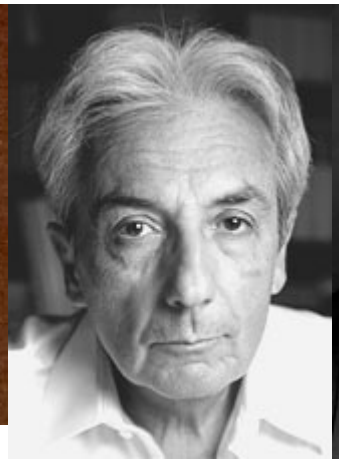
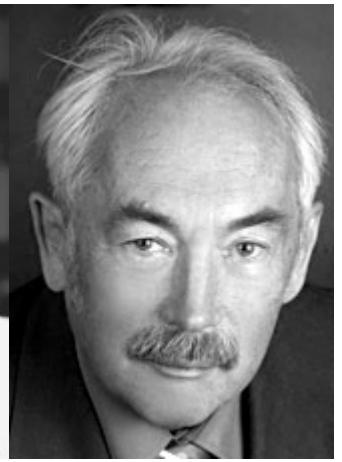




Nobel Prizes in Physics 2007

J.S. Tsay
Department of Physics, National Taiwan Normal University, Taipei

24, Oct. 2007

國立臺灣師範大學物理學系 書報討論演講

The Nobel Prize in Physics 2007

"for the discovery of Giant Magnetoresistance"

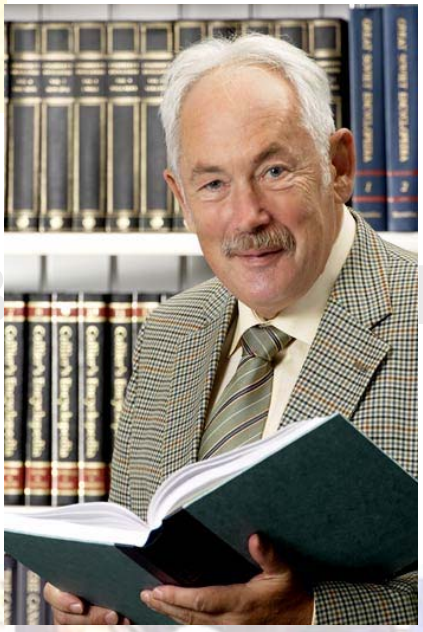
Albert Fert

1/2 of the prize

France

Université Paris-Sud; Unité Mixte de Physique CNRS/THALES, Orsay, France

b. 1938



Peter Grünberg

1/2 of the prize

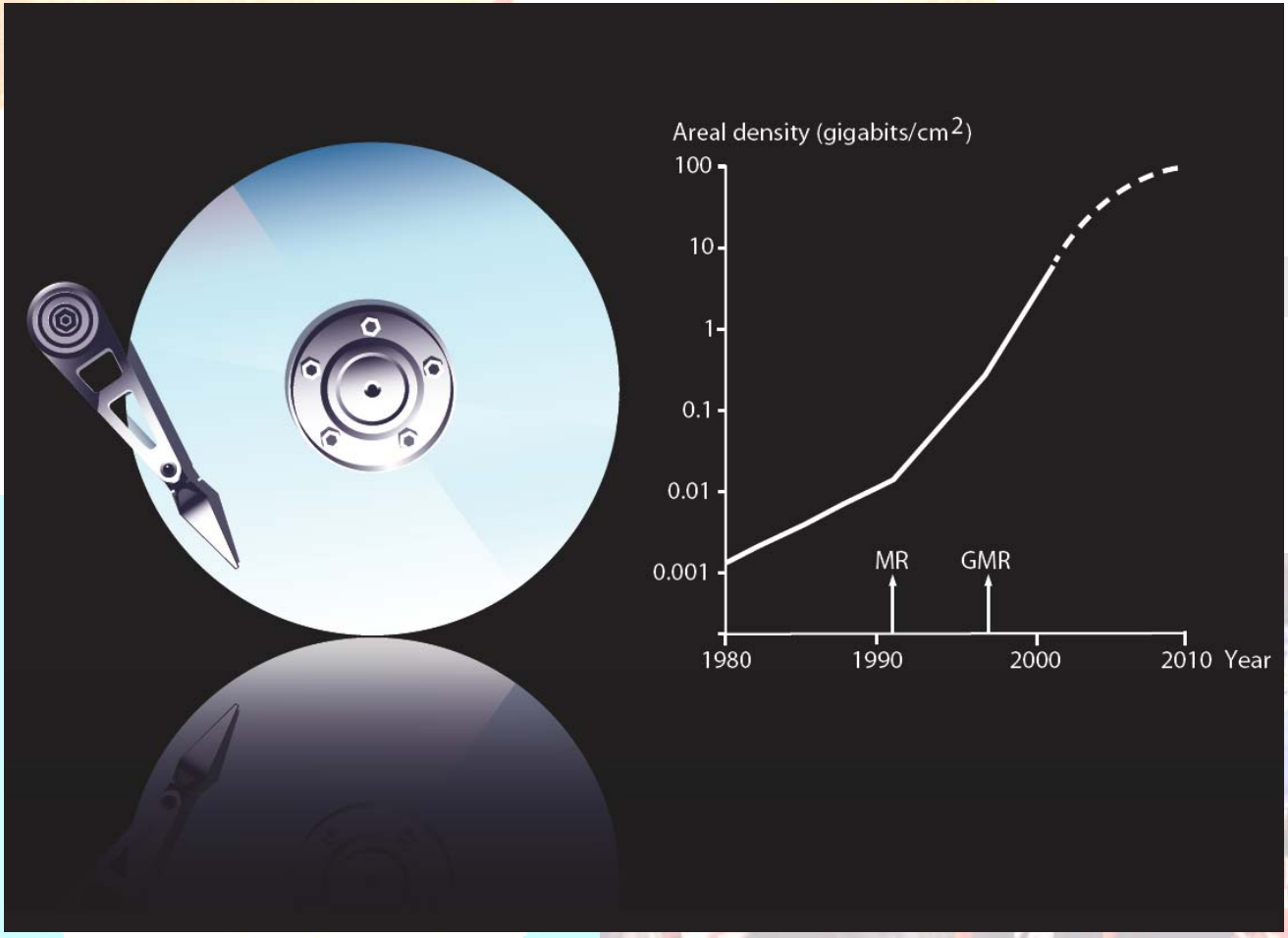
Germany

Forschungszentrum Jülich
Jülich, Germany

b. 1939

The Giant within Small Devices

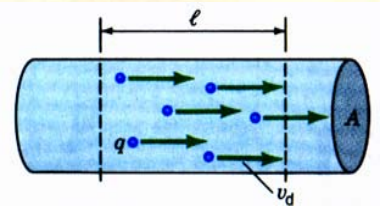
Better read-out heads for pocket-size devices

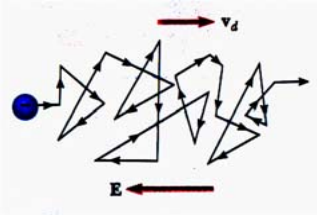


One of the first major applications of the nanotechnology.

