## 7.3.2 Anwendungen außer magnetische Speicher

Dieses Modul ist zur Abwechslung mal auf englisch.

- Es ist direkt aus dem Hyperskript "Electronic Materials" übernommen. Es empfiehlt generell, beim Magnetismus mal in diesem Skript zu blättern.
- Trotz der Überschrift kommen hier auch magnetische Speicher vor; damit ergibt sich eine Gesamtübersicht.

## General Overview

What are typical applications for magnetic materials? A somewhat stupid question – after all we already touched on several applications in the preceding subchapters.

- But there are most likely more applications than you (and I) are able to name. In addition, the material requirements within a specific field of application might be quite different, depending on details.
- So let's try a systematic approach and list all relevant applications together with some key requirements. We use the abbreviation $\mathbf{M_S}$, $\mathbf{M_R}$, and $\mathbf{H_C}$ for saturation, remanence, and coercivity, resp., and **low** ω, **medium** ω, and **high** ω with respect to the required frequency range.

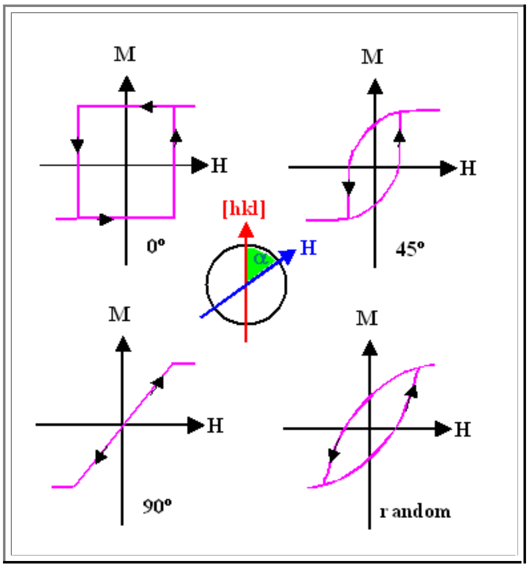
| Field of application | Products | Requirements | Materials |
|---|---|---|---|
| **Soft Magnets** | | | |
| **Power conversion electrical - mechanical** | Motors<br>Generators<br>Electromagnets | Large $\mathbf{M_R}$<br>Small $\mathbf{H_C}$<br>Low losses **=** small conductivity<br>low ω | **Fe**based materials, e.g.<br>**Fe +** ≈**(0,7 - 5)% Si**<br>**Fe +** ≈ **(35 - 50)% Co** |
| **Power adaption** | (Power) Transformers | | |
| **Signal transfer** | Transformer<br>("Überträger") | Linear **M - H** curve | |
| | **LF** ("low" frequency; up to ≈ **100 kHz**) | Small conductivity<br>medium ω | **Fe +** ≈ **36 % Fe/Ni/Co** ≈ **20/40/40** |
| | **HF** ("high" frequency up to ≈ **100 kHz**) | Very small conductivity<br>high ω | **Ni - Zn** ferrites |
| **Magnetic field screening** | **"Permalloy"**<br>**"Mu-metal"** | Large **dM/dH**for **H** ≈ **0**<br>ideally $\mathbf{\mu_r=0}$ | **Ni/Fe/Cu/Cr** ≈**77/16/5/2** |
| **Hard Magnets** | | | |
| **Permanent magnets** | Loudspeaker<br>Small generators<br>Small motors<br>Sensors | Large $\mathbf{H_C}$ (and $\mathbf{M_R}$) | **Fe/Co/Ni/Al/Cu** ≈**50/24/14/9/3**<br>$\mathbf{SmCo_5}$<br>$\mathbf{Sm_2Co_{17}}$<br>**"NdFeB"** **(**$\mathbf{=Nd_2Fe_{14}B}$**)** |
| **Analog data storage** | Video tape<br>Audio tape | Medium $\mathbf{H_C}$ (and $\mathbf{M_R}$),<br>hystereses loop as rectangular as possible | **NiCo**, **CuNiFe**,<br>$\mathbf{CrO_2}$<br>$\mathbf{Fe_2O_3}$ |
| **Digital data storage** | Ferrite core memory<br>Drum | | |
| | Hard disc, Floppy disc | | |
| | Bubble memory | Special domain structure | Magnetic garnets **(**$\mathbf{AB_2O_4}$, or $\mathbf{A_3B_5\,O_{12}}$), e.g.<br>with **A=** Yttrium (or mixtures of rare earth), and **B=**mixtures of **Sc**, **Ga**, **Al**<br>Most common: $\mathbf{Gd_3Ga_5O_{12}}$ |

| Specialities | | | |
|---|---|---|---|
| **Quantum devices** | ***GMR*** reading head<br>***MRAM*** (for recent developments see also here) | Special spin structures in multilayered materials | |

