Magnetoresistances

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Xu group meeting
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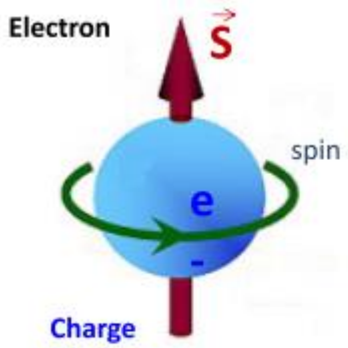
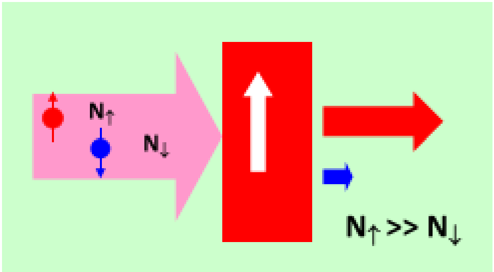
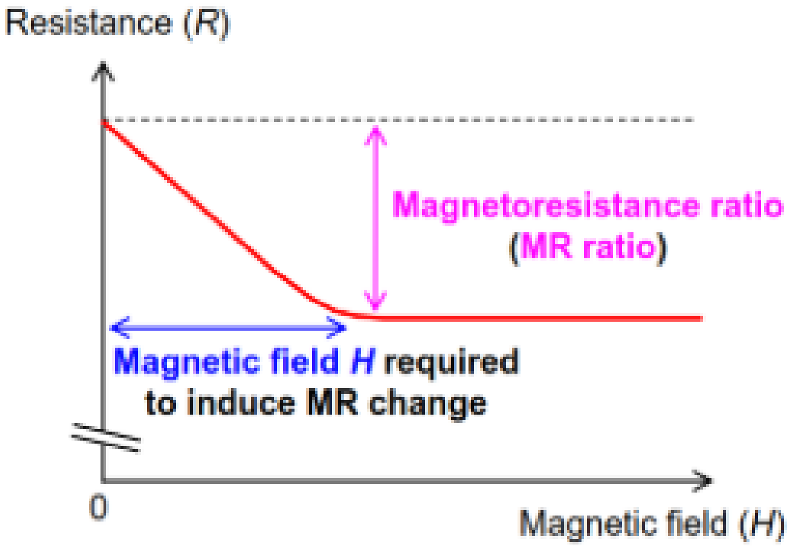
Overview:

Change in resistance by an application of H

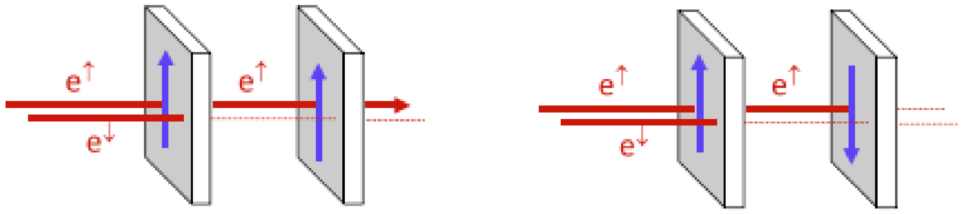






$$= \frac{R_H - R_0}{R_0}$$

Spin filters



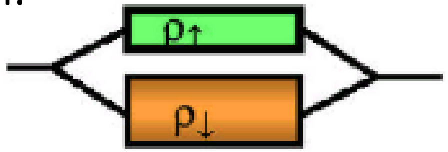
$$\sigma_{\uparrow\uparrow} > \sigma_{\downarrow\uparrow} \Rightarrow R_{\uparrow\uparrow} < R_{\downarrow\uparrow}$$

Two channel for conduction:

$$\sigma = \sigma_\uparrow + \sigma_\downarrow$$

$$n_\uparrow \neq n_\downarrow \rightarrow \sigma_\uparrow \neq \sigma_\downarrow$$

