Magnetic Materials: Magnetic Recording

Magnetic recording of the human voice was first carried out in 1898 by a Danish engineer, named Poulsen. The recording was made on a ferromagnetic wire, but due to a lack of amplification the recording quality was very poor. In 1927, magnetic tape was simultaneously invented in the USA and Germany. However, the familiar oxide tapes for audio recording were not developed until 1947, by the 3M corporation.

The first hard disk drive, known as the “RAMAC”, was introduced by IBM in 1957, and had a storage capacity of 2000 bits in-2. The storage capacity has rapidly and steadily increased since the “RAMAC” and in the year 2000 reached approximately 10 Gbits in-2, i.e. an increase by a factor of five million. This increase in storage capacity is illustrated in figure 13, in terms of the decrease in area on the disk required to store the information.

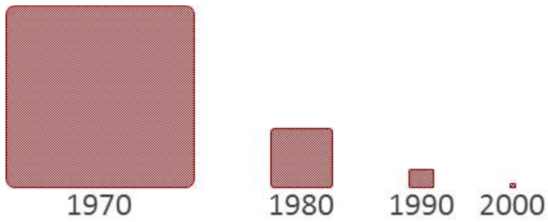

Figure 13: *The block represents the size of one bit of data on a hard disk. The sizes have been enlarged 1000 times.*

Magnetic Tapes

Magnetic tapes are extensively used for recording audio and video signals, although it is unclear how long this technology will continue to be used with the rising popularity of the digital versatile disk (DVD).

Tapes can be made with either a particulate media adhered to a plastic substrate or a metal evaporated (ME) film on the substrate. The magnetic layer on a particulate tape is only 40% magnetic material whereas ME tapes have a 100% magnetic layer. Therefore, ME tapes give better quality recording, but they are more time consuming to produce and are more expensive. Particulate tapes are much cheaper and hence account for the majority of magnetic tapes.

There is a range of magnetic particulates that can be used for tapes and these are listed in table 4, with their magnetic properties. The values of coercivity quoted in table 4 are approximate averages as the coercivity is highly dependent on particle size and shape, which will vary in any batch of powder.

Smaller particle size and higher magnetisation lead to better quality recording, i.e. greater signal to noise ratio. As the density of recording increases then the magnetic domain size decreases and so the particle size must decrease and the coercivity of the material must increase.

The cheapest and most commonly used material is γ-Fe_2O_3, while increasing quality is achieved through the use of cobalt modified (2-3wt%) γ-Fe_2O_3, chromium dioxide and, the best, pure iron.

Finally, also mentioned in table 4, is barium hexaferrite, which has the highest coercivity and is used for applications where the stored data must be secure and is unlikely to require rewriting, e.g. a credit card.

Material	Saturation Polarisation (mT)	Intrinsic Coercivity (kAm^{-1})	Average Particle Size	Particle Shape
γ-Fe_2O_3	440	30	0.5 x 0.1	Needle
Co modified γ-Fe_2O_3	460	60	0.5 x 0.1	Needle
CrO_2	600	70	0.4 x 0.05	Needle
Fe	2100	125	0.15 x 0.05	Needle
BaO.6Fe_2O_3	460	200	0.15 x 0.05	Disc

Table 4: *Approximate magnetic properties of particulates used in recording media.*

The production route for a particulate magnetic tape is illustrated in figure 14. The magnetic particles are mixed with a binder (dissolved in a solvent), lubricants that will help reduce the friction when then tape is moved over the head and abrasives (such as Al_2O_3) that are hard and help prevent wear of the magnetic tape.