The resistance

Microscopic model of current

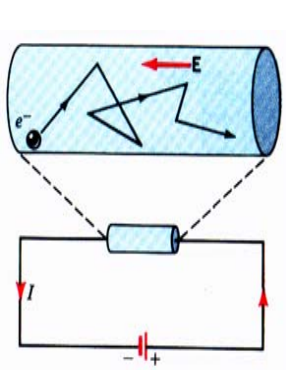


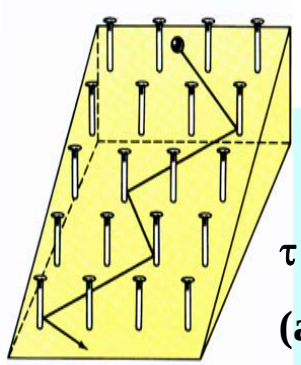


v_d : drift velocity

$$I = n q A v_d$$

if $\vec{v}_d \propto \vec{E}$ ⇒ $\vec{J} = \sigma \vec{E}$ ⇒ $R = \frac{\ell}{\sigma A} = \rho \frac{\ell}{A}$





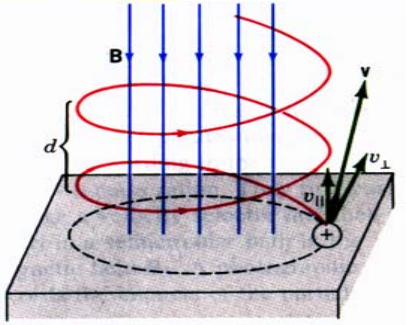
$$v_d = \frac{qE\tau}{m} \Rightarrow \sigma = \frac{nq^2\tau}{m}$$

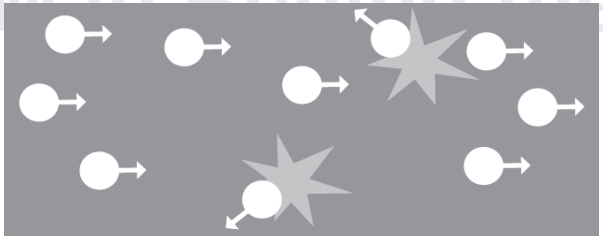
τ : relaxation time

(average time between collision)

Magnetoresistance - MR

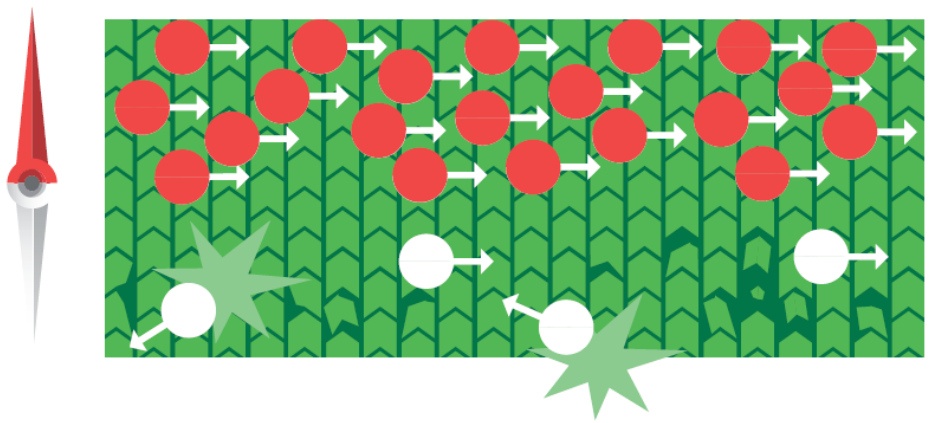
Magnetic field → τ decrease
because # of collisions increases



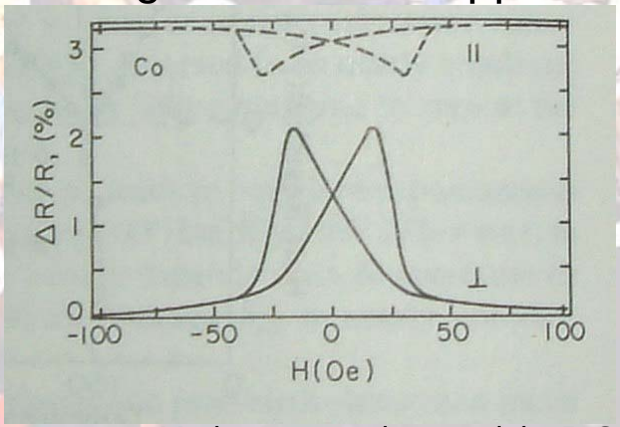


Anisotropic magnetoresistance - AMR

In **magnetic materials**, scattering of electrons is influenced by the direction of magnetization



In 1857, the British physicist **Lord Kelvin** had already published an article showing that the resistance diminishes **along** the lines of magnetization when a magnetic field is applied to a magnetic conductor. If the magnetic field is applied **across** the conductor the resistance increases instead.



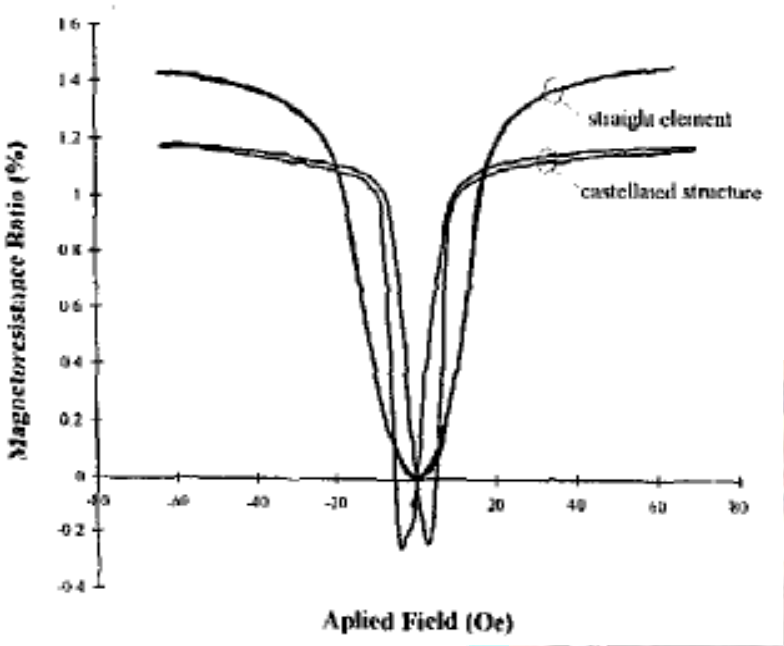
Cobalt films

Modern magnetic materials, R.C. O'Handley, John Wiley & Sons, New York, 2000.

