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Nanocrystalline materials for soft magnetic and magnetocaloric applications

The reduction of the grain sizes to the nanometer range may vary drastically the physical properties of materials, including the magnetic behaviour. Typical examples of such systems are nanocrystalline Fe-based (NANOPERM-type) and FeCo-based (HITPERM-type) alloys prepared by devitrification of melt-spun amorphous precursors, which belong to an important group of soft magnetic materials. The properties of these materials can vary widely, depending on the size and volume fraction of the nanocrystalline grains as well as on the magnetic properties of the intergranular amorphous matrix phase. The nature and strength of magnetic coupling between the grains versus temperature play there a crucial role.

In this talk we focus our attention on the relationship between the microstructure and magnetic behavior in series of $(Fe_{1-x}Co_x)_{81}Nb_7B_{12}$ (x=0, 0.25, 0.33, 0.5) nanocrystalline alloys. We show that the ternary FeNbB nanocrystalline alloys exhibit a variety of phenomena starting from spin-glass like behavior at cryogenic temperatures, followed by very soft magnetic behaviour at intermediate temperatures, and finally, approaching the Curie temperature of the amorphous matrix, T_c(am), a marked magnetic hardening due to a decoupling between nanograins occurs [1]. Above T_c(am), the effects of superparamagnetic relaxations start become dominant, especially in the samples with lower volume fractions of nanocrystalline particles. Strikingly different behaviour is observed for HITPERM-type samples, where the α`-FeCo nanograins remain well magnetically coupled up to high temperatures due to a significant increase of the Curie temperature of the residual amorphous matrix. The differences in the soft magnetic properties at elevated temperatures are discussed for the samples with different cobalt content and various volume fractions of nanocrystals.

The magnetocaloric effect (MCE) is another example where the nanometer size of magnetic particles influences markedly their properties. In early nineties, an enhanced magnetocaloric effect was predicted for some superparamagnetic materials by Shull et al. [2]. They showed that in superparamagnetic spins clusters, the magnetic moments are more easily aligned at lower fields and higher temperatures than are the single spins in a paramagnetic system. This can results for certain temperatures and fields in larger entropy changes than that in paramagnetic or ferromagnetic materials. This prediction was confirmed for some superparamagnetic nanocomposites and more recently for high-spin molecular magnetic clusters. Most of these studies have been devoted to transition metal based materials. In this talk, we present our recent results on the magnetocaloric properties in the dysprosium oxide passivated Dy nanoparticles (Dy(O)), prepared by an arc-discharge method in argon. These nanoparticles are composed of paramagnetic dysprosium oxide and small amount of tiny superparamagnetic Dy, which is located in the core part of bigger nanoparticles. We show that the presence of small amount of metallic Dy in Dy(O) nanoparticles leads to a marked enhancement of the MCE as compared to commercial Dy_2O_3 powder, which was used in this study for sake of comparison. The enhancement of the MCE was particularly strong at low applied fields, which is in agreement with the superparamagnetic nature of the metallic Dy nanoparticles.

[1] I. Škorvánek, S. Skwirblies and J. Kötzler, Phys. Rev. B **46,** 2001, 184437
[2] R.D. Shull, L.J. Swartzendruber and L.H. Bennett, Proc. 6^{th} Int. Cryocoolers Conf., eds. G. Green and M. Knox, David Taylor Research Center Publ. no. DTRC-91/002, Annapolis, MD (1991) p. 231