

Magnetic Actuators (3)

Ref:

Feynman, et al., Lectures on Physics, vol. 2, Chap. 36, 37

J. Judy, Ph.D. Thesis, Berkeley, 1996

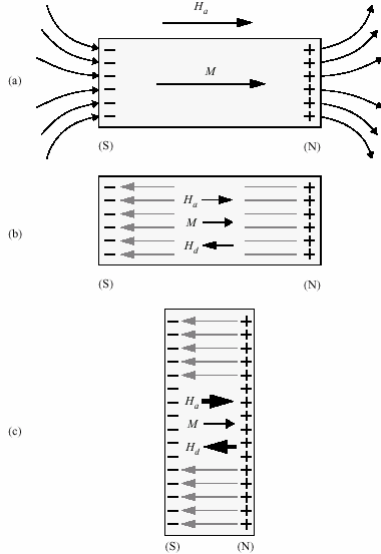


Permalloys – Very Soft Magnetic Materials

- **Very easy to magnetize**
 - Need pure, well-annealed materials with very few dislocations and impurities so the magnetic domain walls move easily
- **Small anisotropy**
 - Fe prefers to magnetize along [100]
 - Ni prefers to magnetize along [111]
 - Right mixture of Ni and Fe wouldn't prefer any direction
 - Right mixture ~ 70% Ni + 30% Fe
- **Useful for high quality transformers**
- **Needs to be handled carefully (low stress, no bending, ..)**



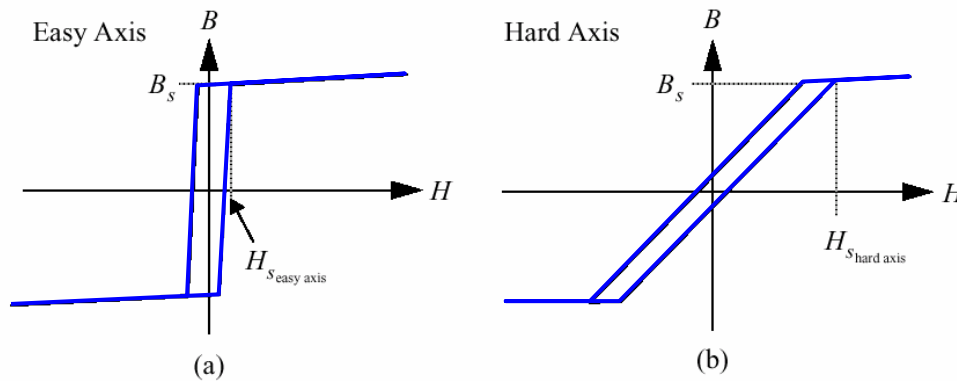
Shape Anisotropy



- Since permalloy has very small material anisotropy (due to crystals, stress, ..), asymmetry in shape can induce significant magnetic anisotropy
- The internal demagnetization field along a short axis is larger (c) than that along a long axis (b).
- It is easier to magnetize the sample along the long axis
Easy axis

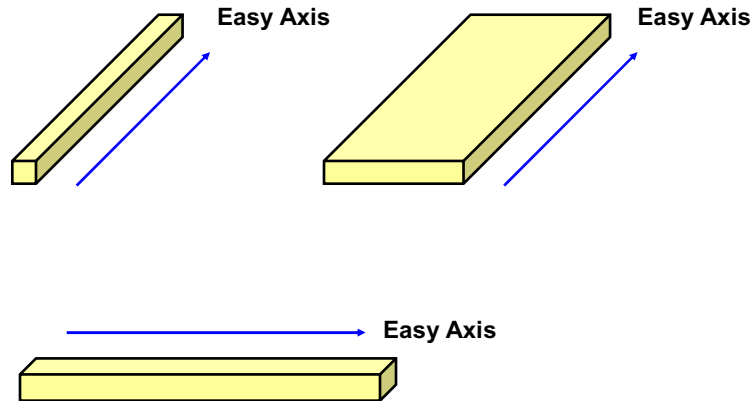


Easy Axis and Hard Axis

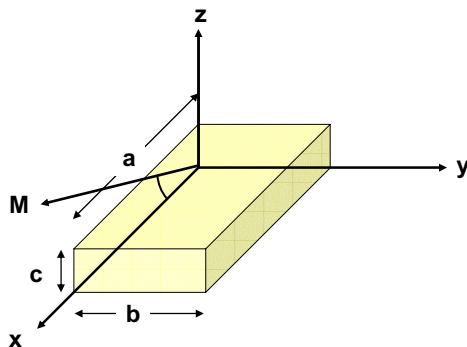


Shape Anisotropy

Easy axis aligns with the longest axis of the sample



Magnetic Shape-Anisotropy Energy



$$u_{ms} = -\frac{1}{2} \vec{H}_d \cdot \vec{M}$$

↓
Demagnetization Field

Special case when M stays in x - z plane:

