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First-order-reversal-curve investigation of Pr-Fe-B-based exchange spring magnets

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Abstract – The spring magnets studied here consist of ~100 nm grains of Fe surrounded by a hard magnetic material based upon Pr-Fe-B. First order reversal curves (FORC) were determined and the FORC probability distribution was determined for two samples, one well-coupled and the other uncoupled. Switching field distributions were calculated from the FORC probabilities and interpreted in terms of the microstructure.

The basic principle behind exchange spring magnets was enunciated by Kneller and Hawig several years ago: nanometer-sized grains of a hard magnetic material may couple to grains of a soft material to produce unusual and interesting properties. This paper presents an analysis of two Pr-Fe-B-based materials doped with Ti-C and Cr in terms of first-order-reversal-curves (FORCs) which allow the characterization of the coercive and interaction field distributions. A detailed analysis of the microstructure of these materials, determined by transmission electron microscopy (TEM), allows us to give a physical interpretation of the parameters obtained from the FORC analysis. Alloys of composition $(Pr_{9.5}Fe_{84.5}B_6)_{0.96}Cr_{0.01}(TiC)_{0.03}$ were produced by melting the elements in an arc furnace. Ribbons were obtained by melt-spinning the alloys on a rapidly rotating Cu wheel in a He atmosphere. The wheel speed was varied (15-25 m/s) in order to produce ananocrystalline composite with optimal magnetic properties. TEM showed the material to consist of 100 nm Fe grains surrounded by hard magnetic material. See figure 1 below. FORC curves, as well as other magnetic properties, were measured with a vibrating sample magnetometer (VSM) mounted on a 90 kOe superconducting magnet. See figure 2 below for the well-coupled sample. For this particular alloy H_c = 12.5 kOe and $(BH)_{max}$ = 13.6 MGOe. FORC curves were obtained for samples where the hard and soft phases are either uncoupled or well-coupled. X-ray diffraction data of the nanocrystalline composites were collected with a Philips PW1710 diffractometer (λ =1.5405 Å). Rietveld analysis of a sample without Cr showed essentially two phases, $Pr_2Fe_{14}B$ (68 wt%) with lattice parameters a = 0.881 nm and c = 1.222 nm, and α-Fe (32 wt%) with a = 0.288 nm., consistent with the TEM observations. Switching field distributions were calculated from the FORC probability distribution and are consistent with the idea that the uncoupled sample has a larger percentage of uncoupled soft magnetic material present.

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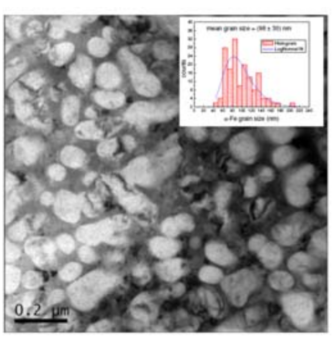

Fig. 1 Microstructure of spring magnet.

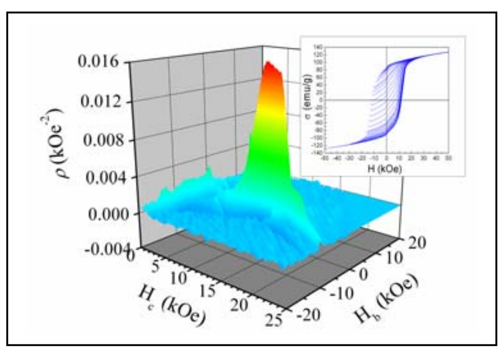

Fig. 2 FORC probability distribution and FORC curves.