- As far as materials are concerned, we are only scratching the surface here. Some more materials are listed in the link

## Soft Ferromagnets

- The general range of applications for soft magnets is clear from the table above. It is also clear that we want the hystereses loop as "flat" as possible, and as steeply inclined as possible. Moreover, quite generally we would like the material to have a high resistivity.
  - The requirements concerning the maximum frequency with which one can run through the hystereses loop are more specialized: Most power applications do not need high frequencies, but the microwave community would love to have more magnetic materials still "working" at **100 GHz** or so.
- Besides trial and error, what are the guiding principles for designing soft magnetic materials? There are simple basic answers, but it is not so simple to turn these insights into products:
  - Essentially, *remanence* is directly related to the ease of movement of domain walls. If they can move easily in response to magnetic fields, remanence (and coercivity) will be low and the hystereses loop is flat.
- The essential quantities to control, partially mentioned before, therefore are:
  - The *density of domain walls*. The fewer domain walls you have to move around, the easier it is going to be.
  - The *density of defects* able to "pin" domain walls. These are not just the classical lattice defects encountered in neat single- or polycrystalline material, but also the cavities, inclusion of second phases, scratches, microcracks or whatever in *real* sintered or hot-pressed material mixtures.
  - The general *anisotropy* of the magnetic properties; including the anisotropy of the magnetization ("*easy*" and "hard" direction, of the magnetostriction, or even induced the shape of magnetic *particles* embedded in a non-magnetic matrix (we must expect, e.g. that elongated particles behave differently if their major axis is in the direction of the field or perpendicular to it). Large anisotropies generally tend to induce large obstacles to domain movement.
- A few general recipes are obvious:
  - Use well-annealed material with few grain boundaries and dislocations. For **Fe** this works, as already shown before.
  - Align the grains of e.g. polycrystalline **Fe**-based material into a favorable direction, i.e. use materials with a **texture**.
  - Doing this by a rather involved process engineered by **Goss** for **Fe** and **Fe-Si** alloys was a major break-through around **1934**. The specific power loss due to hystereses could be reduced to about **2.0 W/kg** for regular textured **Fe** and to **0.2 W/kg** for (very difficult to produce) textured **Fe** with **6% Si** (at **50 Hz** and **B** ≈ **1 T**)
  - Use isotropic materials, in particular **amorphous metals** also called **metallic glasses**, produced by extremely fast cooling from the melt. Stuff like $\mathbf{Fe_{78}B_{13}Si_{19}}$ is made (in very thin very long ribbons) and used.
  - Total losses of present day transformer core materials (including eddy current losses) are around **0,6 W/kg** at **50 Hz** which, on the one hand, translates into an efficiency of **99,25 %** for the transformer, and a financial loss of roughly **1 $/kg** and year – which is not to be neglected, considering that a big transformer weigh many tons.




- Reduce the number of domains. One solution would be to make very small magnetic particles that can only contain one domain embedded in some matrix. This would work well if the easy direction of the particles would always be in field direction, i.e., if all particles have the same crystallographic orientation pointing in the desired direction as shown below.
- This picture, by the way, was calculated and is an example of what can be done with theory. It also shows that single domain magnets can have ideal soft or ideal hard behavior, depending on the angle between an easy direction and the magnetic field.
- Unfortunately, for randomly oriented particles, you only get a mix – neither here nor there.

Well, you get the drift. And while you start thinking about some materials of your own invention, do not forget: We have not dealt with eddy current losses yet, or with the resistivity of the material.

- The old solution was to put **Si** into **Fe**. It increases the resistivity substantially, without degrading the magnetic properties too much. However it tends to make the material brittle and very hard to process and texture.
- The old-fashioned way of stacking thin insulated sheets is still used a lot for big transformers, but has clear limits and is not very practical for smaller devices.
- Since eddy current losses increase with the square of the frequency, metallic magnetic materials are simply not possible at higher frequencies – i.e., as soon as you deal with signal transfer and processing in the **kHz**, **MHz** or even **GHz** region. We now need *ferrites*.

| **Fragebogen** |
| --- |
| **Schnelle Fragen zu 7.3.2** |