14 Applications

14.1 Introduction

The production of ferro- and ferrimagnetic materials is large-scale operation:

- The price of the material that goes into a chip is a minute fraction of the device fabrication cost.
- The annual sales of electrical steel, used for electromotors and similar devices, reach the millions of tons

Other large-scale production items

- Permanent magnets for loudspeakers
- Magnetic recording materials

14.2 Electrical Steels (Soft Magnetic Materials)

The core loss is the energy that is dissipated in the form of heat within the core of electromagnetic devices

Several types of losses : eddy current loss, hysteresis loss

Typical core losses are between 0.3 and 3 W/kg (Table 17.1)

14.2.1 Core Losses

: The energy that is dissipated in the form of heat within the core of electromagnetic devices when the core is subjected to an alternating magnetic field

Eddy current loss

An current in the primary coil causes an alternating magnetic flux in core → induces in the secondary coil an alternating V_e,

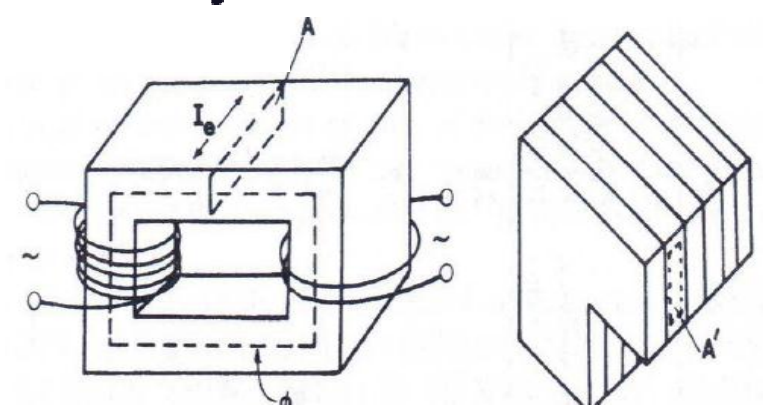
$$V_e \propto -\frac{d\phi}{dt} = -A\frac{dB}{dt}$$

This emf gives rise to the eddy current, I_e (Fig.17.1(a))

Larger eddy current→ the larger μ ($B = \mu_0 \mu \cdot H$) → the larger conductivity σ of core material →the higher the applied frequency→ the larger the cross-section A

Skin effect

At high frequency, the eddy current shields the interior of the core from the magnetic field, so that only a thin exterior layer of the core contributes to the flux multiplication.



14.2.2 Grain Orientation

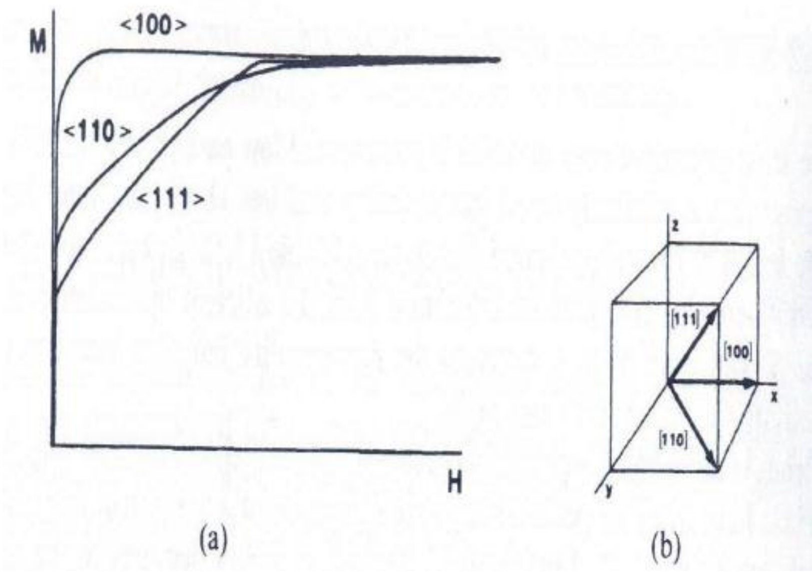
Magnetic Anisotropy

The magnetic properties of Crystalline ferromagnetic materials depend on the crystallographic direction in which an external field is applied

