The $ThMn_{12}$-type iron rich compounds with high intrinsic magnetic properties as permanent magnet materials

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Iron rich compounds $R{Fe}_{12}(N)_x$ (R: rare earth element) with $ThMn_{12}$ structure is expected to have a high spontaneous magnetization $\mu_0 M_S$, since Fe ratio is highest among known ferromagnetic phases so far. Although $R{Fe}_{12}$ phase is known to be unstable in bulk state, we could demonstrate to prepare $R{Fe}_{12}$ by sputtering process and show higher intrinsic magnetic properties recently[1, 2], as well as the first principles calculation predicted[3]. In this talk, we will introduce how to prepare the $R{Fe}_{12}$ phase and how high potential they have as permanent magnetic materials.

Epitaxial $NdFe_{12}$ and $Sm(Fe_{1-x}Co_x)_{12}$ (x = 0, 0.1 and 0.2) films with 0.35 - 0.65 μm in thickness were prepared on a (001)-oriented W and V underlayer, respectively, deposited on a MgO(001) single crystalline substrate at elevated temperature by a co-sputtering system. Then, for Nd compound, nitriding has been done in nitrogen atmosphere of 1 Pa at 550 °C for 1 hour in order to obtain the uniaxial anisotropy along c axis. The magnetic properties were measured by using SQUID VSM (Quantum Design Inc. MPMS3) and VSM (Quantum Design Inc. DynaCool) in the temperature range of 300 – 700 K with a maximum magnetic field of 7 and 14 T, respectively.

Both $NdFe_{12}N_x$ and $Sm(Fe_{1-x}Co_x)_{12}$ have uniaxial anisotropy along the c-axis which is perpendicular to the MgO(001) plane. Figure 1 showed $\mu_0 M_S$ and $\mu_0 H_A$ against the temperature of $R{Fe}_{12}$ phase together with known ferromagnetic phases. Higher $\mu_0 M_S$ of 1.66 ± 0.08 T and 1.78 ± 0.02 T at 300 K for $NdFe_{12}N_x$ and $Sm(Fe_{0.8}Co_{0.2})_{12}$ were obtained, respectively. 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 $Sm(Fe_{0.8}Co_{0.2})_{12}$, which is due to the strong exchange coupling of Fe and Co. This value was by more than 200 K higher than that of $Nd_2Fe_{14}B$. Therefore, these $R{Fe}_{12}$ phases have high potential as permanent magnet materials. The next step should be the investigation to find a way to stabilize the $R{Fe}_{12}$ phase in the bulk state in order to put this phase into practical use.

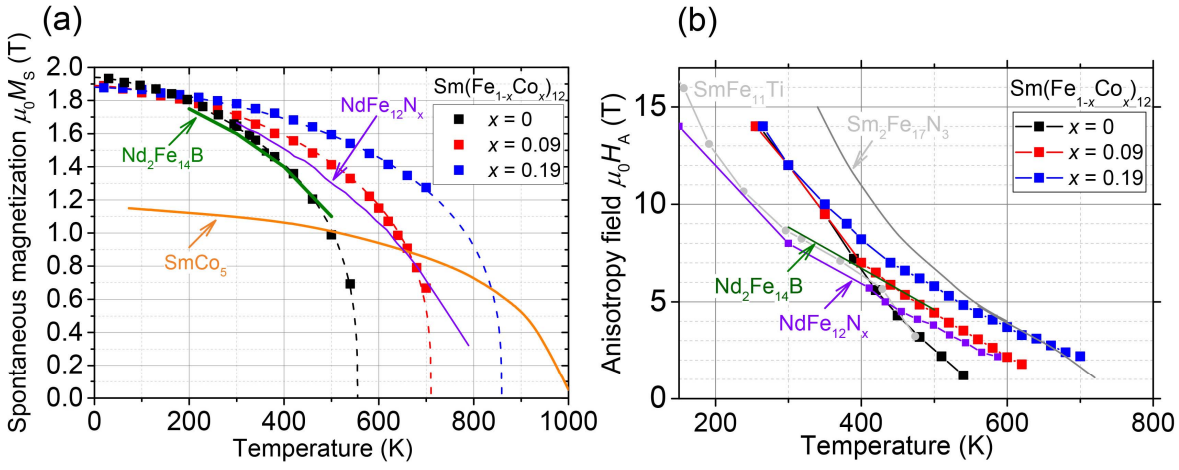

Figure 1 Temperature dependence of (a)spontaneous magnetization and (b)anisotropy field [2] together with known ferromagnetic phases.

Reference

[1] Y. Hirayama *et al.*, *Scripta Materialia* 95 (2015) 70-72. [2] Y.Hirayama *et al.*, *Scripta Materialia* 138 (2017) 62-65.
[3] T. Miyake *et al.*, *Journal of the Physical Society of Japan* 83 (2014) 043702.