High performance permanent magnets without critical elements

Research Project Outline for the 3rd Phase (FY2018-2021)

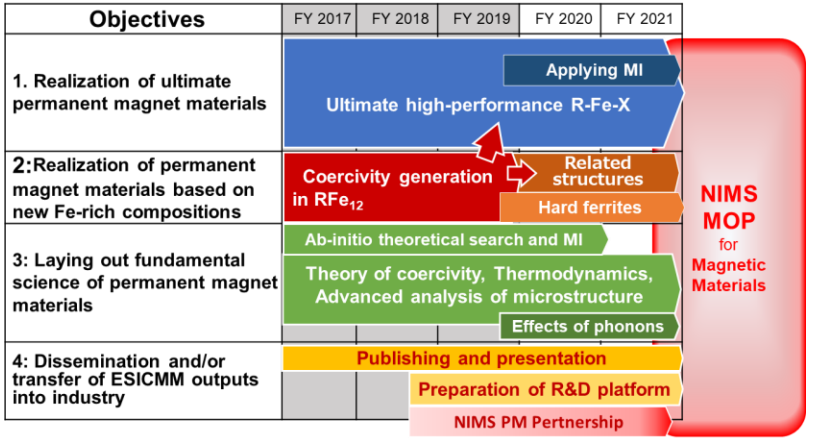
Ultimate Performance and Materials Science of Permanent Magnets

I. Realization of ultimate magnetic performance at operating high temperatures

I. Search and realization of Fe-based magnets (e.g., 1-12 compounds)

II. Laying out basic science of permanent magnets to optimize extrinsic properties (physics of coercivity and energy product, data base, and materials informatics)

IV. Dissemination of ESICMM basic research outputs to Industry and to create an open research platform for academia-industry cooperative research (NIMS-MOP)



ESICMM Road Map for FY 2018−FY2021 toward NIMS-MOP

Selected Research Results of FY 2019

◆Realization of high coercivity 1-12-type Sm-Fe-Co magnet

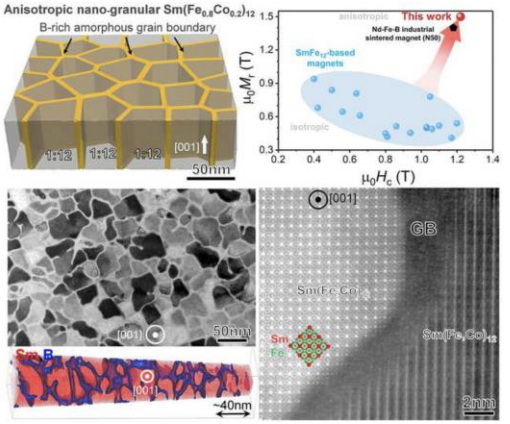
✓Large room-temperature coercivity of **1.2T** and remanence of **1.5T** have been realized in co-sputtered Sm($Fe_{0.8}Co_{0.2}$)-B films (Patents applied).[1,2)]

✓Microstructure with textured columnar grains partitioned by thin B-rich grain boundary phase is realized for the first time (right figure).[2)]

✓Temperature dependence of coercivity is very small compared with Nd-Fe-B, promising excellent stability at T ≥ 150ºC.

(K. Hono, YK. Takahashi, T. Shima, H.Sepehri-Amin)

Formation of high H_c microstructure



Sm($Fe_{0.8}Co_{0.2}$)$_{12}$-B film with $\mu_0 H_{cJ}$=1.2T

1) **Japan Patent Applications, 2019-181786, 2020-084275.**

2) **H. Sepehri-Amin et al. Acta Mater. (2020), in press, doi: 10.1016/j.actamat.2020.05.026.**

