Application oriented development of amorphous and nanocrystalline soft magnetic materials.

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Introduction and Basic Features

The talk surveys characteristic features of amorphous and nanocrystalline alloys particularly relevant for soft magnetic applications. Both materials have much in common starting from their way of production by rapid solidification as a thin ribbon and ranging over to the key factors which determine their magnetic properties. Thus, their structural correlation length, *D*, is much smaller than the exchange length L_{ex} (domain wall width). This results in a virtually negligibly magneto-crystalline anisotropy contribution (Fig. 1) − the prerequisite for good soft magnetic behaviour.

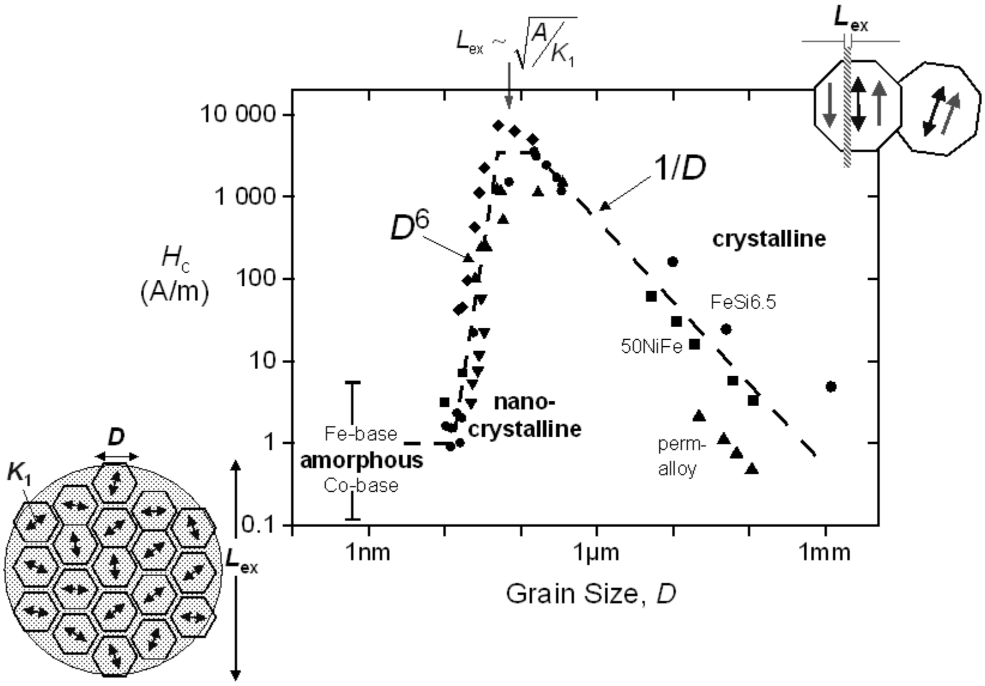

Fig. 1: Coercivity, H_c, versus structural correlation length (grain size), *D*, for various soft magnetic metallic alloys. In amorphous and nanocrystalline systems the randomly oriented magnetocrystalline anisotropy, K_1, is averaged out due to the smoothing effect of exchange interaction *A* (cf. [1]).

Superior soft magnetic properties additionally require a low magnetostriction (Fig. 2). This is realised for amorphous Co-based alloys and for nanocrystalline Fe-base alloys on which we will focus. An important point to stress is that for both amorphous and nanocrystalline materials a vanishing saturation magnetostriction λ_s really results in stress insensitivity of the soft magnetic properties. This is again a consequence of the small structural correlation length. The situation, thus, contrasts with that for large grained crystalline systems, where an average zero saturation magnetostriction does generally not imply stress-insensitivity of the hysteresis loop.

Due to their production inherent low thickness and relatively high electrical resitivity, finally, rapidly solidified materials additionally reveal a favourable high frequency behaviour making them even competitive with MnZn ferrites (Fig. 3). This is ultimately a most important issue for their success in application.

