

Lecture 2 Summary

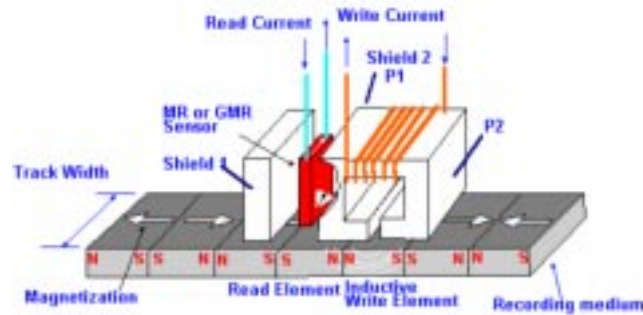
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Relevance of Magnetoresistance to Data Storage II

- MR Heads permit individual tailoring of Write and Read



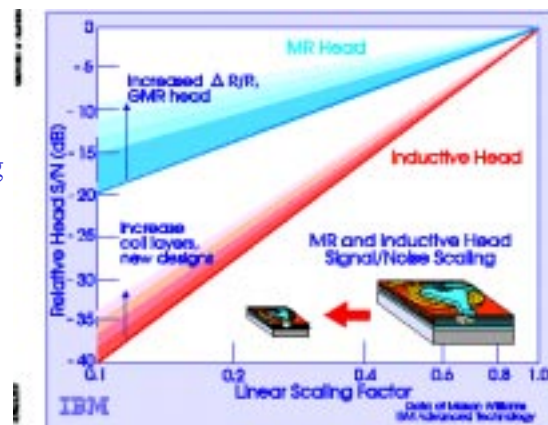
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Fig from <http://www.storage.ibm.com/oem/nrheads/mainmrhead.htm>

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Relevance of Magnetoresistance to Data Storage III

- MR heads have more favorable SNR scaling than inductive heads



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Fig from <http://www.storage.ibm.com/oem/nrheads/mainmrhead.htm>

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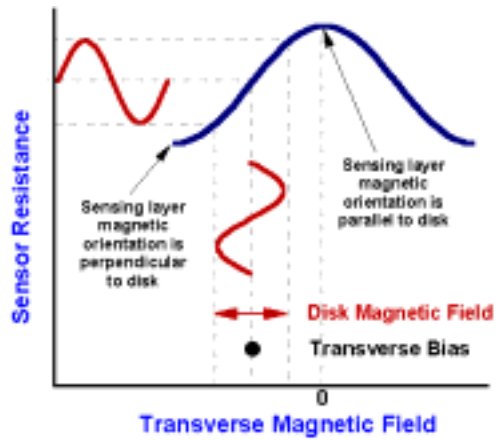
Phenomenology of AMR

$$\rho = \rho_0 + \Delta\rho_0 \cos^2 \theta$$

$$\rho = \rho_0 + \Delta\rho_0 \left[1 - \left(\frac{H}{H_k} \right)^2 \right]$$

where $\sin \theta = \left(\frac{H}{H_k} \right)$

Note: Deviation from perfect parabola is due to demagnetizing effects



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Fig from <http://www.storage.ibm.com/oem/mrheads/mainmrhead.htm>
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Implementation of AMR

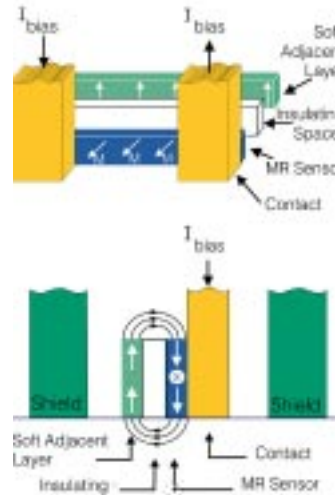
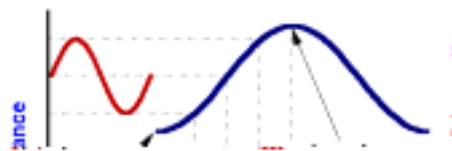


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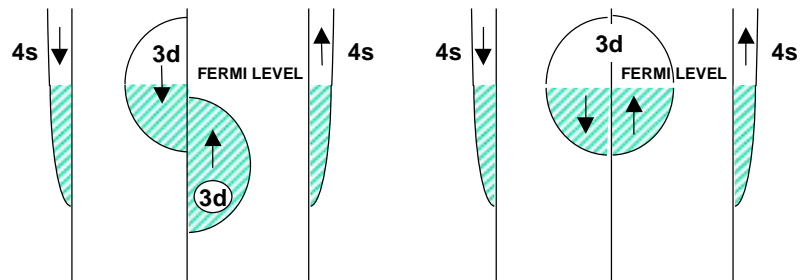
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Magnetoresistance

- Resistance behavior determined by scattering of electrons
- Spin Dependent Scattering
 - Scattering center differences and/or
 - Differences in final state availability