Magnetization curves of single crystals

If the external field is applied in the <100> direction, saturation is achieved with the smallest possible field strength

Easy Direction



14.2.3 Composition of Core Materials

carbon steel

: The least expensive core material is commercial low relatively small permeability, higher core losses than grain-orientd silicon iron

Iron-silicon alloys

: higher permeability and a lower conductivity than low carbon steel, heat treatments of these alloys can be performed at much higher temperatures with out interference from phase changes during cooling

Permalloy, Supermalloy, Mumetal

: The highest permeability (multicomponent nickel based alloys)

14.2.4 Amorphous Ferromagnets

14.3 Permanent Magnets (Hard Magnetic Materials)

: Devices that retain their magnetic field indefinitely.

Hard magnetic materials

A large remanence B_r (or M_r).

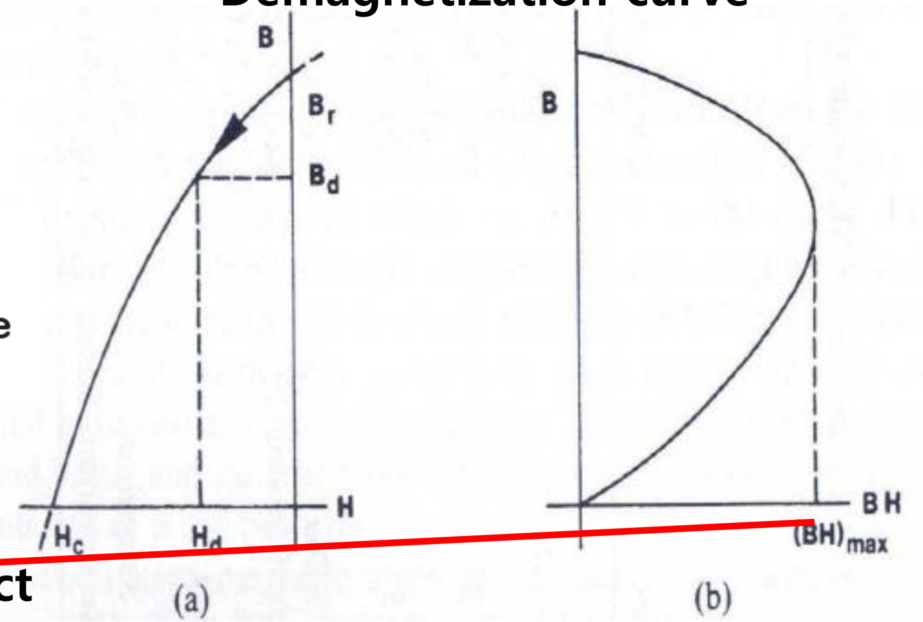
A relatively large coercivity H_c.

A large area within the hysteresis loop.

the area within the hysteresis loop.

the energy product peaks somewhere between these extreme values.