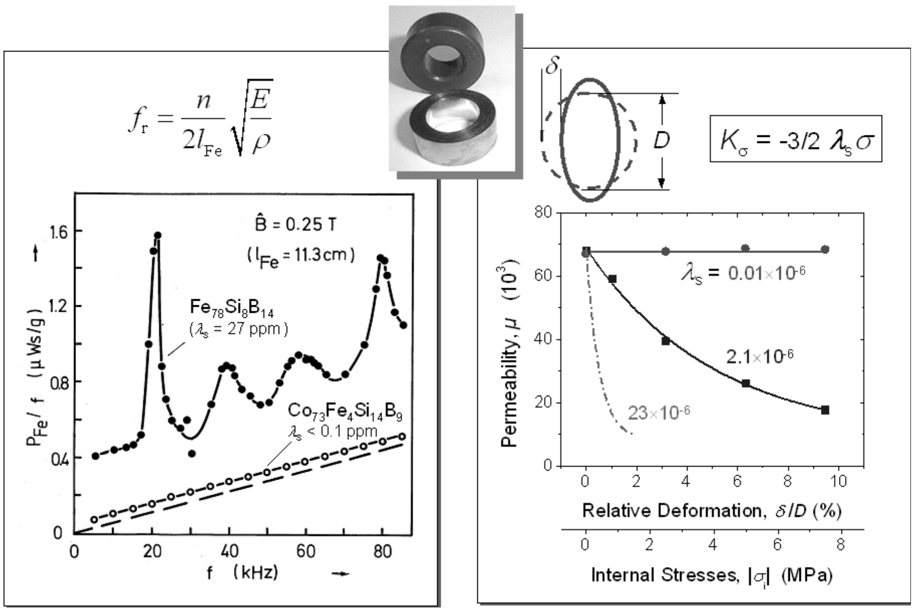

Fig. 2: Effect of magnetostriction on losses P_{Fe} and permeability.

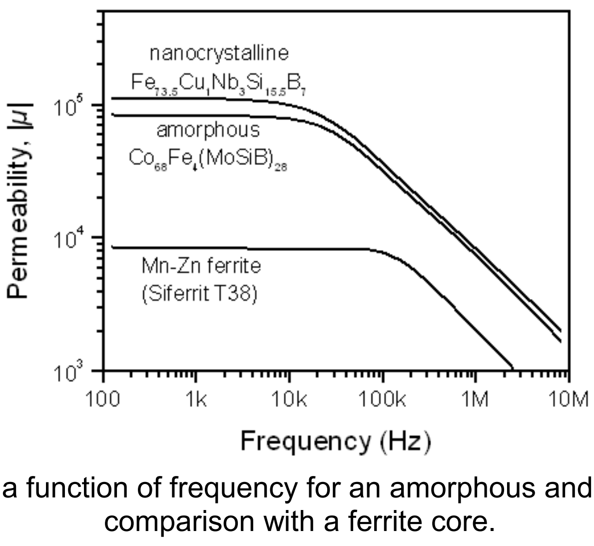

Fig. 3: Permeability as a function of frequency for an amorphous and nanocrystalline alloy in comparison with a ferrite core.

Tayloring the Soft Magnetic Properties

Soft magnetic applications typically require a well defined shape of the hysteresis loop with a specific level of permeability. This is accomplished by annealing induced uniaxial anisotropies. In particular, magnetic field induced anisotropies are of tremendous practical relevance. Their orientation relative to the magnetic path controls the shape of the hysteresis loop (Fig. 4a). The magnitude of the induced anisotropy constant, K_u, controls the level of the permeability (Fig. 4b) and, particularly for square loops, it is a decisive factor for excess eddy current losses (Fig. 5). Appropriate choice of the alloy composition and the annealing conditions allows to vary K_u by about three orders of magnitude.

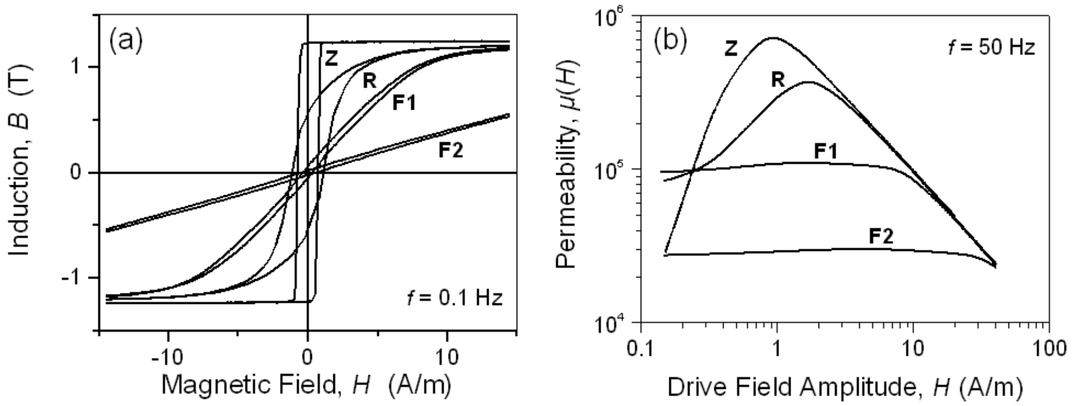

Fig. 4: Typical dc hysteresis loops and 50 Hz permeability of nanocrystalline $Fe_{73.5}Cu_1Nb_3Si_{15.5}B_7$ (VITROPERM® 800) annealed without magnetic field (R), with a magnetic field oriented parallel (Z) and transverse (F1, F2) to the magnetic path (F1 and F2 refer to different temperature time profiles [1]).

