Potential of RFe_z (z = 9-12) alloys as permanent magnet materials

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RFe_z compounds (R = rare earth element, z = 9-12) crystalized in the $ThMn_{12}$ structure [1] or the $TbCu_7$ structure [2] have been investigated as promising candidates for next-generation high-performance permanent magnet materials because they can contain large amounts of iron. Some of these compounds are reported to exhibit intrinsic magnetic properties of exceeding that of $Nd_2Fe_{14}B$ [3,4]. We have focused on the crystal phases appearing in such iron-rich R-Fe alloys, their phase stability, and the magnetic properties of these compounds for the last 30 years, and mainly obtained the following results and findings.

(1) The atomic radius of the element occupying the rare-earth site is an important factor to stabilize the $ThMn_{12}$ structure in $RFe_{10}Si_2$ system. The $ThMn_{12}$ phase was found in the system in which the individual rare-earth atomic radius were smaller than those of neodymium in $RFe_{10}Si_2$. In the $(Nd,Zr)Fe_{10}Si_2$ system, zirconium occupies the neodymium site and facilitates the formation of the $ThMn_{12}$ phase owing to the decrease in the atomic radius of the neodymium site [5].

(2) In $(Nd,Zr)Fe_{12-x}Si_x$, the $ThMn_{12}$ phase was not observed at $x \leqq 1$, and the Th_2Ni_{17} phase or the Th_2Zn_{17} phase were observed together with α-Fe. However, in $(R,Zr)(Fe,Co)_{10}$ rapidly quenched alloys (R=Nd, Sm, V_s = 40m/s), almost a single phase with the $TbCu_7$ structure was obtained. The presence of zirconium makes it possible to realize a $TbCu_7$ structure with a high lattice constant ratio c/a of more than 0.87. In the structure, it is believed that a greater number of the dumbbell arrangements of iron atoms exist. $(Sm,Zr)(Fe,Co)_{10}N_x$ prepared by rapid quenching, annealing, and nitogenation exhibited a high saturation magnetization ($\mu_0 M_s$) of 1.70 T and an anisotropy field ($\mu_0 H_a$) of 7.7 T [4].

(3) We have developed isotropic magnet powder with the composition of $(Sm,Zr)(Fe,Co)_zB_{0.1}N_x$ (z = 9-10). A small addition of boron is effective for forming the amorphous phase in the rapidly quenched alloys and for obtaining uniform and fine grains of the $TbCu_7$ phases after annealing. The magnetic properties of these powders are B_r = 1.00-1.07 T, H_{cJ} = 640-880 kA/m, $(BH)_{max}$ = 160-180 kJ/m^3. Isotropic bonded magnets fabricated using such powder show highest $(BH)_{max}$ = 123 kJ/m^3 [6] and are currently commercialized and used in various motors.

(4) Compounds containing a greater number of the dumbbell arrangements of iron atoms such as RFe_{12} having the $ThMn_{12}$ structure and RFe_{9-12} having the $TbCu_7$ structure tend to be appeared in alloys having the smaller atomic radius of the rare-earth site. However, use of heavy-rare-earth lowers the saturation magnetization. Therefore, it is important to realize a situation similar to the heavy-rare-earth compounds by the substitution of Nd or Sm with the element having a smaller atomic radius such as Zr.

In this presentation, I also mention recent topics on the intrinsic magnetic properties of RFe_{9-12} compounds and attempts to improve the coercivity, as well as some interesting issues that have not been solved for these compounds.

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