Demagnetization curve

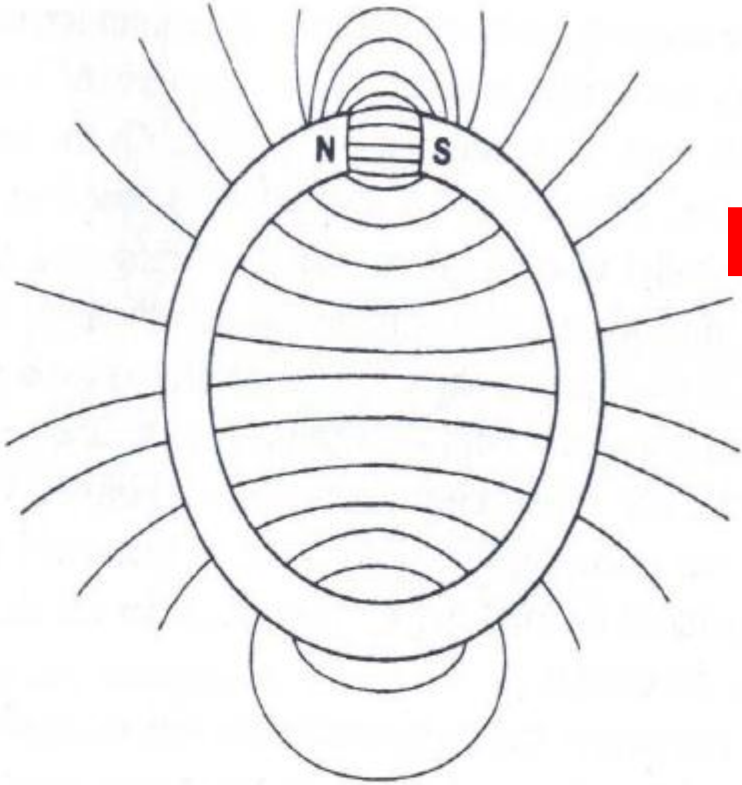


Maximum energy product

Table 17.2. Properties of Materials Used for Permanent Magnets.

Material	Composition (mass %)	Remanence B_r (kG)	(T)	Coercivity H_c (Oe)	(A/m)	Maximum energy product $(BH)_{max}$ per Volume (MGOe)	(kJ/m^3)
Steel	Fe–1% C	9	0.9	51	4×10^3	0.2	1.6
36 Co steel	36 Co, 3.75 W, 5.75 Cr, 0.8 C	9.6	0.96	228	1.8×10^4	0.93	7.4
Alnico 2	12 Al, 26 Ni, 3 Cu, 63 Fe	7	0.7	650	5.2×10^4	1.7	13
Alnico 5	8 Al, 15 Ni, 24 Co, 3 Cu, 50 Fe	12	1.2	720	5.7×10^4	5.0	40
Alnico 5 DG	same as above	13.1	1.3	700	5.6×10^4	6.5	52
Ba-ferrite (Ceramic 5)	$BaO \cdot 6\,Fe_2O_3$	3.95	0.4	2,400	1.9×10^5	3.5	28
PtCo	77 Pt, 24 Co	6.45	0.6	4,300	3.4×10^5	9.5	76
Remalloy	12 Co, 17 Mo, 71 Fe	10	1	230	1.8×10^4	1.1	8.7
Vicalloy 2	13 V, 52 Co, 35 Fe	10	1	450	3.6×10^4	3.0	24
Cobalt–Samarium	Co_5Sm	9	0.9	8,700	6.9×10^5	20	159
Iron–Neodymium–Boron	$Fe_{14}Nd_2B_1$	13	1.3	14,000	1.1×10^6	40	318

Demagnetizing Curve



All permanent magnets need to have exposed poles.

The exposed poles create a demagnetizing field, H_d→ reduces the B_r

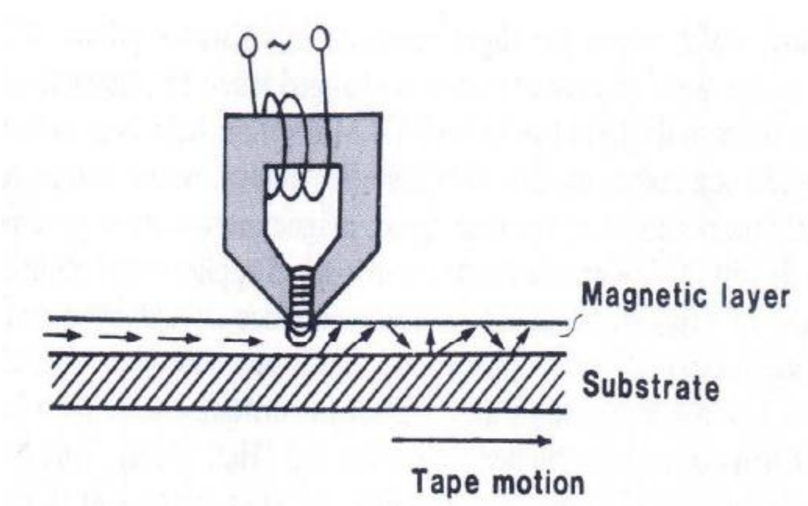
The demagnetizing field depends on the shape, size, and gap length of magnet.

