Synthesis of R-TM hard magnetic powder by thermal plasma

Yusuke Hirayama
(National Institute of Advanced Industrial Science and Technology)

[Background]

Not so many compounds with higher potentials than those of $Nd_2F_{14}B$ as a permanent magnet material have been reported[1, 2]. Among them, only compounds that have been successfully synthesized in bulk are Ti-less compounds with a $ThMn_{12}$ structure[3] or nitrides with a $TbCu_7$ structure[4]. However, there are some difficulties to obtain an anisotropic fine powder of these compounds. It is well known that single-crystalline for an anisotropic magnet with higher remanence and fine particles for higher coercivity are necessary to exploit the potential of the compound as a permanent magnet. Here, the induction thermal plasma (ITP) process as a new process for further particle size refinement was focused on. For nanopowder fabrication, this process has the advantages of a high production rate, control over particle size, and an inherently contamination-free process. Moreover, it could be possible to obtain fine particles with stable and metastable phases by tuning the cooling rate. Attention should be paid to the handling of ultrafine metal particles which is highly reactive with oxygen and humidity in the air. Recently, we developed a low-oxygen ITP system (LO-ITP)[5], which enables us to prepare ultrafine metal powder in the controlled low-oxygen atmosphere. This technique was applied to prepare single-crystal ultrafine R-Fe alloy powders, especially for R = Nd in this research, with stable and metastable phases.

[Experiment]

The mixed powder of Fe (Kojundo Chemical Lab. Co., Ltd., Japan) and Nd with the atomic ratio of Nd : Fe = 2 : 3 was used as a starting powder. A TP-40020NPS (JEOL Co., Ltd.) was used for the ITP process, and a TP-99010FDR (JEOL Co., Ltd.) was used as the powder feeding system. In the thermal plasma process, the conditions of a process pressure of 100 kPa and a feed rate of up to 0.3 g/min were used. Transmission electron microscopy (TEM) sample was prepared by focused ion beam (FEI, Scios), and the microstructure was observed by TEM (JEOL ltd., JEM-ARM200CF equipped with CEOS ASCOR corrector) using an accelerating voltage of 120 kV. The anisotropic powder samples were prepared in the external magnetic field of 9 T at 400 K.

[Result and discussion]

According to the XRD profile, Nd-Fe alloy particles with the stable Th_2Zn_{17}-type phase and the metastable $TbCu_7$-type phase were selectively prepared by controlling the cooling rate of the ITP process. The single-crystal of particles was confirmed by HAADF-STEM. The fine particle size of less than 100 nm was obtained. From the numerical calculation, it was found that the alloying mechanism revealed that Nd and Fe nucleate and condense simultaneously in the liquid temperature range due to the formation of the alloy droplet during cooling. Both obtained powders could be aligned by the external magnetic field, indicating that obtained ultrafine powders by the LO-ITP process were anisotropic, which was confirmed by the XRD and magnetic measurement. Therefore, this process is a new promising way to achieve a new-generation anisotropic permanent magnet.

Reference

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