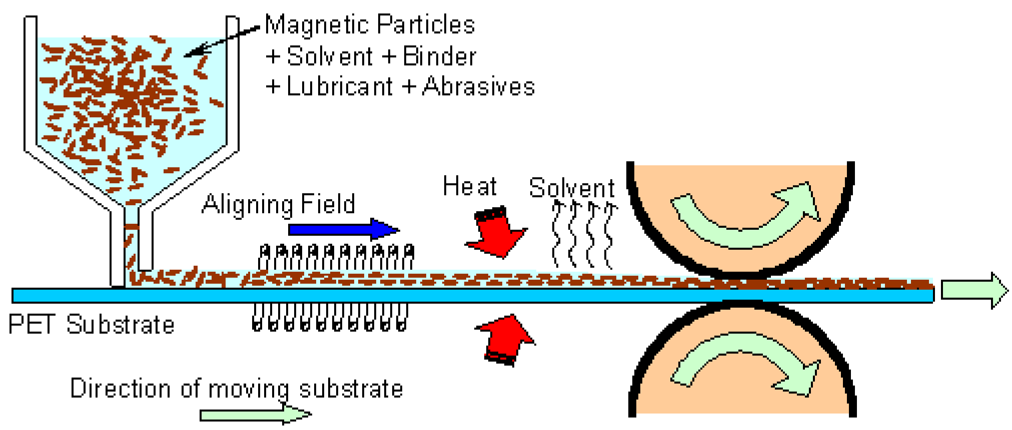

Figure 14: *The processing route for particulate magnetic tape.*

This mixture is poured onto a PET (polyethylene tetraphthalate) substrate, which is ~25mm thick. Sometimes aramid substrates are used for long play cassettes, as these substrates can be as thin as 5mm.

The particles are magnetically anisotropic, usually due to their shape, and the next stage of the process is to align these particles in the length of the tape while the magnetic layer is still liquid. The solvent is then evaporated by heating the tape and it is rolled to improve the density and leave a magnetic layer of about 3-5mm thick.

Magnetic Disks

Recording data onto a disk has obvious advantages with respect to access times, as the head can readily be moved to the appropriate place on the disk whereas a tape would need to be rewound or advanced. There are two types of disk: floppy and hard. The principles of manufacturing and recording on floppy disks are very similar to that of particulate magnetic tape, i.e. the same particulate materials on a plastic substrate.

Hard disk drives are formed on a rigid substrate, usually aluminium, which is around 2mm thick. On to the substrate are deposited several layers: an underlayer to help adhesion (~10nm nickel phosphide); a layer of chromium (5-10nm) to control orientation and grain size of magnetic layer; the magnetic layer (50nm PtCo with various additions of Ta, P, Ni, Cr); a protective overcoat (e.g. 10-20nm zirconia) and finally lubricant to reduce friction and wear of the disk (e.g. a monolayer of long chain fluorocarbons). The magnetic layer forms a cellular structure of Co-rich magnetic cells in a non-magnetic matrix. These cells act just like particulate recording media but on a much finer scale.

The construction of a hard disk drive is shown schematically in figure 15. The disk is attached to a spindle motor that will spin the disk; for greater storage capacity several disks can be built into a stack. Read and write heads are attached to a swinging arm (one for each side of the disks) that can be scanned across the disk using a voice coil.

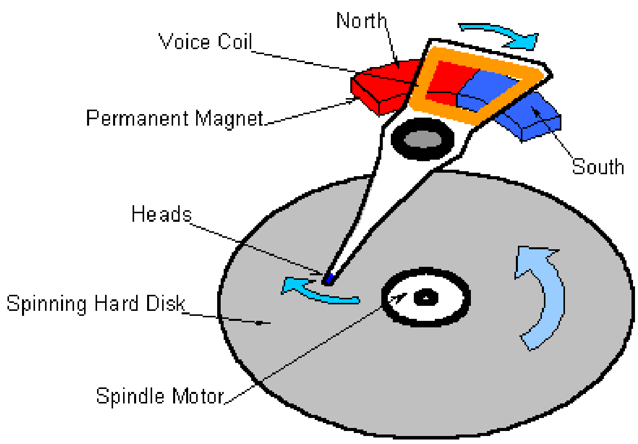

Figure 15: *Schematic representation of the construction of a hard disk drive.*

Writing & Reading Data

Writing of data is performed using an inductive head, as illustrated in figure 16. Reading of data also uses an inductive head or, as in modern hard disk drives, a giant magnetoresistive (GMR) head (illustrated in figure 16).