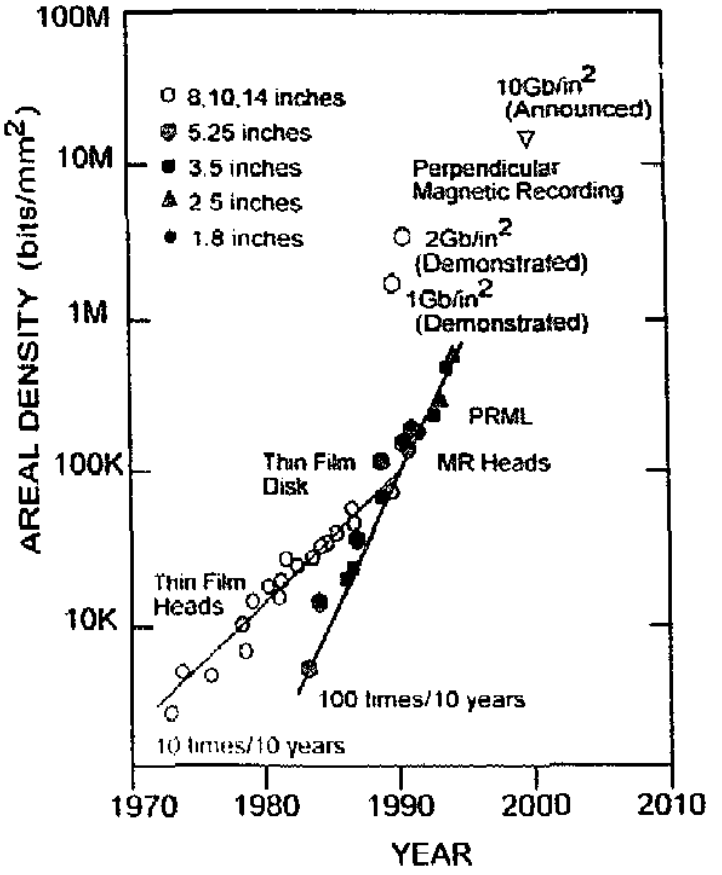
Anisotropic magnetoresistance - AMR

140 years after Lord Kelvin: in industry

Typical MR ratio at/until 1997.



Predication of areal density of HD



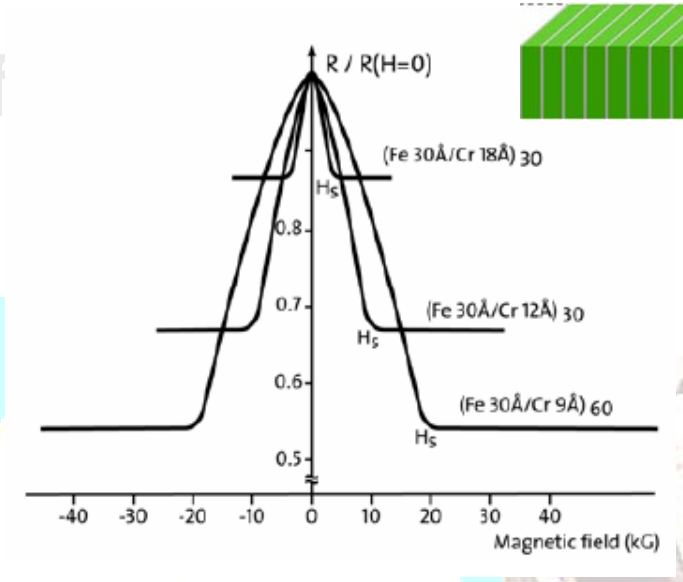
Sensor and Actuators A 59 (l997) 9.

Giant magnetoresistance - GMR

The birth of GMR (1988):

Albert Fert

$(Fe/Cr)_n$ multilayer, 4.2 K

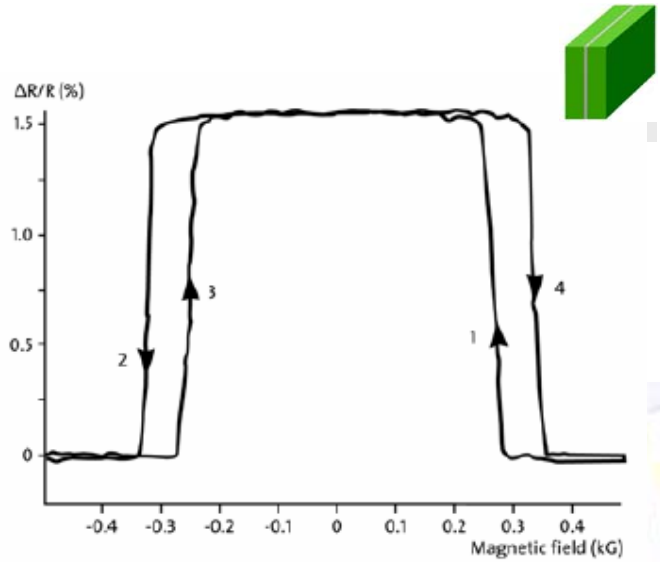


MR ratio: few % → 50 %

Fert named the **GMR** for this multilayer

Peter Grünberg

Fe/Cr/Fe trilayer, RT



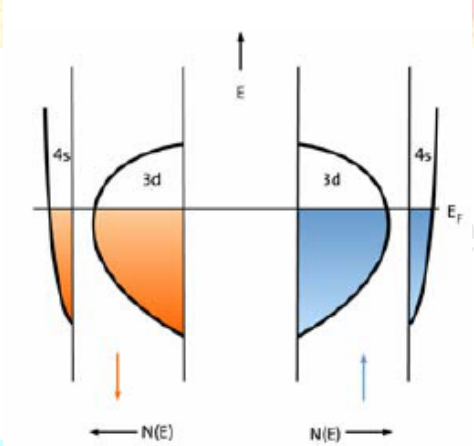
Nm-thickness is enough for few % MR.