$$u_{ms} = \left[\frac{1}{2\mu_0} (N_c - N_a) M_s^2 \right] \sin^2 \theta$$

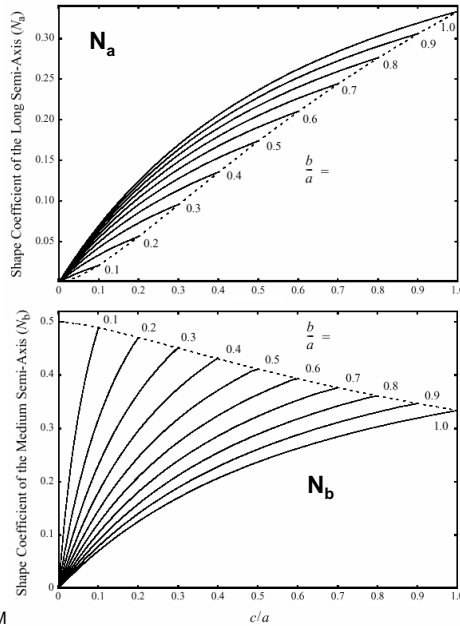
$$= K_a \sin^2 \theta$$

Shape anisotropy constant:

$$K_a = \frac{1}{2\mu_0} (N_c - N_a) M_s^2$$

N_a , N_b , N_c are shape coefficients

Shape Coefficients



N_a , N_b , N_c depends on shape parameters a , b , c (convention: $a \geq b \geq c$)

For example, $a = 50 \text{ } \mu\text{m}$, $b = c = 5 \text{ } \mu\text{m}$

$b/a = 0.1$, $c/a = 0.1$

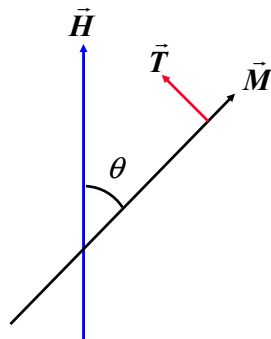
$N_a = 0.02$, $N_b = 0.48$, $N_c = 0.48$



M

7

Magnetostatic Energy



Consider a magnetic material with magnetization \vec{M} and volume V in a magnetic field \vec{H} , the magnetostatic energy is

$$U_{ms} = -V\vec{H} \cdot \vec{M}$$

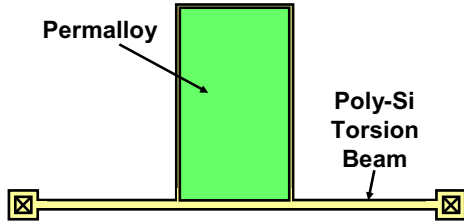
Torque

$$\vec{T} = -\frac{\partial U_{ms}}{\partial \theta} = V\vec{M} \times \vec{H}$$

Note the torque is proportional to volume (volume force)



Permalloy Plate in Magnetic Field



$$\vec{T}_H = V\vec{M} \times \vec{H}$$

$$T_H = VHM \sin \alpha$$

$$= VHM \sin(\gamma - \theta - \phi)$$

$$T_{Aniso} = -VK_a \sin(2\theta)$$

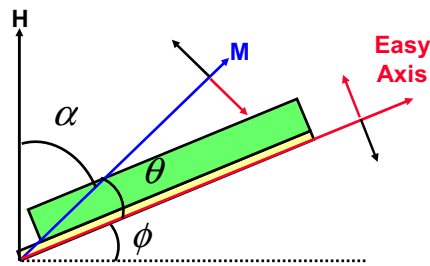
$$T_{Mech} = -k_\phi \phi$$

At equilibrium:

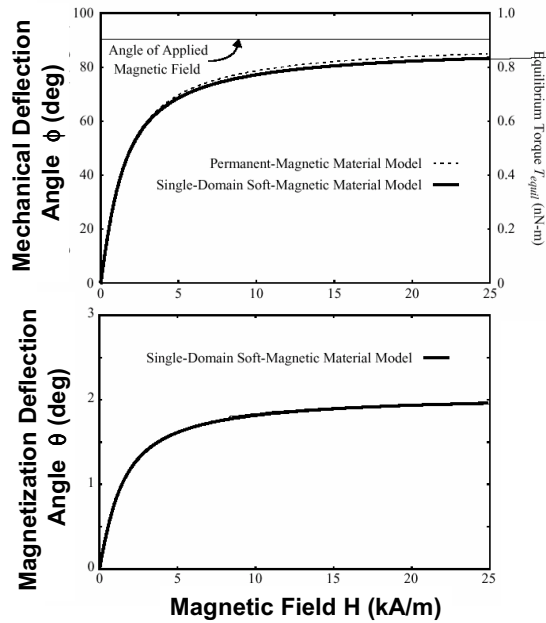
$$\begin{cases} T_H + T_{Aniso} = 0 \\ -T_{Aniso} + T_{Mech} = 0 \end{cases}$$

$$K_a \sin(2\theta) =$$

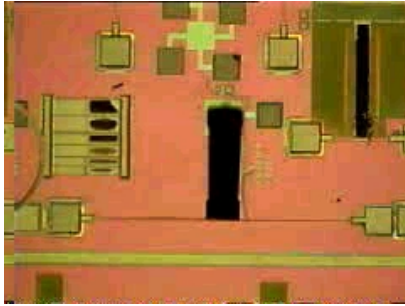
$$HM \sin(\gamma - \theta - \frac{VK_a}{k_\phi} \sin(2\theta))$$



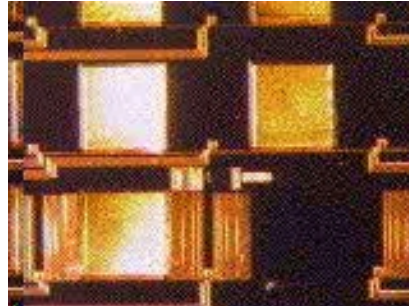
Transfer Characteristics



Magnetic Actuators in Motion (1)



Magnetically Actuated Torsion Plate
(Courtesy Prof. J. Judy)

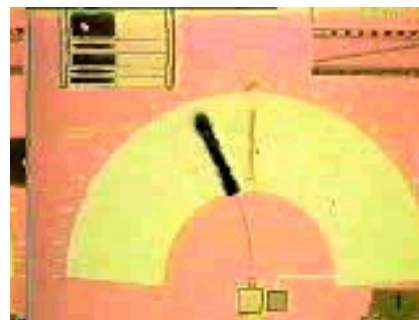


Magnetic Actuator with Electrostatic Clamp
(Courtesy Prof. J. Judy)

Magnetic Actuators in Motion (2)

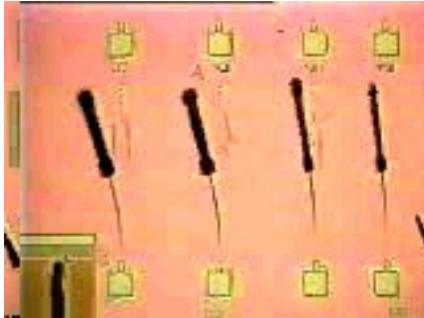


Magnetic Actuator in Liquid
(Courtesy Prof. J. Judy)

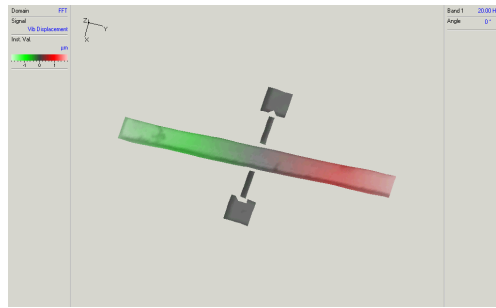


Large Deflections
(Courtesy Prof. J. Judy)

Magnetic Actuators in Motion (3)



Multiple Magnetic Actuators
(Courtesy Prof. J. Judy)



Magnetometer Motion Measured by LDV
(Courtesy Prof. J. Judy)