14.4 Magnetic Recording and Magnetic Memories

Magnetic recording tapes, disks, drums, or magnetic strips on credit cards consist of small, needlelike oxide particles about 0.1 X 0.5 ㎛.

Recording head

The recording head of a tape machine consist of a laminated electromagnet made of permalloy or soft ferrite (Table 17.1) which has air gap about 0.3㎛ wide (Fig. 17.5)



Magneto-resistance

In magnetic field a conductor is perpendicular to an electric field, the Lorentz force causes the paths of the drifting electrons to bend in near circular form. (Hall effect)

$$\sigma_0 = N_e \cdot \mu_e \cdot e = \frac{1}{\rho_0} \qquad \frac{\Delta \rho}{\rho_0} = (\mu_e \Delta B)^2$$

Ferrite-core memories

The dominant devices for random-access storage in computers.

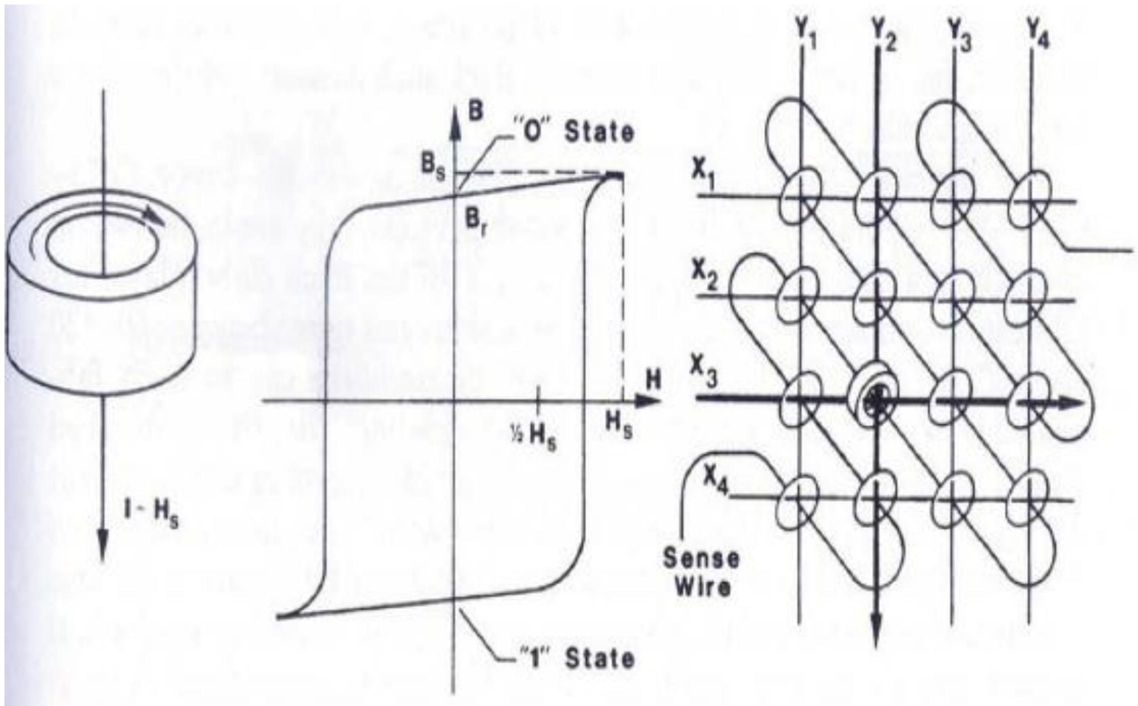
A nearly square-shaped hysteresis loop and a low coercivity, is threaded with a wire (Fig. 17.6(a))

A sufficiently high current pulse→ the core becomes magnetically saturated.

An opposite-directed current pulse→ magnetizes the ferrite core counterclockwise.