Grünberg **patent**ed GMR.

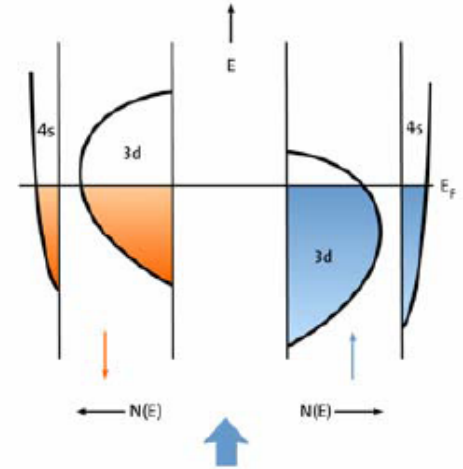
GMR - background

Ferromagnetic metals

non-magnetic state



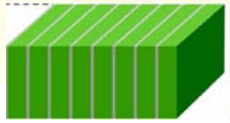
ferromagnetic state

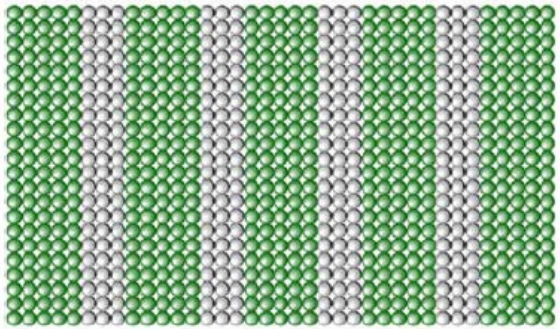


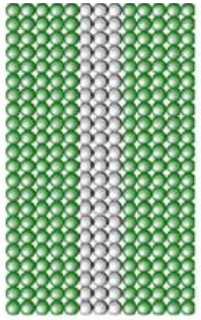
spin polarization, $P = (N\uparrow - N\downarrow)/(N\uparrow + N\downarrow)$,

GMR - background

Growth of superlattices





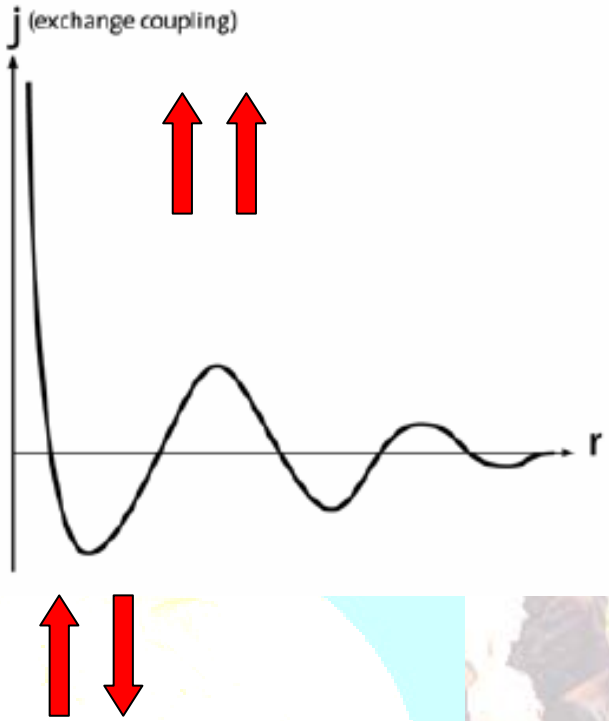


High quality specimen: by MBE method.

Surface science technique: interface control.

GMR - background

Interlayer coupling



Majkrzak reported an anti-parallell magnetic moment alignment Gd/Y/Gd in 1986.

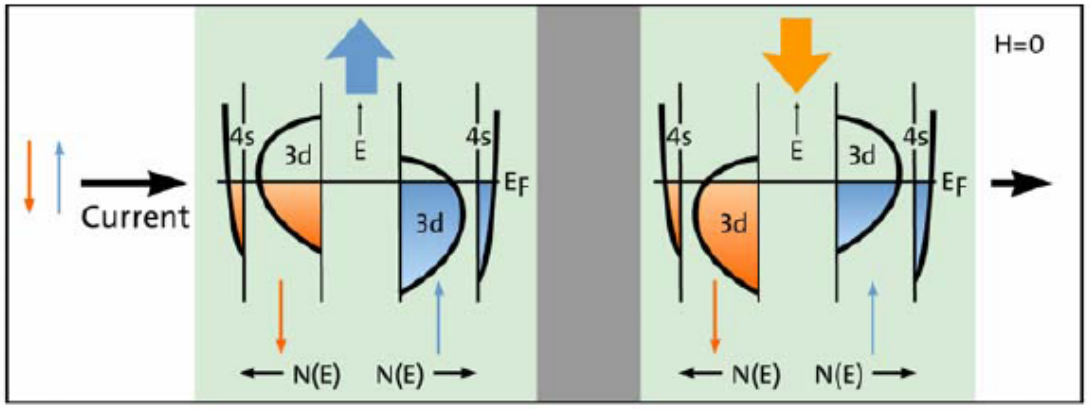
Grünberg reported an anti-parallell magnetic moment alignment Fe/Cr/Fe in 1986.

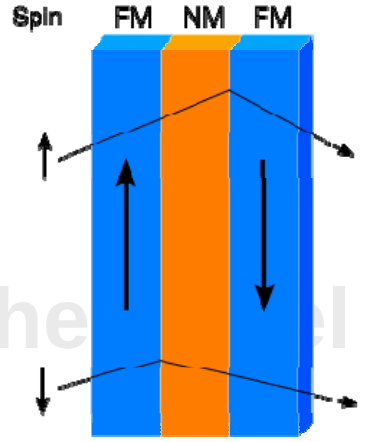
C.F. Majkrzak, et al, Phys. Rev. Lett. **56**, 2700 (1986).

