Oral | Material, processing, and characterization

Tue. Jul 29, 2025 9:00 AM - 10:25 AM JST | Tue. Jul 29, 2025 12:00 AM - 1:25 AM UTC Convention Hall(300, 3F)

[O5] RE-Fe-B Magnets III

Session Chair: Prof. Dagmar Goll(Aalen University)

Invited

9:00 AM - 9:20 AM JST | 12:00 AM - 12:20 AM UTC

[O5-1] New Insight into Development of Pr-based Grain Boundary Diffusion Process for High-Performance HRE-Free Nd-Fe-B Sintered Magnets

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Keywords：Nd-Fe-B sintered magnets、Pr-based grain boundary diffusion process、Heavy rare-earth free

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The Pr-based grain boundary diffusion process (GBDP), which forms the high-anisotropy Pr-rich shell within the Nd-Fe-B magnets, is the most promising method for obtaining high-coercivity in the magnets without use of heavy rare-earths (HRE, Tb or Dy)[1]. However, the coercivity gain by the current Pr-GBDP is only 0.2-0.3 T[1], which is insufficient to realize a high-coercivity above 2.5 T that can be achieved in HRE-free magnets by the HRE-GBDP[1]. To overcome this limitation, most researchers have focused on increasing the GBD-depth of Pr and controlling the Pr-concentration of shell to be higher by reducing the thickness of shell[2]. However, such microstructures are difficult to be realized simultaneously by the conventional approach[2]. A recent report by Kim *et al*. provides a novel insight into increasing both the GBD-depth of Pr and Pr-concentration of shell[3]. They found that shell formation induces undesirable grain growth during the GBDP because a unique grain boundary migration phenomenon, termed chemically induced liquid film migration (CILFM), is dominantly involved in the shell formation[3]. By the CILFM, Nd-rich GBP migrates while consuming the GBD source, leaving the shell behind[3]. Based on such a phenomenological feature, the CILFM can be defined as 1) GBD source consuming and 2) grain coarsening phenomenon. This directly indicates that if the CILFM is hindered during GBDP, the GBD-depth of HRE can be increased and thickness of the shell can be controlled to be thinner, which could lead to an increase in the HRE-concentration of shell[3]. Thus, to breakthrough the limit of the coercivity gain by the Pr-GBDP, a CILFM-inhibited GBDP should be developed. In this study, we developed HRE-free two-step GBDP consisting of the 1st-step GBDP with refractory metal (RM)-compounds or -alloys for forming the intergranular precipitates to hinder the CILFM, and the 2nd-step GBDP with low-melting Pr-containing alloys for forming the high-anisotropy Pr-rich shell. The low-melting TaF_5 compound (denoted as TF, T_m : ~100 ℃), eutectic Ti-Cu (denoted as TC, T_m : ~900 ℃ and Zr-Cu (denoted as ZC, T_m : ~950 ℃) alloys were selected as the RM-containing GBD source for the 1st-GBDP, which is a key step for the CILFM inhibition. The coercivity of HRE-free Nd-Fe-B magnets increases from 1.45 T to 1.85~2.0

T after the Pr-GBDP alone (one-step GBDP). Interestingly, by the CILFM inhibited two-step GBDP developed in this work, the coercivity of magnets reached 2.35 T (TF-Pr-GBDP sample, coercivity gain : 0.91 T), 2.46 T (TC-Pr-GBDP sample, coercivity gain : 1.02 T), and 2.47 T (ZC-Pr-GBDP sample, coercivity gain : 1.03 T), respectively, as shown in Fig. 1. The remanence of the one-step and two-step GBDP samples were 1.35 T (one-step GBDP), 1.31 T (TC-Pr-GBDP), and 1.30 T (ZC-Pr). The TEM observation revealed that the nano-sized RM-containing precipitates is formed along the grain boundaries during the 1st-step GBDP, thereby inhibiting the CILFM occurred to form the Pr-rich shell during the 2nd-step GBDP. As a result, compared to the one-step GBDP magnets, the grain size was decreased, the GBD-depth of Pr was increased, and thinner shell with higher Pr-concentration was formed in the two-step GBDP magnets. The hard magnetic properties of HRE-free magnets achieved in this work are sufficient to replace the commercial HRE-GBDP magnets. We believe that the CILFM-inhibited GBDP is a promising method that can eliminate the need for HRE in obtaining high-coercivity in Nd-Fe-B sintered magnets.

References 1. M. Komuro *et al*., IEEE Trans. Magn., 46 (2010) 3831. 2. T. Oikawa *et al.*, AIP Advan., 6 (2016) 056006. 3. T. H. Kim *et al*., Scr. Mater., 178 (2020) 433.