Grain boundary/Interface modification of Nd-Fe-B sintered magnets by low melting temperature Nd-TM (TM : Cu, Al, Zn) alloys

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One way to enhance the coercivity of Nd-Fe-B sintered magnets with minimum use of Dy is known to be Dy diffusion process [1]. In this process, microstructure of Nd-Fe-B sintered magnets is modified to $(Nd,Dy)_2Fe_{14}B$ shell and $Nd_2Fe_{14}B$ core region. The mechanism of the coercivity enhancement in Dy-diffusion processed magnets has been reported to be increase of magnetocrystalline anisotropy field, $H_a = 2K_u/M_s$, at the Dy-rich shell region [2]. Our finite element micromagnetic simulation studies have shown that the main reason for the coercivity enhancement by Dy diffusion process is reduction of saturation magnetization of Dy-rich shell region with a comparable magnetocrystalline anisotropy constant to the core region. In addition, coercivity of Dy-diffusion processed Nd-Fe-B sintered magnets cannot be enhanced unless $Nd_2Fe_{14}B$ grains are enveloped by a Nd-rich grain boundary phase. In this talk, we will present our efforts on how to reduce the saturation magnetization of the surface region of $Nd_2Fe_{14}B$ grains by introduction of a non-ferromagnetic element at the surface of $Nd_2Fe_{14}B$ grain combined with grain boundary modifications of large grain sized Nd-Fe-B sintered magnets.

Porous Nd-Fe-B sintered magnet which was partially sintered at 950°C with a composition of $Nd_{14.5}Fe_{79.1}B_{5.97}Al_{0.37}$ (at.%) was selected as starting material. The average grain size in the porous Nd-Fe-B sintered magnet was ~6µm. The magnet was covered by various Nd-TM (RE : Nd, TM : Cu, Al, Zn, …) powders followed by heat treatment at a temperature range of 550°C-800°C for 1-3h. The magnetic properties of the samples were measured using a SQUID-VSM. Microstructure of the samples were analyzed using SEM/FIB (Carl Zeiss 1540EsB) and TEM (Titan G2 80-200)).

Nd-Cu diffusion process on porous Nd-Fe-B sintered magnets just enhanced the coercivity from 0.4 T to 1.3 T. This obtained coercivity is much lower than that of Nd-Cu diffusion processed hot-deformed Nd-Fe-B magnets with a coercivity of 2.3 T. Back scattered electron (BSE) SEM observations showed that Nd-Cu phases remain at the triple junctions as isolated Nd and NdCu grains rather than infiltration into the grain boundaries of ~6µm grain sized sintered magnets. However, diffusion process of porous sintered-magnet using $Nd_{82}Al_{18}$ alloy led to the coercivity enhancement from 0.4 T to 1.45 T. Fig. 1 shows SEM-BSE image of Nd-Al diffusion processed sintered magnet. A thick Nd-rich phase was formed at the grain boundaries. Composition analysis of the grain boundary phase showed that this phase is free from Fe and Co suggesting that the grain boundary phase is non-ferromagnetic. Al was found to diffuse into the surface of $Nd_2Fe_{14}B$ grains and substitute for Fe forming $Nd_2(Fe,Al)_{14}B$ shell and $Nd_2Fe_{14}B$ core microstructure as shown in EDS maps in Fig. 1. Diffusion of Al into the $Nd_2Fe_{14}B$ grain and its substitution for Fe decreases saturation magnetization of the surface region leading to the enhancement of the anisotropy field locally at the surface of $Nd_2Fe_{14}B$ grains [3]. Although achieved coercivity in this work is just 1.45 T which is not as high as small grain sized Nd-Fe-B sintered magnets or Dy-diffusion processed Nd-Fe-B sintered magnets, the obtained microstructure can shed a light for development of a new process as a substitute for Dy-diffusion process to enhance the coercivity of Nd-Fe-B sintered magnets.

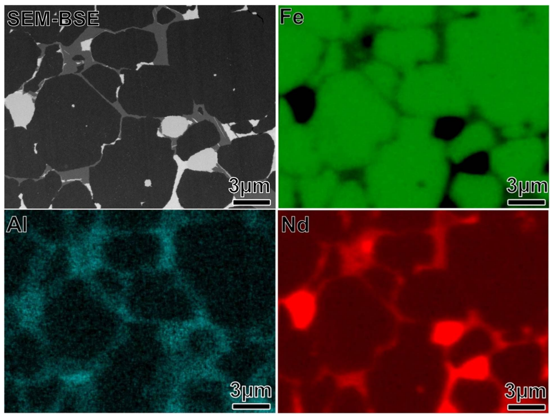

Fig. 1. Back scattered electron (BSE) SEM and EDS maps of Fe, Al, and Nd obtained from grain boundary and interface modified sintered Nd-Fe-B magnets. $Nd_2(Fe,Al)_{14}B$ shell region can be found on the surface of $Nd_2Fe_{14}B$ grains.

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