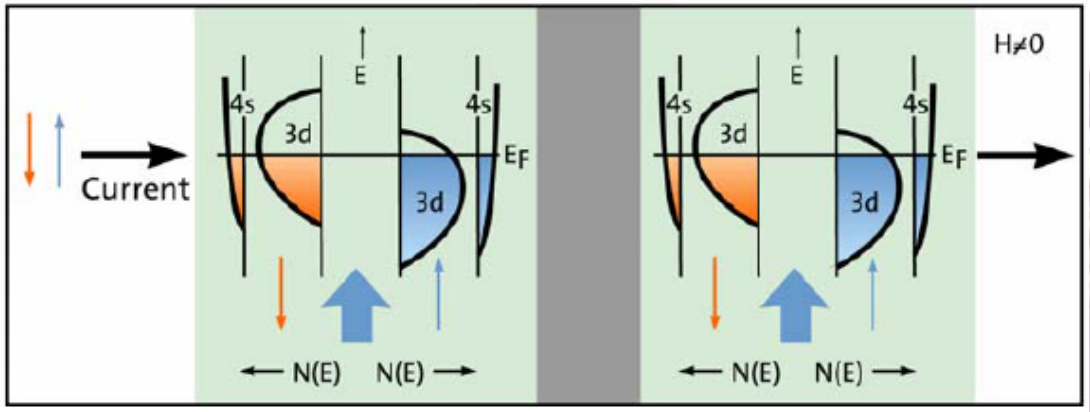
P. Grünberg, et al, Phys. Rev. Lett. **57**, 2442 (1986).

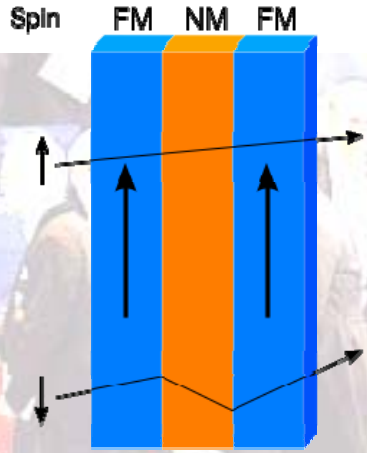
GMR

GMR effect:



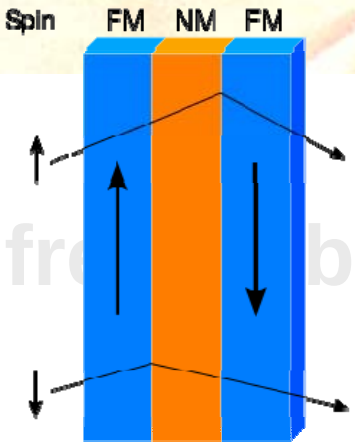


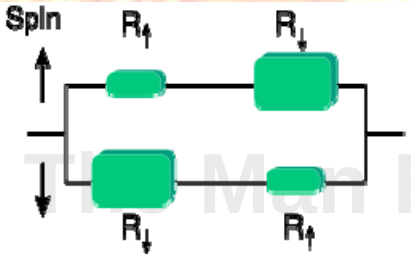




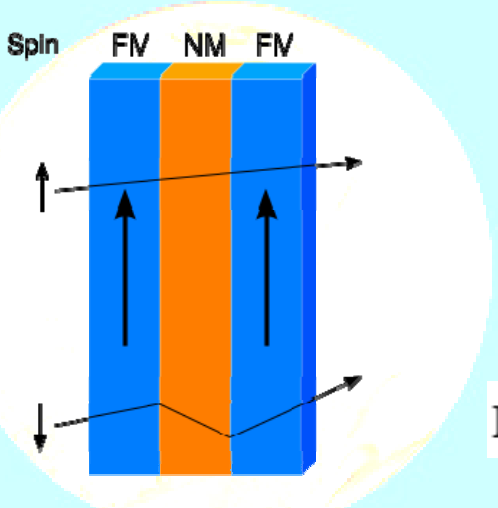
GMR

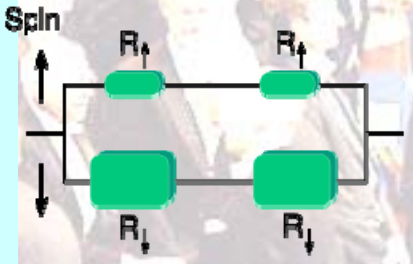
GMR effect: the MR values





$$R_0 = (1/2)(R_\uparrow + R_\downarrow)$$



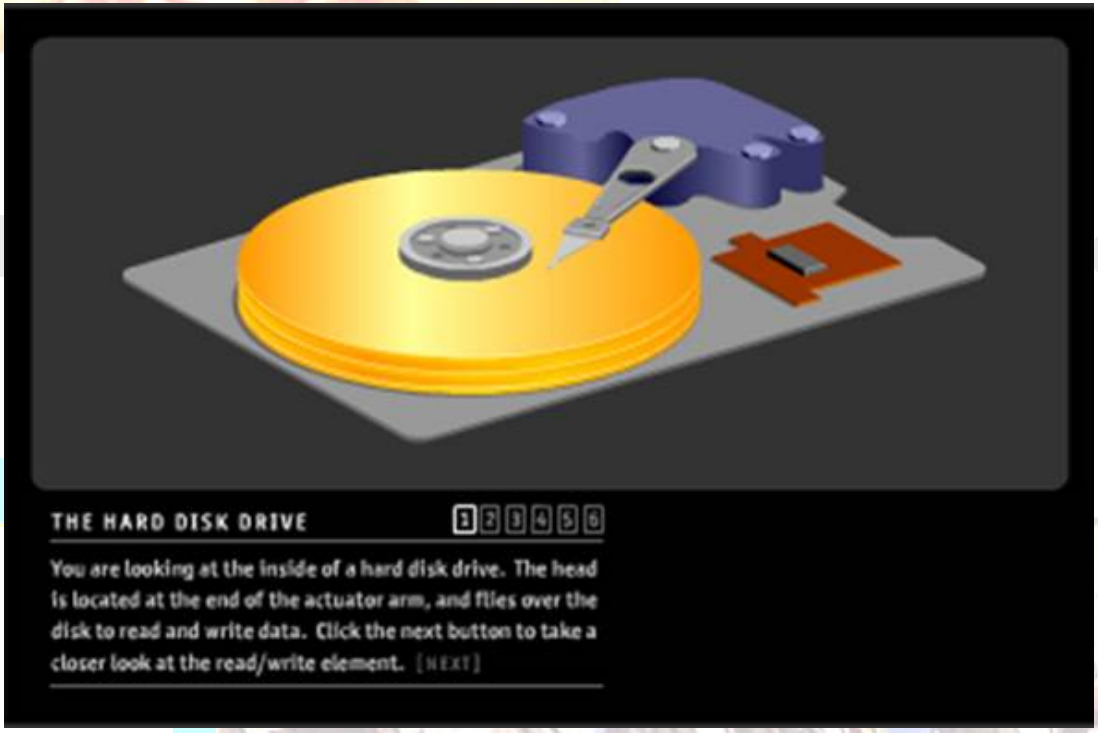


$$R_H = 2R_\uparrow R_\downarrow/(R_\uparrow + R_\downarrow)$$

$$\Delta R = R_H - R_0$$

$$= -(1/2)(R_\uparrow - R_\downarrow)^2/(R_\uparrow + R_\downarrow)$$

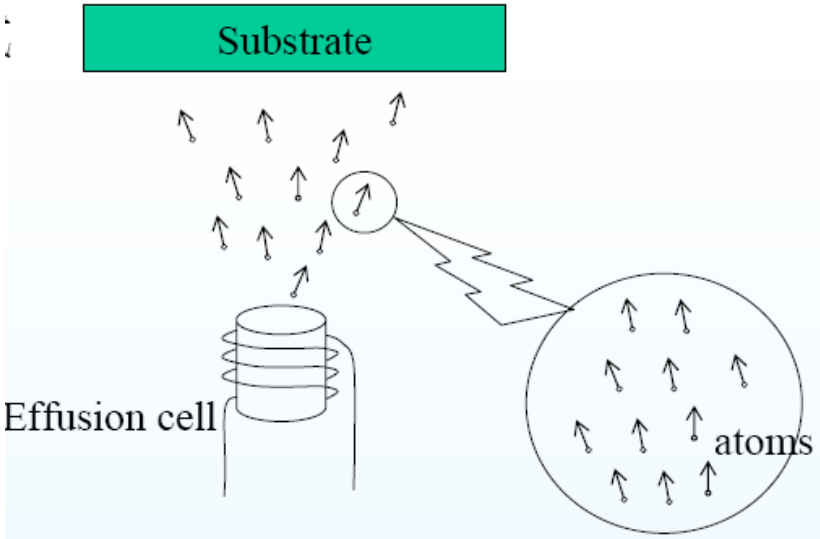
GMR – application



GMR - application

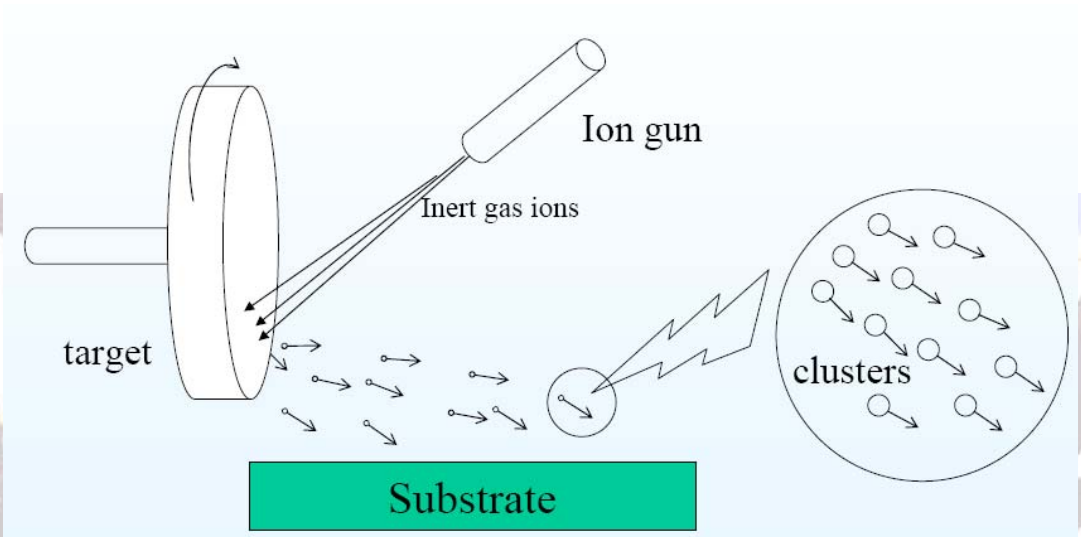
Stuart Parkin demonstrated that it was possible to achieve the same effect using a much simpler technology called **sputtering**.

MBE:



Expansive, time consuming

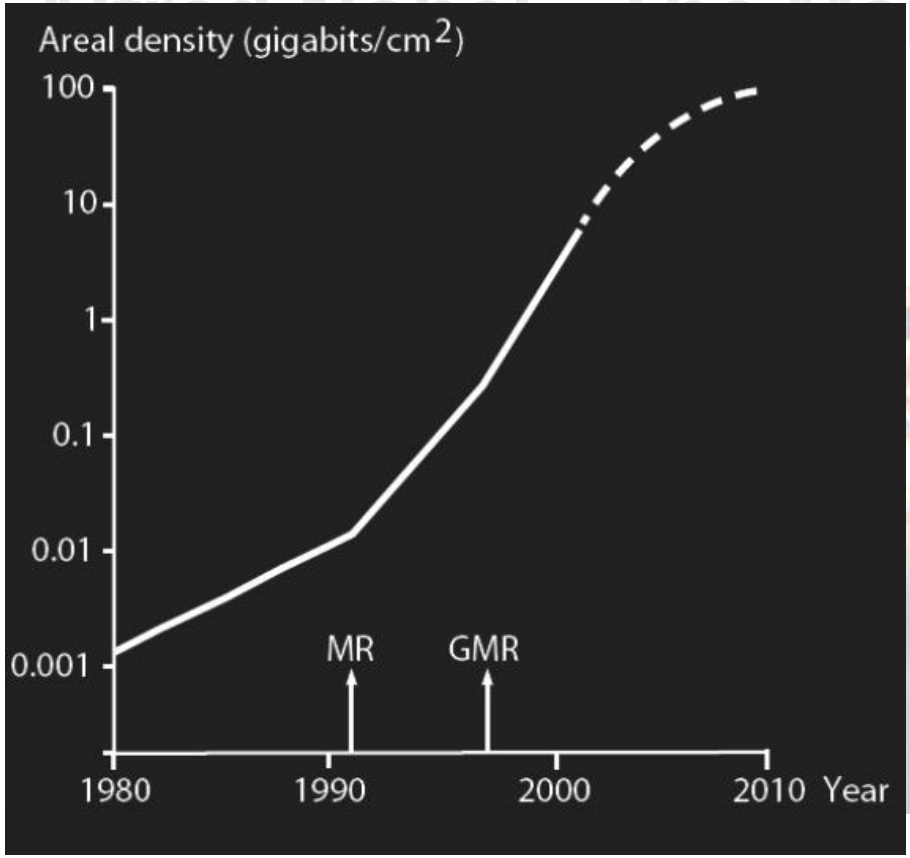
Sputter deposition.



