

📅 Tue. Jul 29, 2025 9:00 AM - 10:25 AM JST | Tue. Jul 29, 2025 12:00 AM - 1:25 AM UTC 🏛️ Convention Hall(300, 3F)

[O5] RE-Fe-B Magnets III

Session Chair: Prof. Dagmar Goll(Aalen University)

9:55 AM - 10:10 AM JST | 12:55 AM - 1:10 AM UTC

[O5-4] Direct reduction of Rare Earth Oxides to Magnets

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Traditional production of rare earth (RE) permanent magnets involves melting and casting of the constituents. Refining the metals from the oxides is a costly and typically energy intensive process [1]. On the other hand, the light RE (LRE) metals are compatible with a co-reduction of the RE-oxide with Ca in the presence of Fe [2] since there is no solubility between Fe and Ca even in the liquid state [3]. The reduction of the LRE_2O_3 proceeds rapidly once the Ca is melted (842°C) in an inert environment and the Ca is mutually immiscible in all the RE metals except Eu and Yb [3]. This provides a direct route to form LRE-Fe intermetallic compounds from LRE_2O_3 [4, 5]. The challenge with this synthesis route is forming monolithic magnets, which require: 1) formation of phase pure LRE-Fe compounds, 2) separation of the intermetallic compounds from the CaO and other impurities, 3) formation of single grain, single phase powder with sizes of a few microns suitable for forming high coercivity magnets, 4) formation of grain aligned magnets. In this presentation, we will discuss the synthesis steps to form magnets of $\text{Sm}_2\text{Fe}_{17}\text{N}_3$ and $\text{Nd}_2\text{Fe}_{14}\text{B}$ directly from their oxides. The advantage of this processing route for the $\text{Sm}_2\text{Fe}_{17}\text{N}_3$ is we can produce well-controlled particles of $\sim 3\ \mu\text{m}$ with a coercivity (H_c) of 10.7 kOe and a maximum energy product $(BH)_{\text{max}}$ of 17.3 MGOe for the grain aligned powders [6]. By densifying the $\text{Sm}_2\text{Fe}_{17}\text{N}_3$ powders using high-pressure spark plasma sintering, a bulk magnet with a $(BH)_{\text{max}}$ of 21.1 MGOe with 88% of theoretical density was produced [7]. The high-temperature (at 1050 °C) processing of the $\text{Nd}_2\text{O}_3+\text{Ca}+\text{Fe}+\text{FeB}+\text{dispersant}$ mixture results, according to both the literature [5] and our current work, in highly pure $\text{Nd}_2\text{Fe}_{14}\text{B}$ powder after Ca-rich by-products are washed out by slightly acidic reagents. We demonstrated that for the Fe particles sized between 10 and 75 μm the optimized calcio-thermic reduction diffusion process can produce XRD-pure hard magnetic material with magnetization ($M \sim 164\ \text{emu/g}$) approaching theoretical limit of 169 emu/g. However, the coercivity of the powder sample is rather small ($H_c \sim 2\ \text{kOe}$), as expected, due to lack of a RE-rich grain boundary (GB) phase. The next steps in the optimization are to develop the appropriate GB phase to blend in with stoichiometric compound and reduce the overall oxygen content in our material. The goal is to establish the one-step direct metallization route from Nd_2O_3 to $\text{Nd}_2\text{Fe}_{14}\text{B}$ as a viable alternative to

the currently dominant strip-casting technology. The techno-economic analysis shows that the process can recuperate the investment cost and become profitable after one year of operation, assuming 80% conversion of Nd from oxide into the $\text{Nd}_2\text{Fe}_{14}\text{B}$ compound is achieved.

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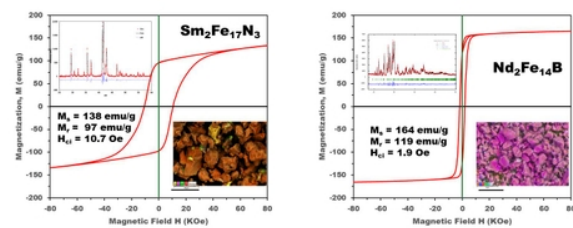


Figure. Magnetization as a function of applied magnetic field of $\text{Sm}_2\text{Fe}_{17}\text{N}_3$ (RHS) and the $\text{Nd}_2\text{Fe}_{14}\text{B}$ (LHS) powder samples prepared using Ca thermodynamic reduction showing their hard magnetic properties. Insets: X-ray powder diffraction pattern of powder samples and SEM/EDS maps of milled and washed powders showing particle size less than $5 \mu\text{m}$ (scale bar $10 \mu\text{m}$).