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The Characterization of Interaction Effects in Nd-Fe-B-based Nanocomposite Hard Magnets Prepared by Spark Plasma Sintering

N. Lupu[(1)*], M. Grigoras[(1)], M. Lostun[(1,2)] and H. Chiriac[(1)]

(1) Magnetic Materials and Devices Department, National Institute of R&D for Technical Physics, 700050 Iasi, Romania, e-mail: nicole@phys-iasi.ro
(2) Faculty of Physics, "Alexandru Ioan Cuza" University, 700506 Iasi, Romania
*Corresponding author.

Abstract – Composite magnets were obtained by SPS consolidation of a mixture of ball-milled powders prepared from $Nd_{15}Fe_{79}B_6$ and $Nd_{16}Fe_{78}B_6$ nanocrystalline melt-spun ribbons and Fe or Fe_2Co alloys. The addition of soft magnetic powders increases the remanent magnetization of the SPS magnets to 6.4-6.7 kG, whilst the maximum energy product is also increased to 9-10 MGOe. The profile of the demagnetizing curves is smoother for SPS nanocomposite magnets compared with ball-milled powders, being an indication of a cooperative process in which both exchange-coupling between grains and magnetostatic interactions between the powders of hard and soft magnetic materials are present.

Nanocomposite RE-Fe-B permanent magnets mainly consist of a fine mixture of $RE_2Fe_{14}B$ hard magnetic phase and one magnetically soft component with high saturation magnetization (most commonly Fe-based), exchange coupled [1]. Recent work proved the important role played by magnetostatic interactions in the increase of the nucleation and coercive field values of nanocomposite permanent magnets in the detriment of the exchange coupled interactions [2].

In this paper, we will discuss our results on the magnetic properties of nanocomposite magnets prepared by spark plasma sintering (SPS) method from mixtures of ball-milled powders of non-stoichiometric Nd-Fe-B nanocrystalline melt-spun ribbons and Fe-based or Co-based alloys. Non-stoichiometric $Nd_{15}Fe_{79}B_6$ and $Nd_{16}Fe_{78}B_6$ nanocrystalline melt-spun ribbons as well as Fe_2Co crystalline melt-spun ribbons having thicknesses of 25 μm and widths of 3-5 mm were prepared. The ribbons have been further used as precursors to prepare powders by high-energy ball-milling. The size of the micropowders varied between 5 and 150 μm, depending on the milling time. Commercial Fe based micropowders (below 10 μm in diameter) have been used, too. The powders have been mixed in different weight ratios, placed into a graphite die, and then sintered under vacuum by SPS technique at 2 different pressures of 50 and 70 MPa, respectively, applied during the heating to 600^0C. The specimens were 1 mm in diameter and 1-2 mm in thickness.

The optimum magnetic properties were obtained for NdFeB/Fe nanocomposite magnets consolidated at an applied pressure of 50 MPa: B_r = 6.6 kG, $_iH_c$ = 18.5 kOe and $(BH)_{max}$ = 10.9 MGOe for $Nd_{15}Fe_{79}B_6$-5Fe or B_r = 6.4 kG, $_iH_c$ = 17.5 kOe and $(BH)_{max}$ = 10.2 MGOe for $Nd_{16}Fe_{78}B_6$-4Fe. Whereas Fe_2Co ball-milled powders have B_s = 22 kG, their mixture with NdFeB followed by SPS consolidation leads to moderate values of the magnetic characteristics, i.e. B_{3T} = 7.4 kG, B_r = 5.7 kG, $_iH_c$ = 20.0 kOe and $(BH)_{max}$ = 8.1 MGOe for 4 wt.% addition of Fe_2Co and an applied pressure of 50 MPa. By consolidation through the SPS technique the maximum energy product generally increases with about 10% for optimal processing parameters, the values being comparable with those obtained up to now for anisotropic nanocomposite magnets [3,4].

Despite the fact that the powders exhibit larger coercive field, the coupling between soft and hard magnetic phases is improved for nanocomposite magnets. The strength of the coupling/decoupling is indicated by the second shoulder of dM/dH=f(H) curves appearing at almost zero applied field, which is very small for SPS consolidated nanocomposite magnets, but also by the height of the first peak. The exchange coupling plays the predominant role in melt-spun nanocrystalline ribbons and the presence of the second shoulder is missing, whereas for nanocomposites the magnetostatic interactions become more predominant. However, the percentage of exchange interactions contribution to the macroscopic response of the nanocomposite systems is still very important, considering that usually the magnetostatic interactions are reducing the coercive field values. All these aspects will be discussed in detail considering the composition and ratio of the mixed powders, as well as the compaction parameters.

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References

[1] E.F. Kneller, R. Hawig, IEEE Trans. Magn., 27 (1991) 3588-3560.
[2] A.M. Gabay, M. Marinescy, G.C. Hadjipanayis, J. Appl. Phys., 99 (2006) 08B506.
[3] M. Yue, J. Zhang, Y. Xiao, G. Wang, T. Li, IEEE Trans. Magn., 39 (2003) 3551-3553.
[4] T. Saito, IEEE Trans. Magn., 37 (2001) 2561-2563.