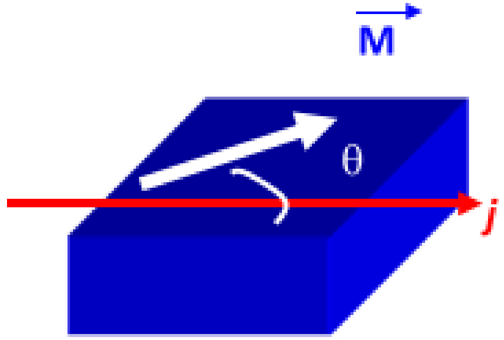
$$\rho = \frac{\rho_\uparrow \rho_\downarrow}{\rho_\uparrow + \rho_\downarrow}$$

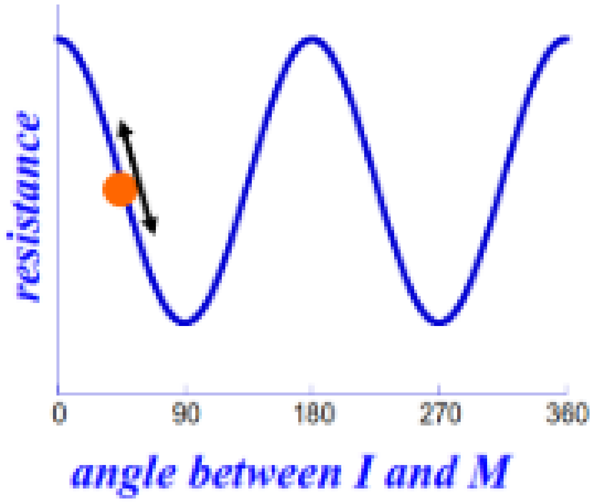


Anisotropic magnetoresistance(1-2%):

Dependence of electrical resistivity on the relative angle between the current and magnetization direction.

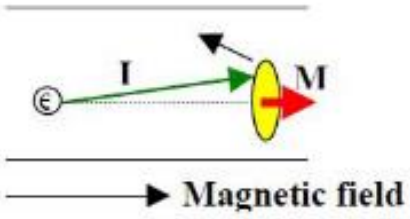
$$\rho_{long}(\theta) = \rho_{\perp} + (\rho_{\parallel} - \rho_{\perp})\cos^2\theta$$
$$\rho_{trans}(\theta) = (\rho_{\parallel} - \rho_{\perp})\, sin\,\theta\, cos\theta$$

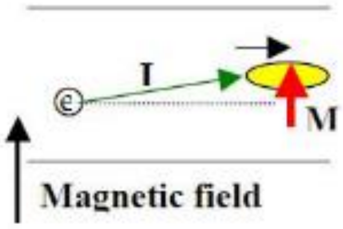




$$\text{AMR} = \frac{(\rho_{\parallel} - \rho_{\perp})}{\rho_{avg}}$$

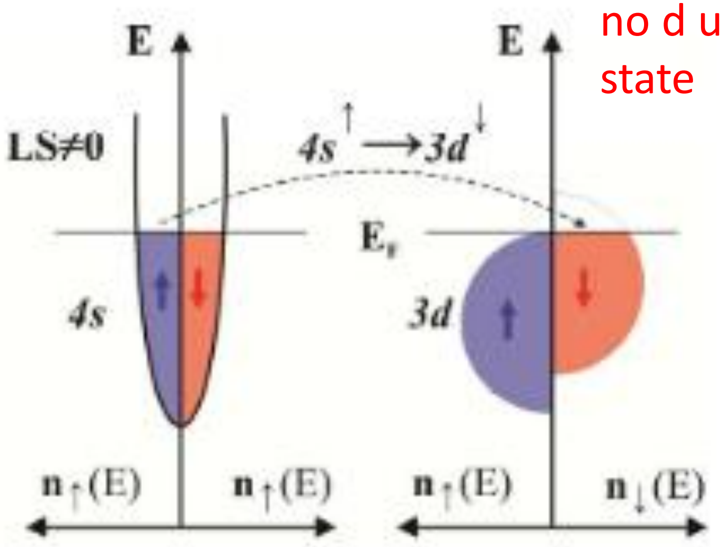
AMR phenomenological:
$(\rho_{\parallel} > \rho_{\perp})$