Fast deposition, lower cost

GMR quickly became standard

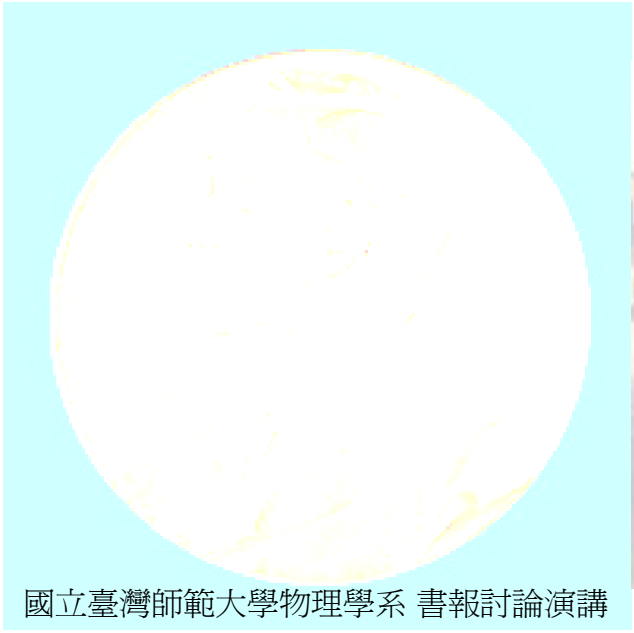
The first commercial GMR-head had been produced in 1997.



For GMR

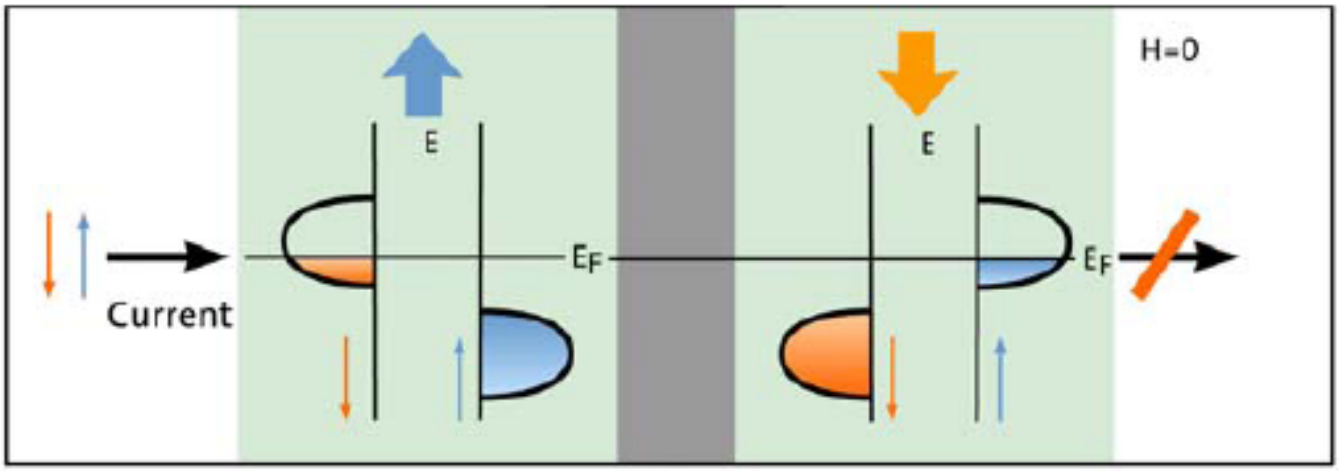
Not the end! To be continued!