Ferrite-core memories

Two magnetization directions constitute the two possible values (0 and 1) in the binary system.



(a) (b) (c)

Bubble domain memory

Form in thin crystals of “canted” anti-ferromagnetic oxides, amorphous alloyed films, or in ferri-magnetic materials.

The domains can be visibly observed and optically read by the way in which they rotate the plane of polarization of polarized light(Faraday effect, or Kerr effect).

Each such domain constitutes one bit of stored information.

Thin magnetic films

Consisting of Co-Ni-Pt or Co-Cr-Ta or Co_{75}-Cr_{13}-Pt_{12} in hard-disk devices.

H_c : 60-120kA/m (750-1500Oe)

Easily fabricated –vapor deposition, sputtering, electroplating.

Switched rapidly, a small unit size.

A density of 1.8 Mbits/mm^2 with a track saperation of 3 ㎛ and a bit length of 150nm.

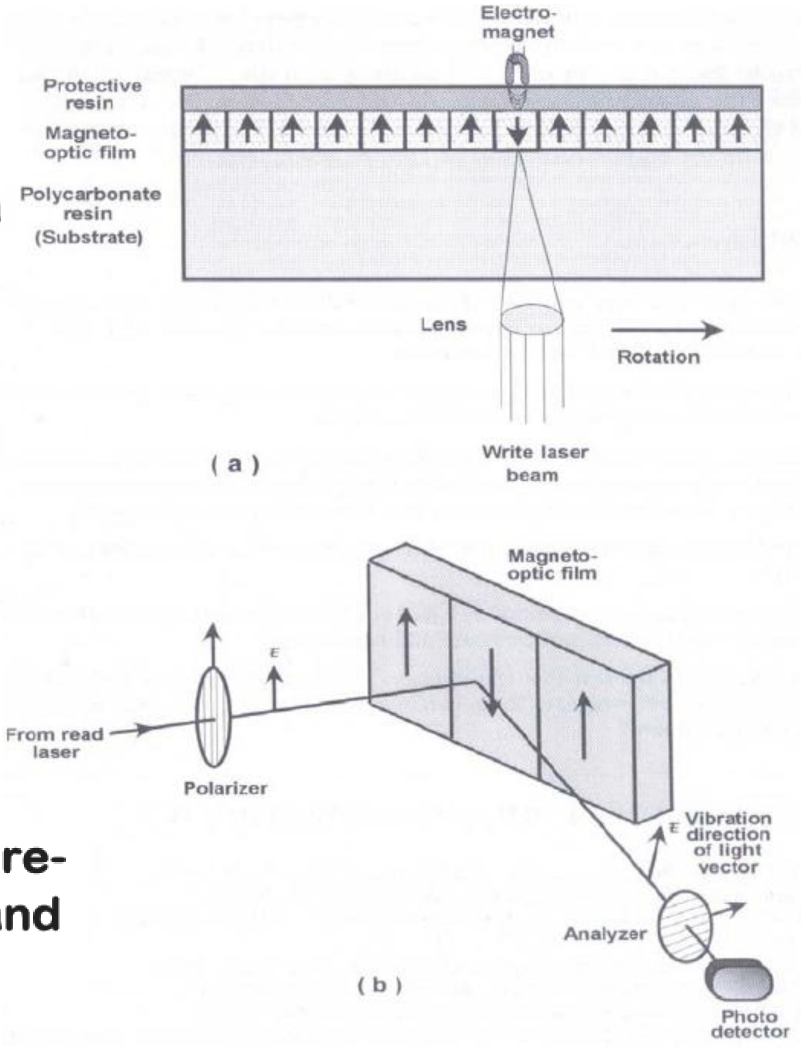
Magneto-optical memories

No mechanical contact between medium and beam.

A polycarbonate disk is covered by a certain magnetic material.

Their spins are initially vertically aligned ,see Fig. 17.7(a).

Laser beam heat→ cooling in magnetic field→ delivers the information to be stored



→ the spins in the magnetic domain re-orient according to the strength and direction of magnetic field.