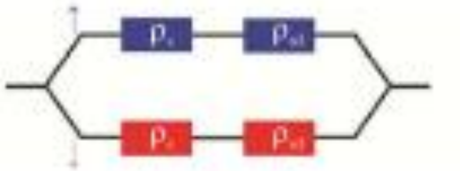
Spin orbit interaction (SOI):

- Conduction electron (sp) and final state (d)
- $\boldsymbol{L.S}$ → rising and lowering operator
- Mixes up and down states
- Change in up and down states leads AMR



no d up state

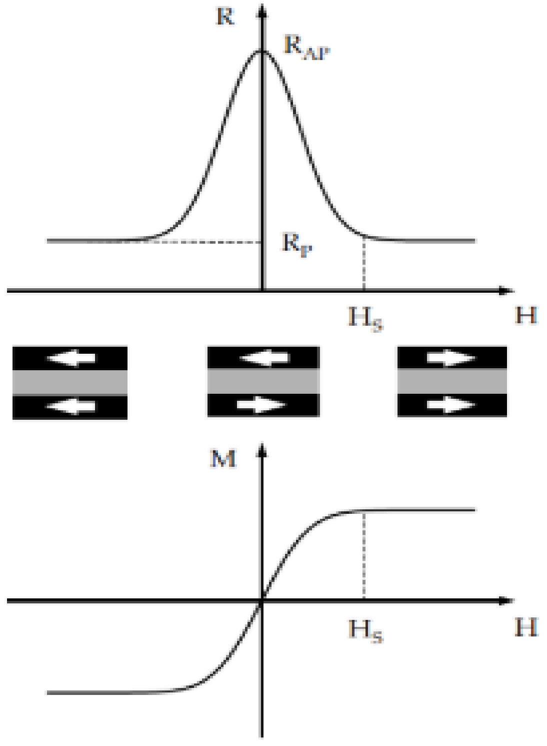
s-d interaction rate depends on direction of momentum of s electrons relative to orbital d.



Giant Magnetoresistance(5-15%)

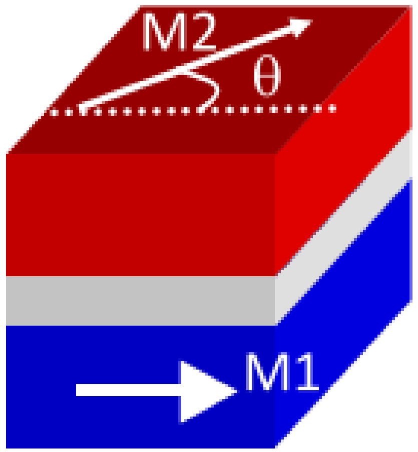
Alternating ferromagnetic multilayer

$$GMR = \frac{R_{AP} - R_P}{R_P}$$



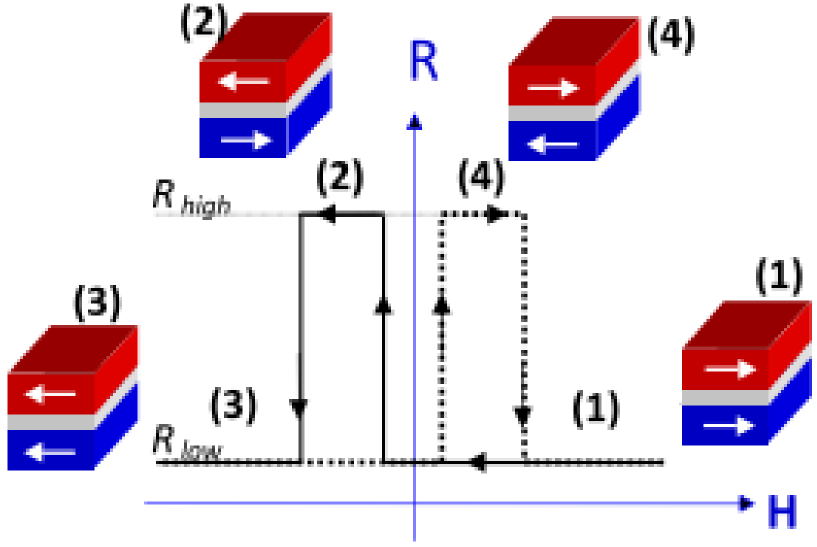
Schematic representation of the GMR effect

