Prospect of 1-12 based permanent magnets

~ Demonstration of high coercivity in thin films and current status of 1-12 bulk magnet~

[1]Y.K. Takahashi, [1]D. Ogawa, [1]H. Sepehri-Amin, [2]T. Shima, [1]T. Ohkubo, [1]S. Hirosawa, [1]K. Hono
([1]NIMS, [2]Tohoku Gakuin Univ.)

$SmFe_{12}$-based compound is one of the candidates for next generation permanent magnet due to its high saturation magnetization ($\mu_0 M_s$), high anisotropy (K) and high Curie temperature (T_c) [1]. Since $SmFe_{12}$-based compound is unstable at RT, the addition of the phase stabilizing element is necessary, which causes large reduction in magnetization. Recently, Kuno *et al*.[2] reported high $\mu_0 M_s$ by reducing Ti composition which is one of the phase stabilizing elements and substituting Fe and Sm with Co and Zr, respectively. Later, Hirayama *et al.* [3] prepared the single crystal $Sm(Fe_{0.8}Co_{0.2})_{12}$ film by sputtering and demonstrated high magnetic properties of $\mu_0 M_s$=1.78 T, H_a =12 T and T_c =859 K., which are superior to those of $Nd_2Fe_{14}B$. Even in the working temperature of the motor in electric vehicle (EV) or hybrid EV (HEV), these properties are higher than those of $Nd_2Fe_{14}B$. One drawback in $Sm(Fe_{0.8}Co_{0.2})_{12}$ compound is too low coercivity ($\mu_0 H_c$) for the permanent magnet application. In order to demonstrate the high $\mu_0 H_c$, we have controlled the microstructure by the diffusion process [4] and cosputtering of the nonmagnetic elements [5].

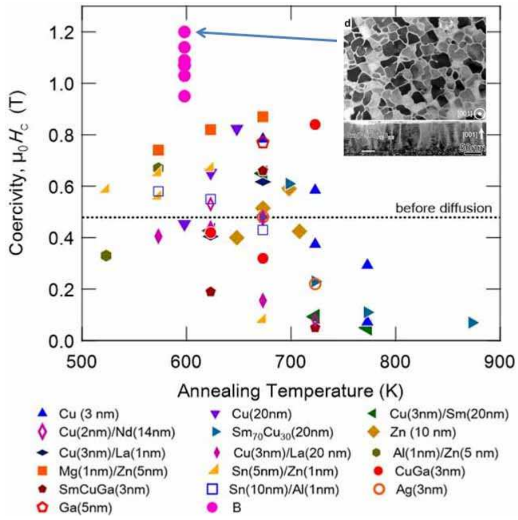

Fig. 1 Change of $\mu_0 H_c$ of the diffusion processed $Sm(Fe_{0.8}Co_{0.2})_{12}$ film as a function of annealing temperature. $\mu_0 H_c$ of the cosputtered $Sm(Fe_{0.8}Co_{0.2})_{12}$-B film is also shown.

Fig. 1 shows $\mu_0 H_c$ of the diffusion processed $Sm(Fe_{0.8}Co_{0.2})_{12}$ film as a function of annealing temperature. The optimum annealing temperature ranges from 623 K to 723 K. Cu, Cu-Ga, and Mg-Zn are the effective infiltration sources for igh $\mu_0 H_c$ corresponding to 0.78 T, 0.84 T, and 0.87 T, respectively. The microstructure of Cu-Ga diffused sample shows that the Cu and Ga are diffused into the grain boundary of $Sm(Fe_{0.8}Co_{0.2})_{12}$ grains. However, Cu and Ga do not form uniform intergranular phase. It could be the reason for marginal increase of $\mu_0 H_c$. B containing sample shows the highest $\mu_0 H_c$ of 1.2 T. As shown in the in-plane and cross-sectional TEM images of the inset, it forms well-separated nanogranular microstructure with about 40 nm diameter of $Sm(Fe_{0.8}Co_{0.2})_{12}$ grains perfectly enveloped by the B-rich amorphous grain boundary phase. Because of the magnetization and anisotropy difference between $Sm(Fe_{0.8}Co_{0.2})_{12}$ grains and grain boundary phase, the highest $\mu_0 H_c$ of 1.2T was achieved. Fig. 2 shows the temperature dependence of $\mu_0 H_c$ in the $Sm(Fe_{0.8}Co_{0.2})_{12}$ films with high $\mu_0 H_c$. Those in the commercial Nd-Fe-B magnets are shown for the comparison. $Sm(Fe_{0.8}Co_{0.2})_{12}$ films with high $\mu_0 H_c$ have small absolute value of temperature coefficient of coercivity (β ~ -0.2 %/K) due to the high T_c. These results indicate that $Sm(Fe_{0.8}Co_{0.2})_{12}$ could be a superior compound for permanent magnet application compared to $Nd_2Fe_{14}B$ magnet if optimum microstructure can be achieved in bulk with high $\mu_0 H_c$. In the talk, I would review current status of the investigation for 1-12 bulk magnet.

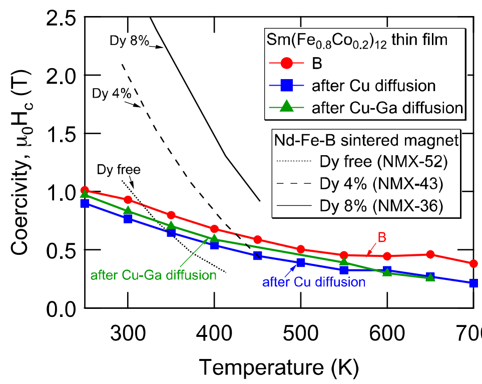

Fig. 2 Temperature dependence of $\mu_0 H_c$ in Nd-Fe-B magnets, $Sm(Fe_{0.8}Co_{0.2})_{12}$ film with Cu and Cu-Ga diffusion.

(1)K. Ohashi *et al.*, *IEEE Trans Magn.***23**, 3101 (1987).(2)T. Kuno *et al.*, *AIP Adv.* **6** 025221 (2016). (3) Y. Hirayama *et al*, *Scr. Mater.***138**, 62 (2017). (4) D. Ogawa *et al*, Scr. Mater164, 140 (2019). (5) H. Sepehri-Amin *et al*, Acta Mater194, 337 (2020).