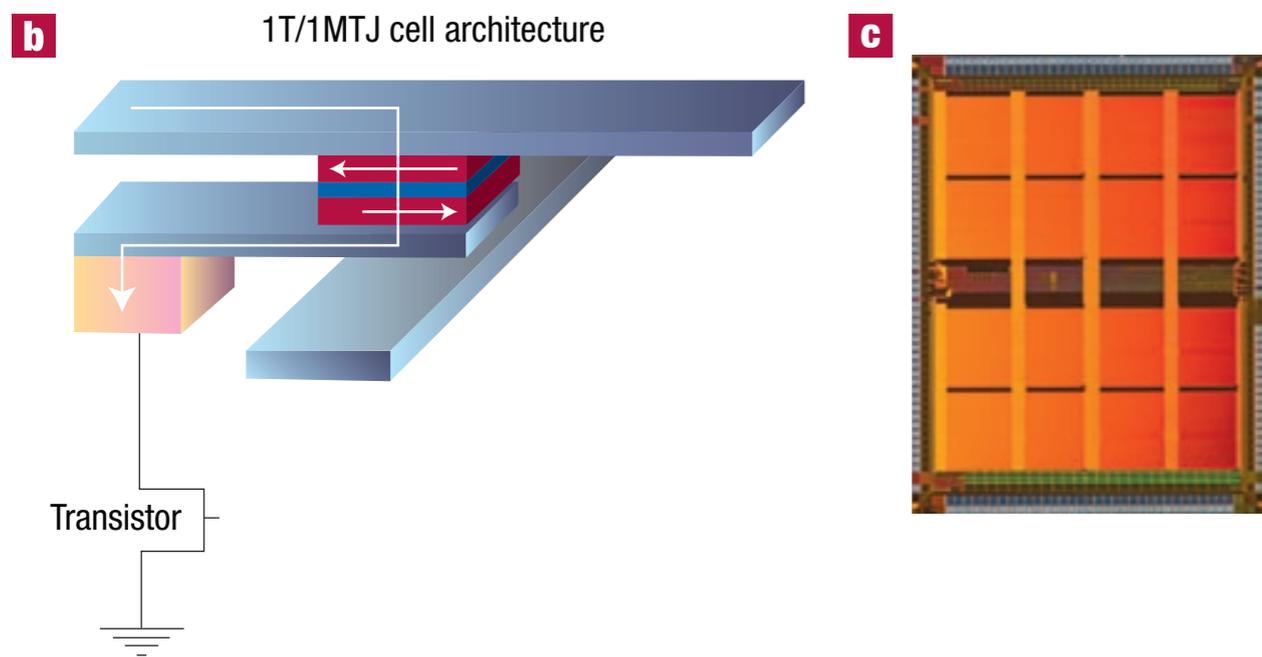
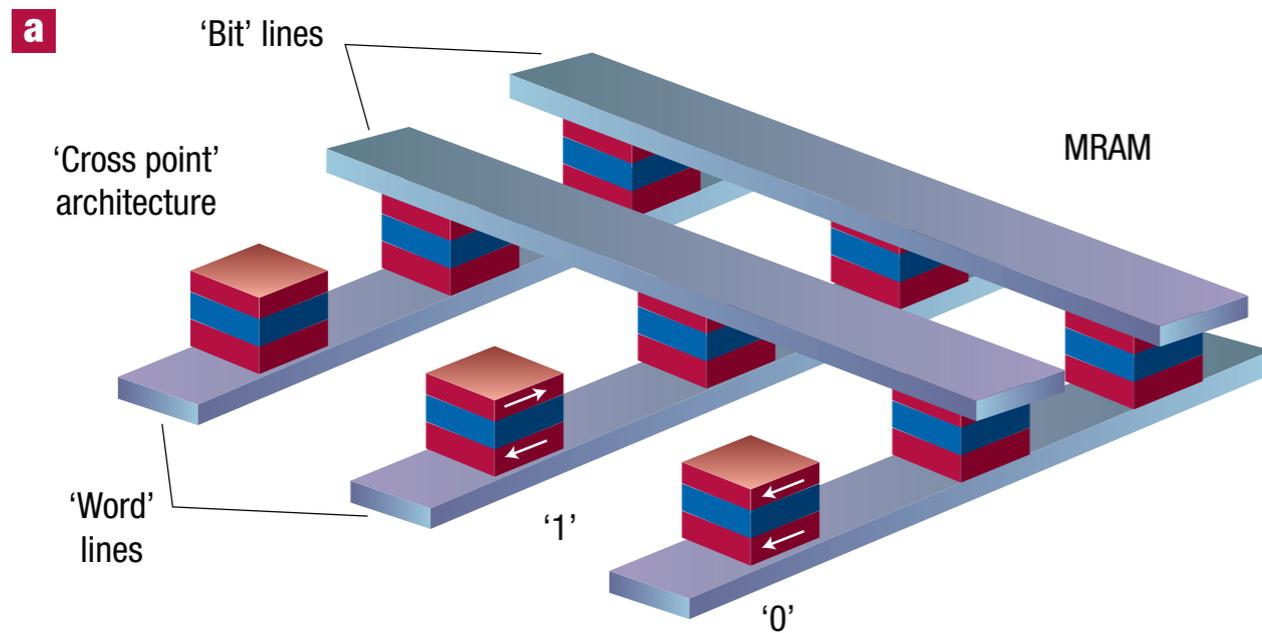
GMR head has the spin-valve mechanism. The top ferromagnetic layer is pinned by the attached AF layer. The bottom ferromagnetic layer is free to rotate by the applied magnetic field.

Tunneling Magnetoresistance (TMR)



- In 1994, first observed in RT
- Spin conservation
- High MR compared to GMR

MRAM (Magnetic Random Access Memory)



- Non-volatility, infinite endurance and fast random access (down to 5 ns read/write time)
- MgO based MTJ (Magnetic Tunnel Junction) using TMR (Tunnel Magnetoresistance) effect
- TMR ratios up to 1800% at low T, 500% at RT

Summary

- Technologies depending on GMR brought huge impact on the mass data storage.
- GMR, Spin-Valve and TMR led to increase areal recording density by three orders of magnitude within 10 years.
- MRAM is potential candidate for becoming the ‘universal memory’

