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Experimental study of intrinsic magnetic properties for *R*($Fe_{1-x}Co_x$)$_{12}$(N_y) (*R* : Sm and Nd) hard magnetic phase with $ThMn_{12}$ structure

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Spontaneous magnetization m_0M_S of RFe$_{12}$(N_y) (*R* : rare earth element) with the $ThMn_{12}$ structure is expected to be higher than that of $Nd_2Fe_{14}B$ because of the high Fe ratio. However, most of the RFe$_{12}$(N_y) compounds are not stable in bulk state. In order to stabilize the phase, the substitution Fe with non-magnetic element such as Ti, V, Mo and Si is required [1, 2], which results in the reduction of m_0M_S. Recently, Kuno *et al.* reported that the substitution of *R* with Zr leads to the stabilization of the $ThMn_{12}$ structure in strip cast alloy with the ($Sm_{0.8}Zr_{0.2}$)($Fe_{0.75}Co_{0.25}$)$Ti_{0.5}$ composition. They reported that the m_0M_S of the alloy is 1.63 T [3], which is higher than that of $Nd_2Fe_{14}B$ at 300 K. However, the alloy contained at least three phases, and it is important to investigate the intrinsic hard magnetic properties of the main phase to explore the potential of the compound as a hard magnetic phase. The first principal calculation has predicted large values for m_0M_S reaching 2.1 T and 1.8 T for $NdFe_{12}N$ and $SmFe_{12}$ at zero kelvin, respectively[4, 5]. In this work, epitaxial $NdFe_{12}N_y$ and Sm($Fe_{1-x}Co_x$)$_{12}$ (x = 0, 0.1, 0.2) films with 0.35 – 0.60 mm in thickness were prepared by using co-sputtering process and their intrinsic properties were investigated [6, 7]. The detail preparation process is described in ref. 6.

X-ray diffraction profile confirmed the epitaxial growth with *c* axis of $ThMn_{12}$ phase perpendicular to the MgO(001). m_0M_S and anisotropy field m_0H_A of $NdFe_{12}N_x$ and Sm($Fe_{1-x}Co_x$)$_{12}$ were evaluated. m_0H_A is defined as a cross point of easy and hard magnetization curves. Figure 1 shows m_0H_A against the theoretical maximum energy product calculated from m_0M_S for $NdFe_{12}N_x$ and Sm($Fe_{1-x}Co_x$)$_{12}$ together with known ferromagnetic phases at 300 K. We found that the compounds had the $ThMn_{12}$ structure without any structure-stabilizing element. As is plotted with a red star symbol in Fig. 1, the Sm($Fe_{1-x}Co_x$)$_{12}$ compounds showed higher intrinsic properties than those of $Nd_2Fe_{14}B$ as the theoretical calculations predicted. Curie temperature T_C was 823K for $NdFe_{12}N_x$ and 555 K for $SmFe_{12}$. By substituting Fe with Co for Sm system, T_C was enhanced with increasing the Co content and reached to 859 K for Sm($Fe_{0.8}Co_{0.2}$)$_{12}$. This value was by more than 250 K higher than that of $Nd_2Fe_{14}B$, indicating that these materials are promising candidates for the base compound on which development of new permanent magnet materials for high temperature application may be expected.

As a next step, in order to put this phase into practical use, we need to prepare the bulk alloy, not films. Here, we confirmed that the $NdFe_{12}N_x$ and Sm($Fe_{1-x}Co_x$)$_{12}$ layer can be grown at least up to 0.35 mm and 0.5 mm in thickness, respectively. Therefore, it seems that, once the compounds with the $ThMn_{12}$ structure nucleate, they can grow into large crystals without being constrained by epitaxy with the substrates, indicating that there might be possible ways to produce the binary RFe$_{12}$ compounds as a bulk.

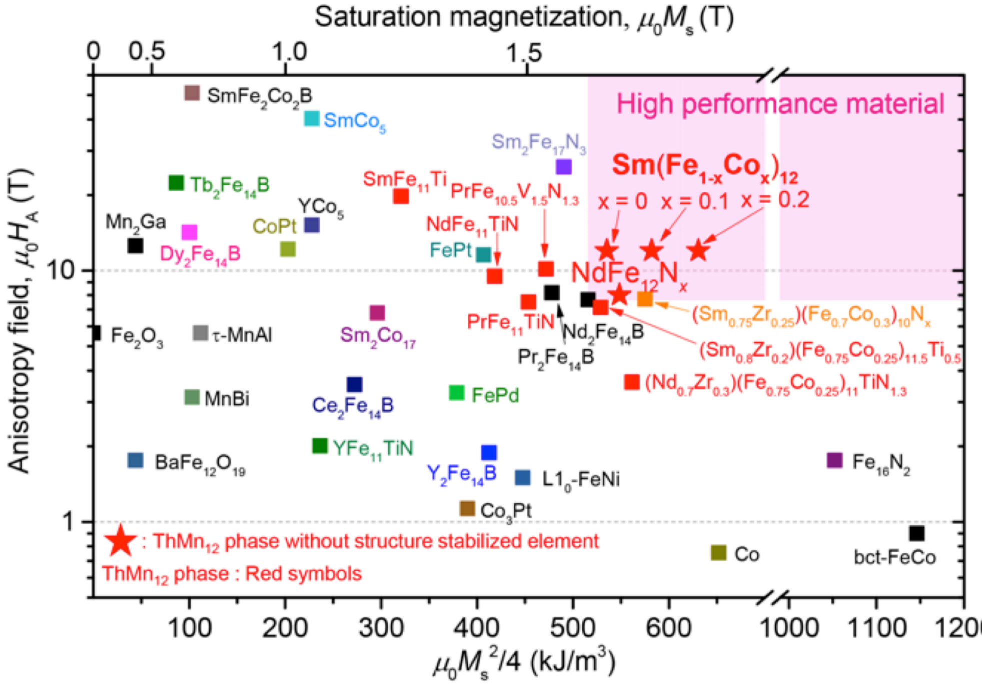

Fig. 1: the potential as a permanent magnet material for known ferromagnetic phases at 300 K. Symbols of red star shows samples with $ThMn_{12}$ structure without any non-magnetic structure stabilized element.

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