Spin valve:
Tuning of resistance
with field

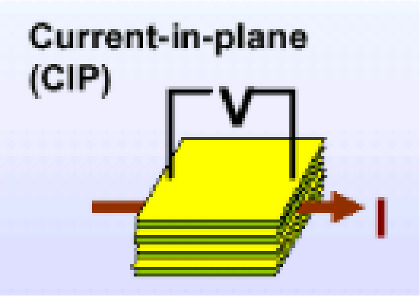


$$R = \frac{R_P + R_{AP}}{2} + \frac{R_P - R_{AP}}{2} cos\theta$$

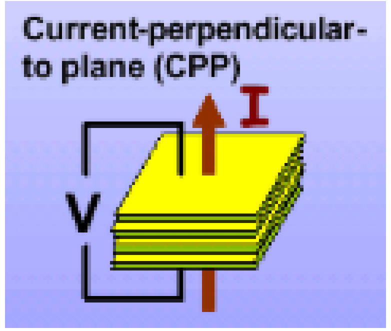
Hard-soft combination



Measurement geometry:



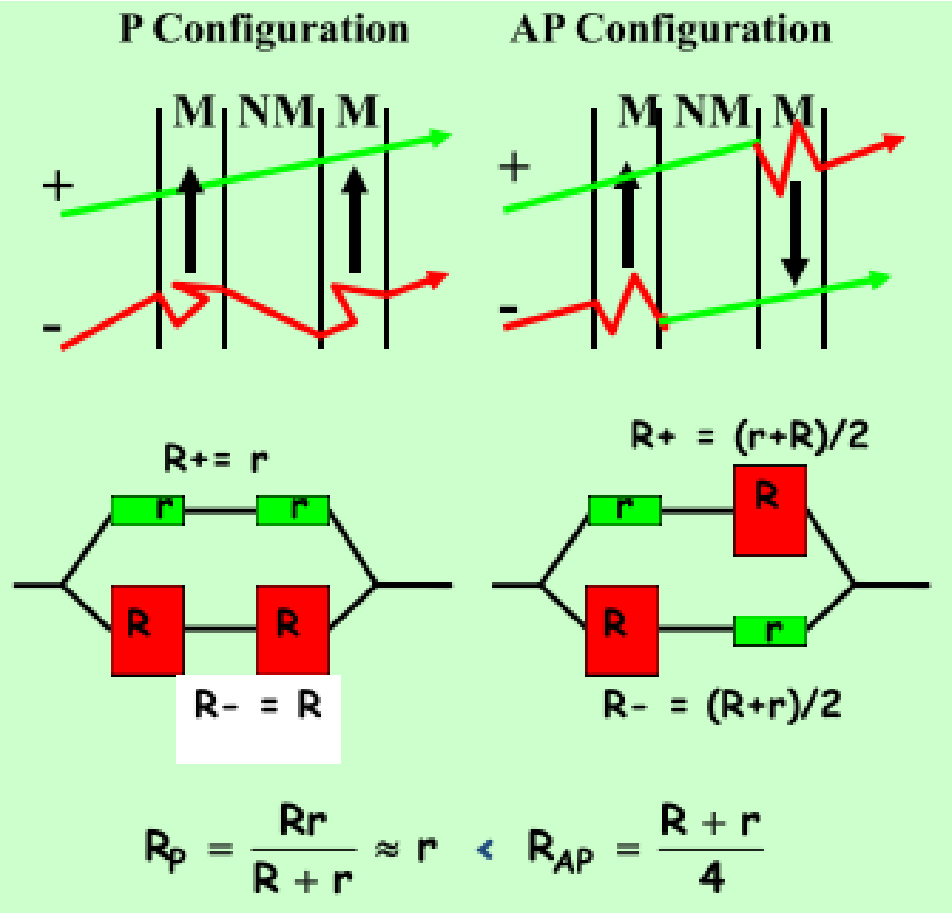
$\lambda \gg d_i$



$\lambda_s \gg d_i$

GMR Mechanism: Resistor model

- Each layer as a resistor
- Separate conduction channel for each spin
- Combination of resistor depends on $\boldsymbol{\lambda}$ *and* $\boldsymbol{d_i}$ relation
- For $\boldsymbol{\lambda} \ll \boldsymbol{d_i}$, resistors for each channel are parallel, each layer conducts independently (No GMR)
- $\boldsymbol{\lambda} \gg \boldsymbol{d_i}$
- Propagate through spacer layer sensing magnetic layers.
- within a given spin channel the total resistance is the sum of resistances of each layer and each interface, i.e. the resistors are connected in series