Alfred Nobel - The Man Behind the Nobel Prize

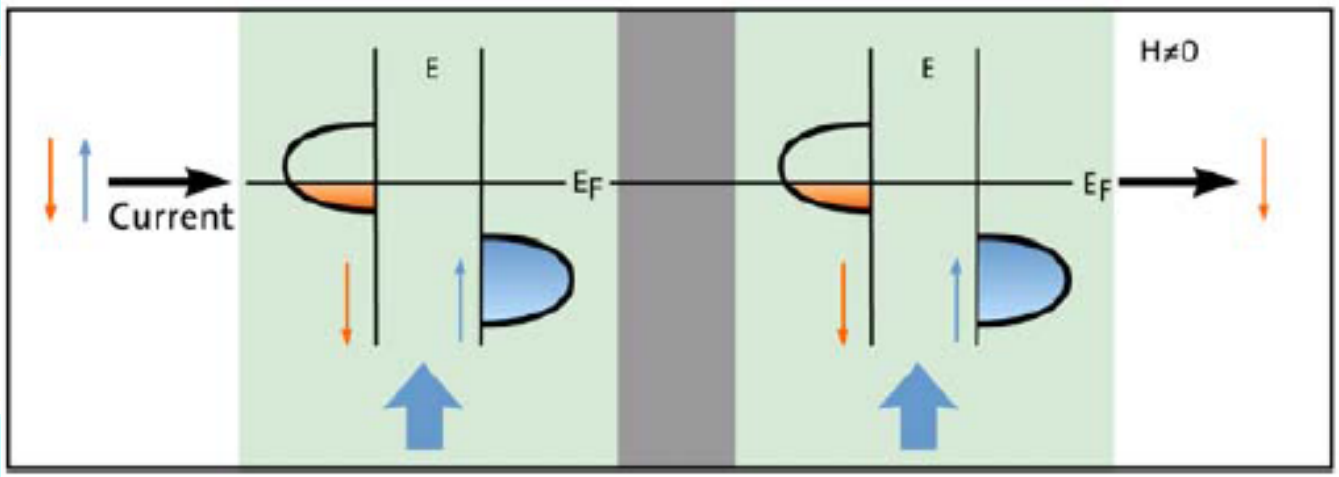


Half metals

CrO_2

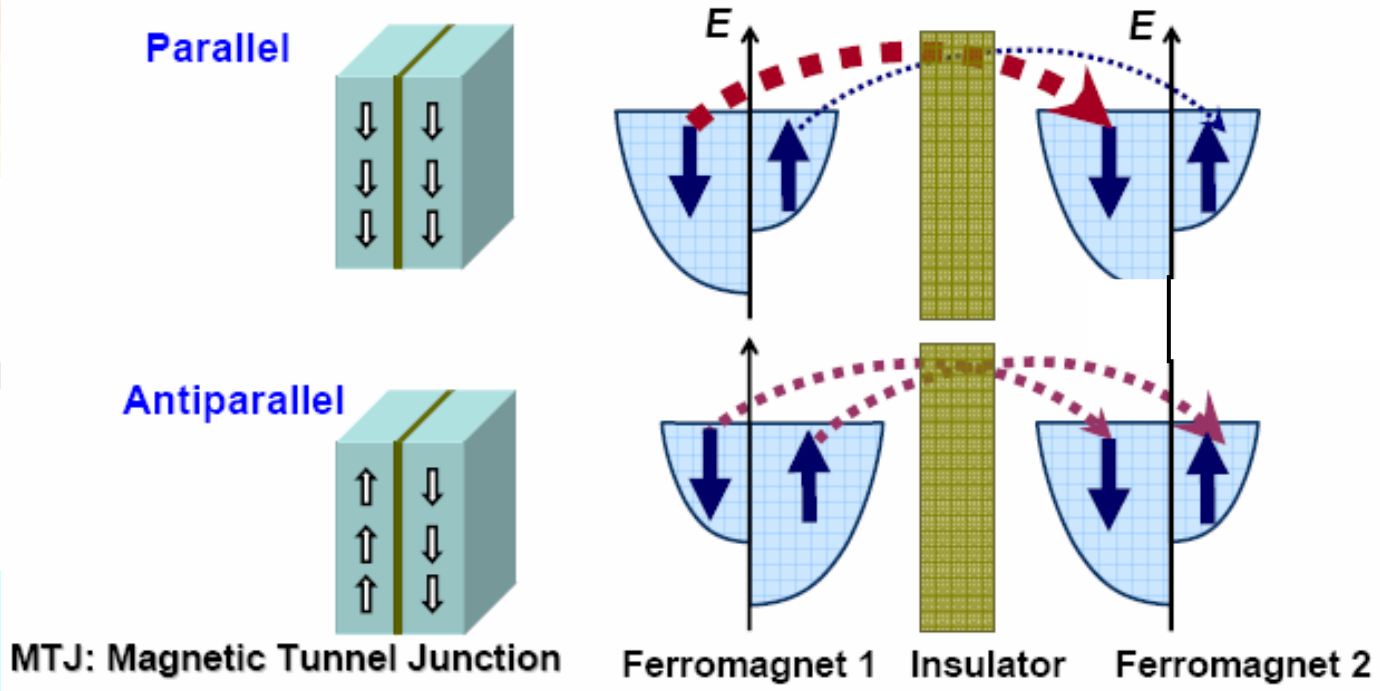


No current



Spin down current only

TMR – Tunneling magnetoresistance



$$\text{Tunnel MagnetoResistance (TMR)} = \frac{R_{AP} - R_P}{R_P} = \frac{2P^2}{1-P^2}$$

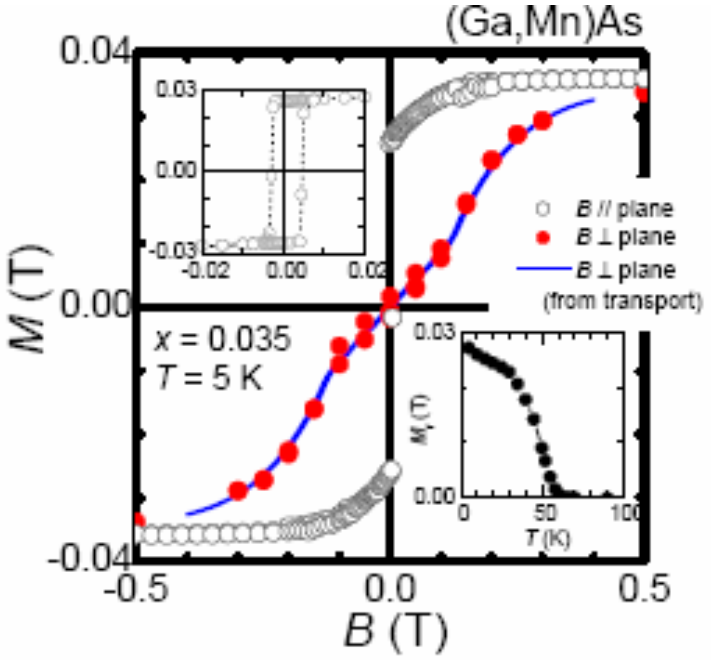
RT under reasonable field:

Recently barriers of Fe/MgO/Fe have been shown to give rise to TMR-values that sometimes exceeded **200%.**

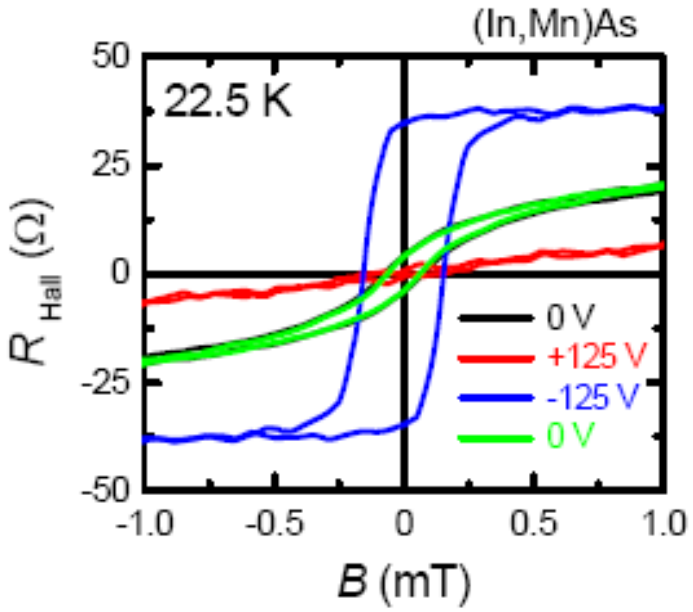
Spintronics

Ferromagnetic III-V semiconductors

integration with conventional semiconductor devices
carrier induced ferromagnetism



H. Ohno *et al. Appl. Phys. Lett.* 1996
H. Ohno *Science* 1998



H. Ohno *et al.*, Nature **408**, 944 (2000).

Prize Awarder for the Nobel Prize in Physics

The Man Behind the Nobel Prize

The Royal Swedish Academy of Sciences

Nobel Committee for Physics 2007

Per Carlson (Chairman)
Professor of Elementary Particle Physics

Lars Bergström (Secretary)
Professor of Theoretical Physics

Börje Johansson (Member)
Professor of Condensed Matter Physics

Björn Jonson (Member)
Professor of Fundamental Physics

Ingemar Lundström (Member)
Professor of Applied Physics

Joseph Nordgren (Member)
Professor of Soft X-ray Physics

Conclusion remark:

Nobel Prize in Physics 2007 – GMR

One of the first major applications of the nanotechnology. All the computers use/need it!

Alfred Nobel - The Man Behind the Nobel Prize

Nobel Prize in Chemistry 2007–Chemical reactions on surface

Laid the methodological foundations for surface chemistry – key technique of nanotechnology.