Nd-Fe-B permanent magnets with ultimate hard magnetic properties

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Due to the recent concern about the stable supply of heavy rare earth elements, attaining high coercivity in Nd-Fe-B magnets without using heavy rare earth (HRE) elements has received intense research interest in the past decade. However, the supply of rare earth elements has been stabilized in the last few years, and the renewed goal is to how to achieve the highest permanent magnetic properties with a balanced use of critical elements. In this talk, we will overview our recent progresses carried out at NIMS in collaboration with many industrial partners that were carried out toward the development of high coercivity Dy-free Nd-Fe-B permanent magnets. Thereafter, we discuss how to achieve ultimate permanent magnet properties with trace additions of HRE. To obtain better understandings of the microstructure-coercivity relationships, we investigated the microstructures of experimental Nd-Fe-B sintered magnets, those processed from HDDR power, and hot-deformed magnets with different values of coercivity depending on chemical compositions, processing routes and post-manufacturing heat treatments. The microstructure and magnetic domain observations have been carried out using aberration-corrected STEM, atom probe tomography (APT), magneto-optical Kerr microscopy and finite element micromagnetic simulations. We found that the intergranular phase parallel to the c-planes are mostly crystalline with a higher Nd concentration in contrast to that lying parallel to the c-axis that contains higher Fe content with an amorphous structure in both sintered and hot-deformed magnets. Micromagnetic simulations suggest the reduction of the magnetization in the latter is critical to enhance the coercivity. Based on these new experimental findings together with our detailed characterization results of the intergranular phases in Ga-doped Nd-Fe-B magnets, we developed a method to increase the coercivity of Nd-Fe-B hot-deformed magnets while keeping relatively high remanence.

This talk includes results obtained in collaboration with industrial collaborators including TOYOTA, Toyota Central Research Lab. Intermetallics and Daido Steel conducted under CREST and Collaborative Research Based on Industrial Demand projects.