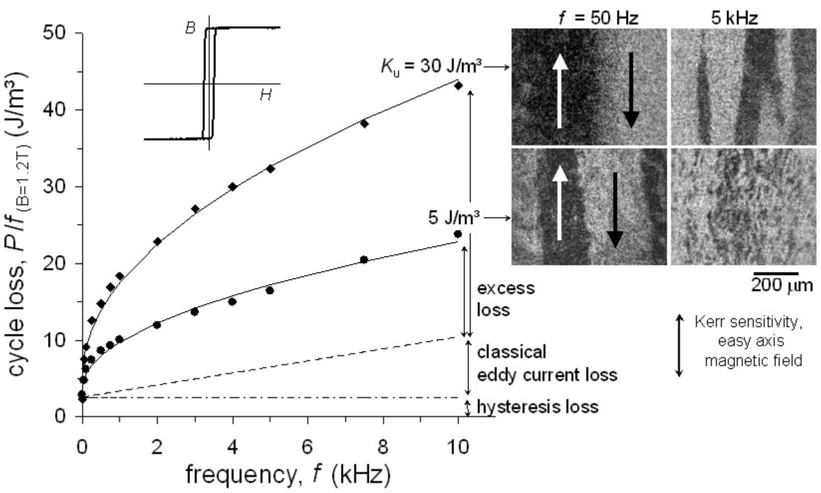

Fig. 5: Power loss and dynamic domain structure of nanocrystalline $Fe_{73.5}Cu_1Nb_3Si_{15.5}B_7$ (VITROPERM® 800) with a square loop achieved by inducing a weak and strong longitudinal anisotropy K_u, respectively.

Conclusions

Amorphous Co-base and nanocrystalline Fe-base alloys presently offer the best available static and dynamic soft magnetic properties. Both alloy systems reveal isotropic near-zero magnetostriction. The advantages of the nanocrystalline material are its higher saturation induction of at least 1.2 T and a significantly better thermal stability of the soft magnetic properties. The combination of high saturation magnetisation, high permeability, good frequency behaviour, low losses and the good thermal stability allows the reduction of size and weight of magnetic components used in, for example, switched mode power supplies or telecommunication. Apart from its technical performance the material is based on the inexpensive raw materials iron and silicon. Accordingly, nanocrystalline alloys are found in a steadily increasing number of applications previously served by amorphous Co-based alloys or MnZn ferrites. Yet, the variability of their soft magnetic properties as well as their form of delivery so far is still restricted compared to amorphous or other soft magnetic materials. Thus, amorphous alloys may reveal good soft magnetic properties already in the as quenched state or after moderate annealing. They, hence, can be delivered as a semi-finished, ductile product useful for e.g. flexible magnetic screening or for sensor applications, most noticeably in electronic article surveillance. Accordingly, the major draw-back of the nanocrystalline materials is the severe embrittlement upon crystallisation which requires final shape annealing and restricts their application mainly to toroidally wound cores.

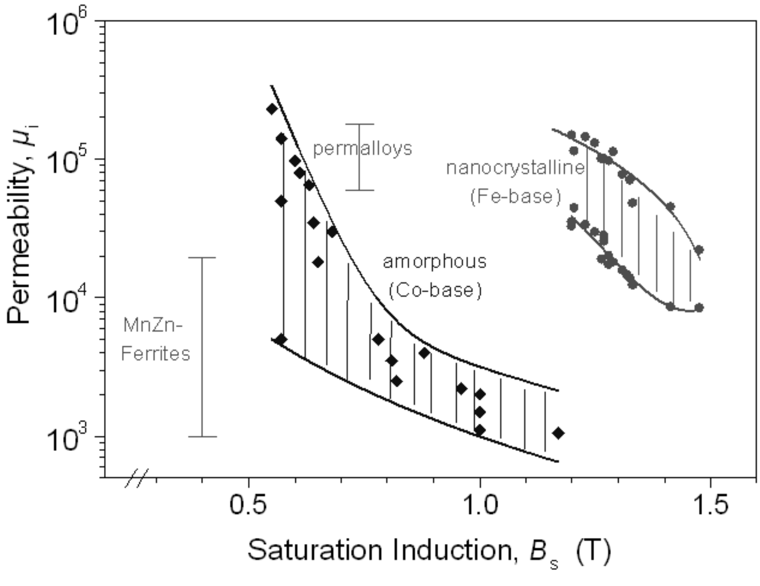

Fig. 6: Permeability and saturation induction of near-zero magnetostrictive soft magnetic materials.

References

[1] G. Herzer, Nanocrystalline Soft Magnetic Alloys in Handbook of Magnetic Materials vol. 10 (Ed. K.H. Buschow) chapter 3, pp. 417-462, Elsevier Science 1997