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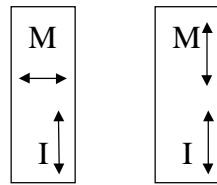


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Two Fluid Model AMR

- Minority and majority carriers in one material when current is parallel (or antiparallel) to field
- No distinction between carriers when field and current are orthogonal



Low R High R

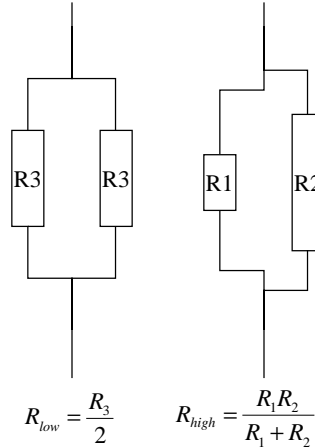


Diagram following R.L. White, "Giant Magnetoresistance: A Primer", IEEE Trans Mag, vol. 28, (1992) pp. 2482-2487

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Phenomenology of GMR

$$\rho = \rho_0 + \frac{\Delta\rho_0}{2} \sin \theta$$

$$\rho = \rho_0 + \Delta\rho_0 \left(\frac{H}{H_k} \right)$$

$$\text{where } \sin \theta = \left(\frac{H}{H_k} \right)$$

Note: superior linearity to AMR

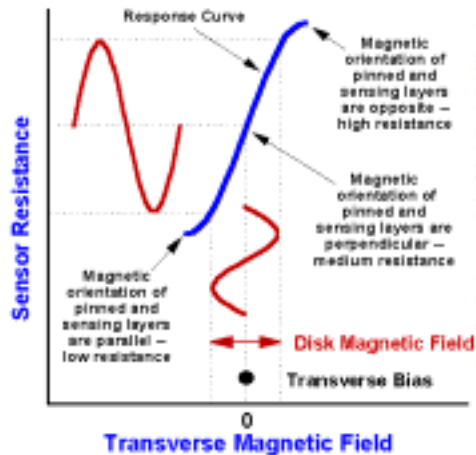
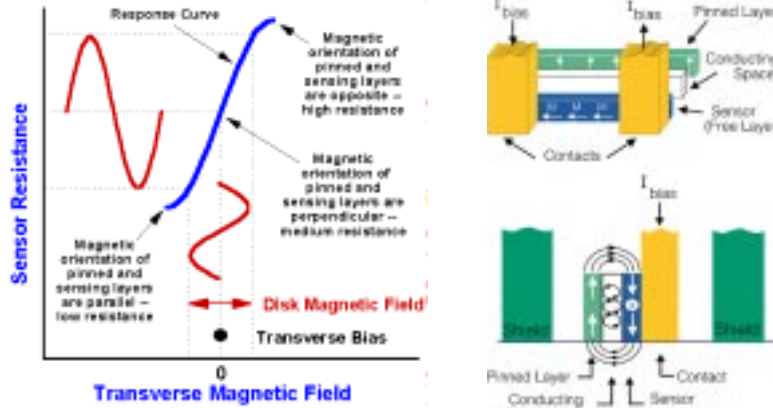


Fig from <http://www.storage.ibm.com/oem/mrheads/mainmrhead.htm>

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Implementation of GMR



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Fig from <http://www.storage.ibm.com/oem/mrheads/mainmrhead.htm>

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Physics of GMR

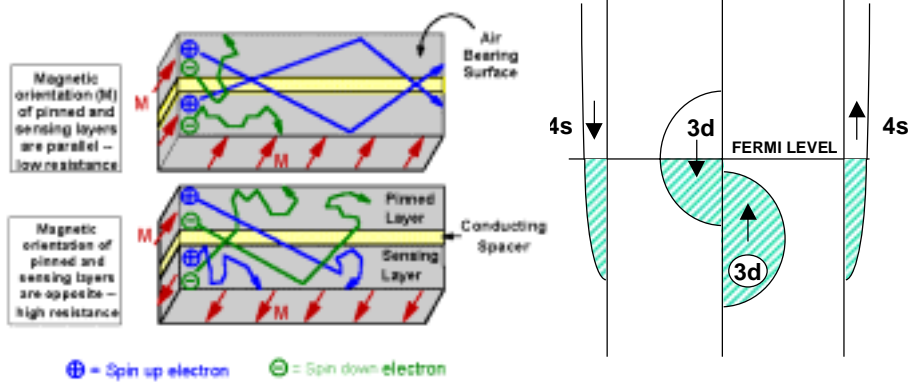


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Two Fluid Model of GMR

- Two ways of combining low and high resistance paths
- Different resistances require spin dependent scattering