- $\frac{\Delta\rho}{\rho_P} = \frac{\Delta R}{R_P} = \frac{(1-\alpha)^2}{4\alpha}$; where $\alpha = \frac{\rho_\downarrow}{\rho_\uparrow}$
- GMR depends on asymmetry parameter α.

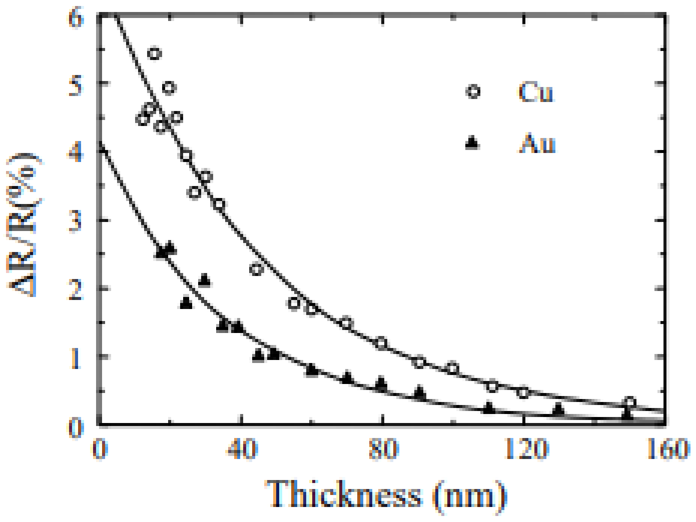


Factor affecting GMR:

Thickness of NM

- Conduction electrons scattering in NM layer
- The shunting current within the spacer
- Phenomenological expression:

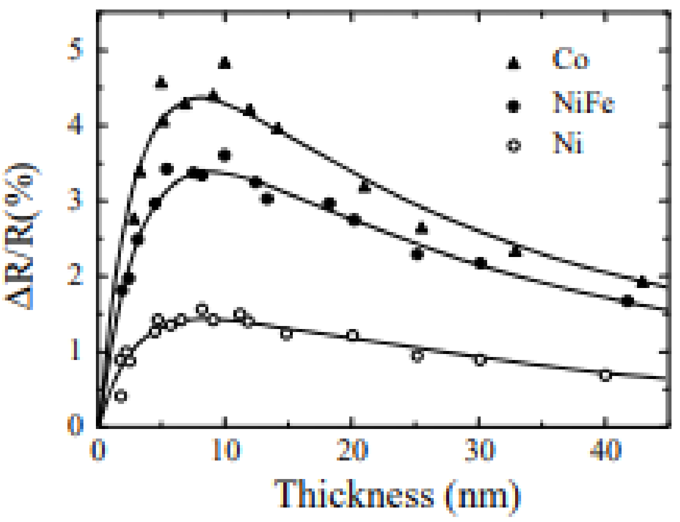
$$\frac{\Delta R}{R} \sim \frac{e^{\left(-\frac{d_{NM}}{l_{NM}}\right)}}{1+\frac{d_{NM}}{d_0}}$$



Thickness magnetic layers:

- Large thickness; shunting current FM layer
- Smaller thickness; scattering at outer boundaries
- Phenomenological expression:

$$\frac{\Delta R}{R} \sim \frac{1-e^{\left(-\frac{d_{FM}}{l_{FM}}\right)}}{1+\frac{d_{NM}}{d_0}}$$



Temperature dependence:

- Inelastic scattering by phonons shorten mean free path in NM layer(spin conserves)
- Electron magnon scattering(spin flip)

Roughness: spin dependent scattering
Impurity: Tuning asymmetry of scattering rates

Dieny et al.