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Exchange coupled hard magnetic materials

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In the last years a new family of hard magnetic materials was developed. In nanocrystalline isotropic rapidly quenched Nd-Fe-(B,Si) a remanence enhancement above 0.5 Ms was found. This reason is that the magnetic exchange length $l_{ex}=\sqrt{\frac{A}{K}}$ (A..exchange,K...magnetocrystalline anisotropy) becomes comparable with the grain size. Nanocrystalline R-Fe-B (R = Nd, Pr) can be produced with low rare earth content, stochoimetric (means close to $R_2Fe_{14}B$) and with high R content. The stochoimetric samples allow the study of the effect of the exchange coupling on various intrinsic properties (such as the spin reorientation, the Curie temperature, the magnetic anisotropy). The material with low R content consists of a nanocomposite between soft magnetic α-Fe or Fe_3B and hard magnetic $R_2Fe_{14}B$. The hard magnetic grains polarize the soft magnetic material (which have a higher saturation magnetization) thus leading to a higher remanence, however accompanied by a reduction of the coercivity.

In the present work the temperature dependence of the magnetic parameters (saturation magnetization, remanence, coercivity, anisotropy field) of remanence enhanced R-Fe-B material is presented. All magnetic properties were measured using a pulsed field magnetometer. The anisotropy field was determined using the SPD technique. In exchange coupled material a small but significant reduction of the anisotropy field was found. The experimentally determined $M_S(T)$, $M_r(T)$, $H_C(T)$ and $E_A(T)$ (anisotropy energy) was used to calculate the temperature dependence of the exchange length, which increases monotonically with increasing temperature. However the enhancement relevant ratio M_r/M_S decreases slightly with increasing temperature which is in contradiction to the expectations. The temperature dependence of M_r/M_S corresponds to the with decreasing temperature increasing„exchange domain" size as determined by neutron depolarization.

Additionally all measured magnetic parameters were used to test the validity of existing models which gives a relation between the remanence and the coercivity such as:

$$\frac{M_r}{M_s}=\frac{1}{2}[\cos(1-2\frac{H_C}{H_A})+\frac{\pi}{2}(1-s\frac{H_C}{H_A})]$$

This formula was derived from the random anisotropy model. It predicts a with increasing M_r/M_S ratio decreasing coercivity. Another model uses a numerical approach based on a micromagnetic calculations using a finite element method leading to the following relation:

$$M_r = M_s[a - b\ln(\frac{D}{\delta^{hard}_B})]$$

$$M_S = M_s^{hard}.v^{hard} + M_S^{soft}.v^{soft}$$

D...grain size, $\delta_b = \pi\sqrt{\frac{A}{K}}$ ...domain wall width of the hard magnetic phase,

M_S^{hard} ....saturation magnetization of the hard magnetic phase.

M_s^{soft} ....saturation magnetization of the soft magnetic phase

v^{hard}, v^{soft} ....volume fractions of hard and soft magnetic material.

The constants a and b depend on the amount of soft magnetic phase.

This model is much closer to the experimental behavior as the previous one, however there exists still deviations which are unclear.