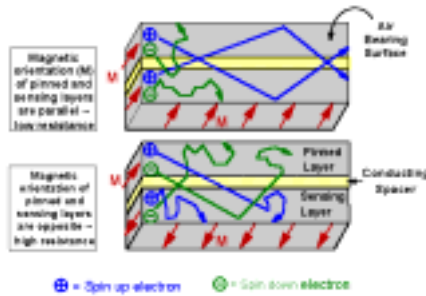


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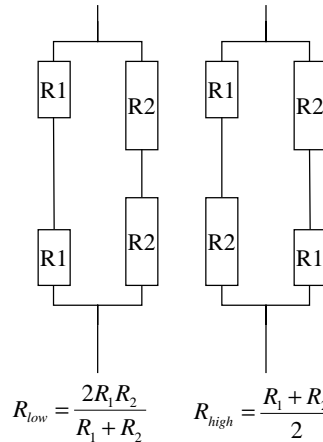


Diagram following R.L. White, "Giant Magnetoresistance: A Primer",
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Differences in AMR and GMR

AMR

- In single material
- Depends on relative orientation of current and magnetization
- Symmetric in field (+/- H is same)
- Quadratic in field $(H/H_k)^2$

GMR

- Requires two materials
- Depends on relative orientation of two magnetizations
- Antisymmetric in field (+H != -H)
- Linear in field (H/H_k)

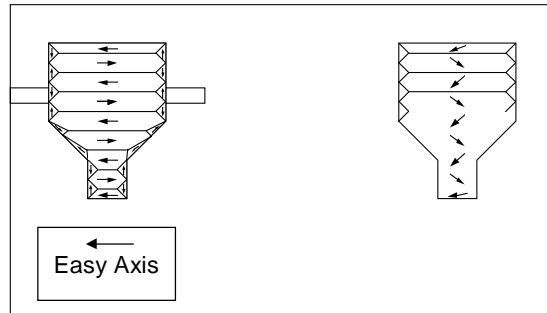
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Sheet Resistance in Thin Films

- Sheet Resistivity

- To find R_{sq}
 - define all geometries



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Energetics of Magnetoelasticity

- Balance Energies

$$E_{m-el}(\vec{M}, \epsilon) = E_{mag}(\vec{M}, \epsilon) + E_{el}(\epsilon)$$

$$\frac{\partial E_{m-el}(\vec{M}, \epsilon)}{\partial \epsilon} = 0 \Rightarrow \text{Equilibrium } \epsilon(\vec{M})$$

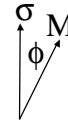
- Beware of Signs

- Tensile is (+)
- Compressive (-)

- Cases:

- Isotropic magnetics + Uniaxial symmetry

$$E_{m-el} = -\frac{3}{2} \lambda \sigma \cos^2 \phi$$



- Cubic

$$E_{m-el} = -\frac{3}{2} \lambda_{100} \sigma (\alpha_1^2 \gamma_1^2 + \alpha_2^2 \gamma_2^2 + \alpha_3^2 \gamma_3^2)$$

$$-3 \lambda_{111} \sigma (\alpha_1 \alpha_2 \gamma_1 \gamma_2 + \alpha_2 \alpha_3 \gamma_2 \gamma_3 + \alpha_3 \alpha_1 \gamma_3 \gamma_1)$$

$$\vec{M} = M (\alpha_1 \hat{i} + \alpha_2 \hat{j} + \alpha_3 \hat{k})$$

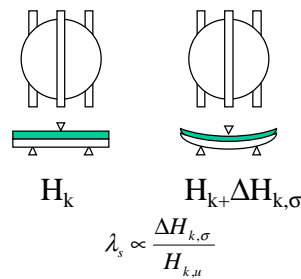
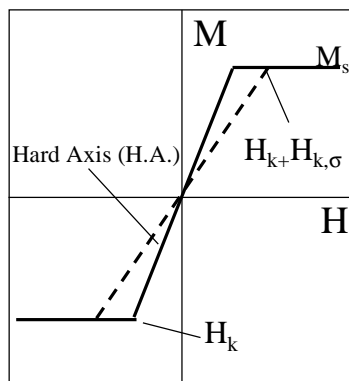
$$\sigma_{ij} = \sigma \gamma_i \gamma_j$$

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Source: S. Chikazumi, Physics of Magnetism, Robert E. Krieger Publishing Co., Inc., Malabar, FL (1964), Ch. 8.

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Magnetostriction: ΔH_k Method



$$\Delta K_{u,\sigma} = \frac{\mu_0 \Delta H_{k,\sigma} M_s}{2} = -\frac{3}{2} \lambda_s \sigma$$

$$\lambda_s = -\frac{\mu_0 \Delta H_{k,\sigma} M_s}{3 \sigma}$$

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Magnetostriction: Strain Method



- Apply field
- Measure displacement (due to bending)
- Calculate elastic strain in film alone (requires knowledge of elastic properties)

Measurement of Magnetostriction

ΔH_k Methods

- Measures change in Field
- Sources of Error:
 - Uniformity of strain
 - Uniformity H_k
 - Uniformity of Pickup
 - Knowledge of elastic constants of film (secondary)

Displacement Methods

- Measures strain
- Sources of Error:
 - Ability to measure small displacements
 - Clamping/Elastic Constraint
 - Elastic constants of film and substrate (primary)