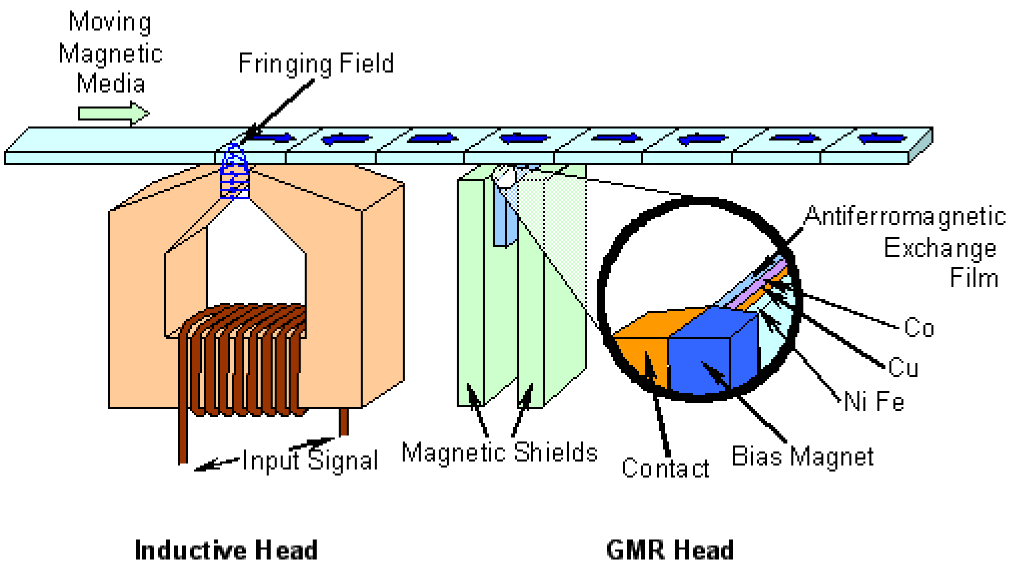

Figure 16: *Schematic of an inductive read / write head and a GMR read head.*

The writing process involves passing a current (i.e. the signal to be recorded) through the coil of the head. This current generates a field in the air gap of the C-shaped core and a fringing field (in the plane of the tape or disk) that extends out of the gap to the tape or disk that is moving past it.

The fringing field will change the magnetic state of the media and if the magnetic properties of the media are appropriate then the remanence of the tape in that region will be proportional to the amount of current applied to the coil. For digital signals only two remanent states are required for the material and hence the material requirements are not as stringent as for analogue recording, although smaller particle size is desired for high storage capacity and faster access time.

The reading process when carried out with an inductive head is very similar to the writing process. The magnetic fields extending out from the tape or disk induce a field in the C-shaped core of the read head, which in turn generates a voltage in the coil. This voltage can then be turned back into the original signal, be it audio, visual or digital data.

In modern hard disk drives the data is read back using a GMR head. The GMR element of this head experiences changes in electrical resistance under the influence of a magnetic field. They can sense very low magnetic fields and have a very high spatial resolution.

The use of GMR heads is essential as the increased storage density and smaller magnetic domain size in the media means that the field strength, at a specific height above the surface of the media, has decreased.

The GMR element shown in figure 16 is a spin valve type with 4 layers: an antiferromagnetic exchange film (e.g. iron/manganese); a layer of cobalt with its direction of magnetisation pinned by the antiferromagnetic exchange film (upwards in fig.16); a layer of copper which is a spacer and a layer of nickel/iron with its direction of magnetisation free to move under the influence of the magnetic field from the recording media.

The biasing magnetic layer magnetises the NiFe in the plane of the film and perpendicular to the direction of magnetisation of the Co film. When the direction of magnetisation of the NiFe moves towards the direction of magnetisation of the Co then there is a drop in resistance; when it moves away then there is an increase in the resistance.