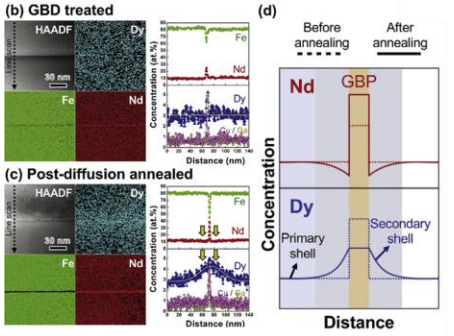
◆Guide lines to realize ultimate Nd-Fe-B sintered magnets

✓We clarified that Dy concentration of about 5at% in the outermost skin of grains is essential to realize room temperature coercivity of 3T by diffusion annealing after grain-boundary infiltration of Dy (right figure). [1)]

✓Theoretical concentration profile of Dy in the shell formed by the grain boundary diffusion process has been successfully calculated using the phase-field method and NIMS data base. [2)]

(K. Hono, T.T. Sasaki, T.-H. Kim, T. Koyama, et al.)

Engineering composition of the outermost skin



Microstructure and distribution of Dy in the outermost skin of main phase grains in Dy-GBD treated Nd-Fe-B sintered magnet of $\mu_0 H_{cJ}$=3 T [1)]

1) **T.H. Kim, T.T. Sasaki, T. Ohkubo, et al., Acta Mater. 172 (2019) 139**
2) **T.H. Kim et al. Scr. Mat. 178 (2020) 433.**

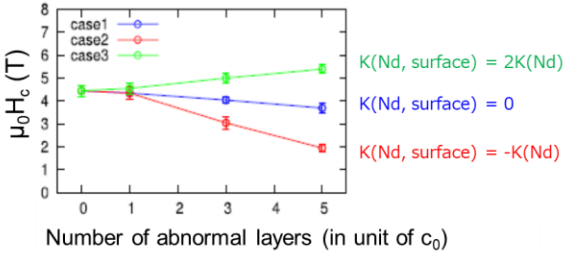
◆Revealing the effects of thermal fluctuations on coercivity

✓Effects of magnetism of grain-boundary phase on the coercivity is clarified for elevated temperatures using stochastic simulation. [1)]

✓For the manifestation of rare earth ion's magnetic anisotropy, several atomic layers are required because of enhanced thermal fluctuation near surface due to weak RE-Fe exchange couplings. [2)]

(S. Miyashita, M. Nishino, and I. Uysal)

Suppression of thermal fluctuation near surface is a key.



Dependence of coercivity on numbers of atomic layers from surface of $Nd_2Fe_{14}B$ in which magnetic anisotropy of rare earth ions are manipulated.

1) **M. Nishino, I. Uysal, S. Miyashita, PRB 101 (2020) 094421**
2) **M. Nishino, S. Miyashita, I Uysal, in preparation**

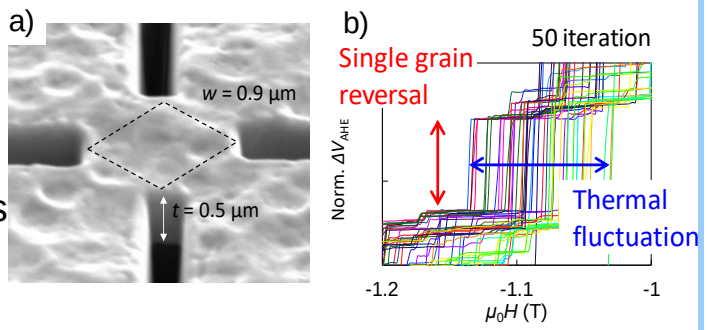
◆Detection of elemental magnetization reversal events in Nd-Fe-B magnet

✓Magnetization reversal events of single grains in micro-patterned Nd-Fe-B hot-deformed magnet were detected for the first time using anomalous Hall effect detection technique. [1)]

✓Evaluation of energy barrier and thermal fluctuations has become possible by statistic analysis of iteration measurements

(S. Okamoto, T. Yomigita, et al.)

Development of verification experiments of atomistic theory



Micro-patterned specimen (a) and magnetization events (b)

1) **T. Yomogita, N. Kikucui, S. Okamoto et al., AIP Adv. 9 (2019) 125052**