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Hard and soft magnetic properties of nanocrystalline Fe–Nd–Zr–B alloys containing intergranular amorphous phase (abstract)

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The nanoscale crystalline and amorphous phases obtained by partial crystallization of an amorphous phase in rapidly solidified $\text{Fe}_{90}\text{Nd}_{7-x}\text{Zr}_x\text{B}_3$ alloys were found to exhibit rather good hard magnetic properties in the composition range below 3 at. % Zr and good soft magnetic properties in the range above 4 at. % Zr. The hard magnetic alloys consist of nanoscale bcc–Fe and bct– $\text{Fe}_{14}\text{Nd}_2\text{B}$ particles surrounded by the remaining amorphous phase, while the soft magnetic alloys are composed of bcc–Fe and remaining amorphous phases. The particle size is measured to be about 20 nm for the bcc–Fe phase and 15 nm for the $\text{Fe}_{14}\text{Nd}_2\text{B}$ phase for the former alloys and about 10 nm for the bcc–Fe phase for the latter alloys. The volume fraction of the remaining amorphous phase is evaluated to be about 20 to 30 at. % and the Nd and Zr contents are much higher than the nominal concentrations for the hard and soft magnetic alloys from the high-resolution TEM images and nanobeam compositional analyses. The remanence (Br), intrinsic coercivity (iHc), and maximum energy product are 1.24 T, 200 kA/m, and 88 kJ/m³, respectively, for the nanocrystalline $\text{Fe}_{90}\text{Nd}_5\text{Zr}_2\text{B}_3$ alloy annealed for 180 s at 1023 K, while the saturation magnetization (Bs), coercivity (Hc), and permeability at 1 kHz are 1.63 T, 16 A/m, and 7000, respectively, for the nanocrystalline $\text{Fe}_{90}\text{Nd}_2\text{Zr}_5\text{B}_3$ alloy annealed for 180 s at 923 K. The high Br and Bs values are presumably due to the magnetic coupling between bcc–Fe particles via the ferromagnetic intergranular amorphous phase and the large iHc for the alloy containing more than 4 at. % Nd is due to the exchange magnetic interaction between $\text{Fe}_{14}\text{Nd}_2\text{B}$ particles via ferromagnetic bcc–Fe and amorphous phases. The appearance of the rather good hard and soft magnetic properties for the same alloy series containing the high Fe content is extremely important for future development of nanocrystalline hard and soft magnetic materials. © 1996 American Institute of Physics. [S0021-8979(96)63808-0]