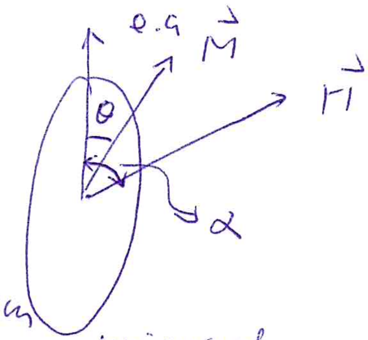
1



1. a) α: e.a. & $\vec{H}$

θ: $\vec{M}$ & e.a

M_s: saturation magnetization

H: external field ; K_u: uniaxial magnetic anisotropy

Total energy $E = K_u \sin^2\theta - M_s H \cos(\alpha - \theta)$

$$\frac{\partial E}{\partial \theta} = 2K_u \sin\theta \cos\theta - H M_s \sin(\alpha - \theta) = 0$$

$$M = M_s \cos(\alpha - \theta)$$

$\alpha = 90^\circ$. $2K_u (M/M_s) = H M_s$

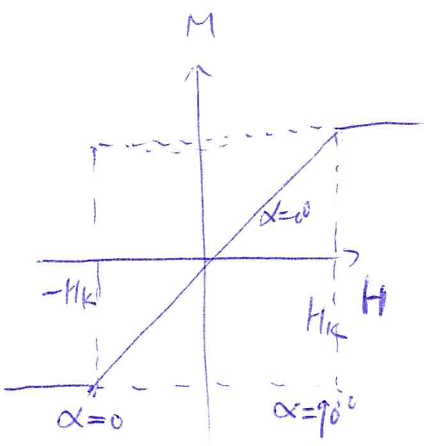
$$M/M_s = H / H_k \qquad H_k = \frac{2K_u}{M_s}$$

linear, hard axis

$\alpha = 0^\circ$ $\quad 2K_u \sin\theta \cos\theta + M_s H \sin\theta = 0$

$\sin\theta = 0$; $E = M_s H$ $\xleftarrow{\min}$ $\frac{\partial^2 E}{\partial \theta^2} > 0$

$\cos\theta = -\frac{M_s H}{2}$; $E = K_u + \frac{M_s^2 H^2}{4K_u}$ $\xleftarrow{\max}$ $\frac{\partial^2 E}{\partial \theta^2} < 0$



$$\Delta E = K_u - M_s H + \frac{M_s^2 H^2}{4K_u}$$

$$= K_u \left(1 - \frac{M_s H}{K} + \frac{M_s^2 H^2}{4K_2^2}\right)$$

$$= K_u \left(1 - \frac{H}{H_k}\right)^2$$

$$H_k = \frac{2K_u}{M_s}$$

②

1. b). $P_{switch} = f_0 \cdot \tau\, e^{-\Delta E / k_B T}$

c) Coercivity point → half switch point.

$$\frac{1}{2} = f_0 \tau \cdot e^{-\Delta E / k_B T}$$

$$\Delta E = k_B T \ln(2 f_0 \tau)$$

$$\Delta E = K_u \cdot V \left(1 - \frac{H}{H_K}\right)^2 = k_B T \ln(2 f_0 \tau)$$

$$H = H_K \left[1 - \left(\frac{k_B T}{K_u V} \cdot \ln(2 f_0 \tau)\right)^{\frac{1}{2}}\right]$$

d) two of the following three candidates.

1) stress anisotropy; (lattice mismatch between two layers)

2) Interface anisotropy; (e.g. CoFeB / MgO) $t < 1.5$ nm

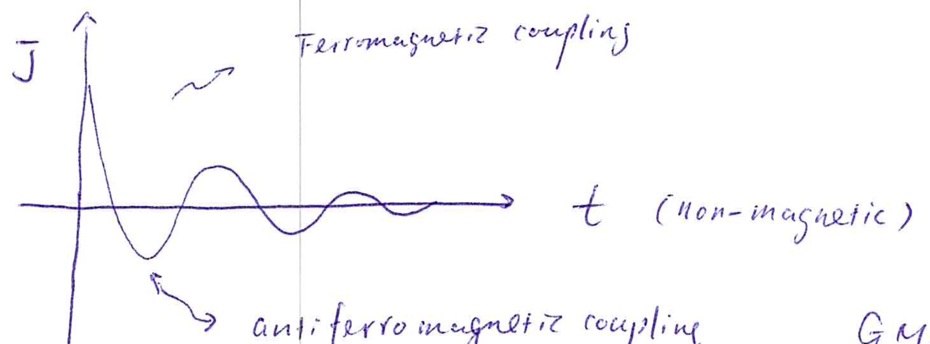
3) shape anisotropy; (patterned structure, ultra thin film)

e) $H_c^{single} > H_c^{packed}$.

$H_c^{packed} \propto (1 - p)\, H_c^{single}$ ← shape anisotropy dominant case

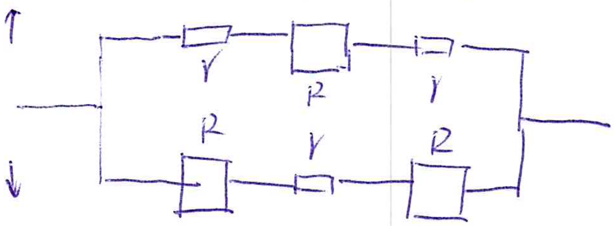
p: packing density.

2. a) RKKY interaction.



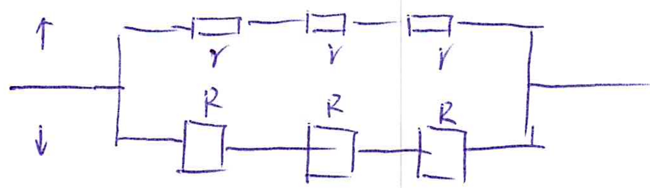
GMR working region.

b) For AP configuration. two-resistor model



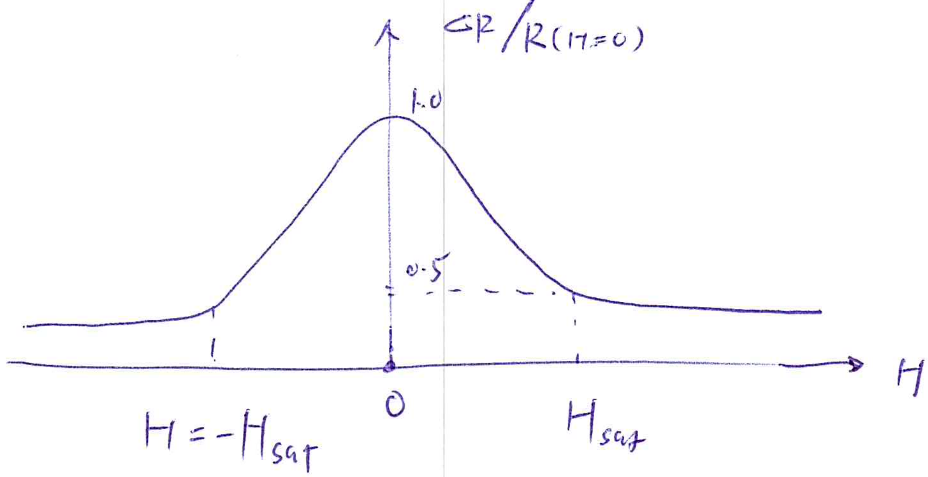
$$R_{AP} = (2r+R) \,//\, (2R+r) = \frac{(2r+R)(r+2R)}{3(r+R)}$$

For P configuration.

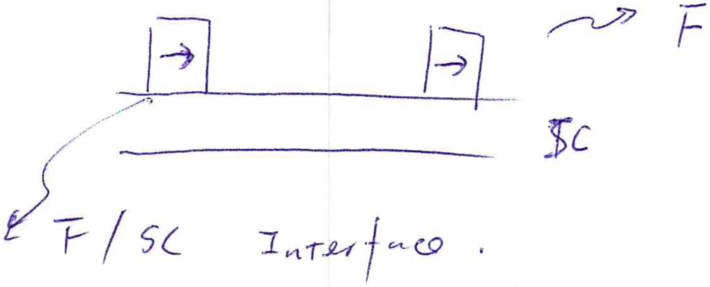


$$R_p = 3R \,//\, 3r = \frac{9R \cdot r}{3(r+R)}$$

$$\Delta R = R_{AP} - R_p = \frac{2(R-r)^2}{3(R+r)}$$



2. c)



F: metal; conductance: G_F

SC: semiconductor; conductance: G_{SC}

$G_F >> G_{SC}$ a large conductance mismatch between F & SC layers.

spin injection will be very inefficient.

Solution: to add a tunneling barrier between F & SC layer.

Basically, we could not identify the spin-dependent resistance or scattering because:

$$R_{sc} + R_{F\uparrow} \approx R_{sc} + R_{F\downarrow}$$