

# Analysis of synchrotron X-ray diffraction on Ga-containing Nd-Fe-B sintered magnets

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In the development of motors for electric vehicles, Nd-Fe-B permanent magnets that have high coercivities under high temperatures are required. It has been shown that Nd-Fe-B sintered magnets that contain small amounts of Ga (Nd-Fe-B-Ga) exhibit much larger coercivity improvements (from 10 to 18 kOe) by post-sinter annealing than standard Nd-Fe-B sintered magnets (without Ga) [1,2]. Since the coercivity of Nd-Fe-B magnets depends on the microstructure (which is comprised of the main  $\text{Nd}_2\text{Fe}_{14}\text{B}$  phase and several Nd-rich secondary phases), it is expected that the changes in these phases during post-sinter annealing will correlate strongly with the coercivity enhancement. In contrast to standard Nd-Fe-B magnets, an additional  $\text{Nd}_6\text{Fe}_{13}\text{Ga}$  phase has been observed in the grain boundary region of optimally annealed Nd-Fe-B-Ga sintered magnets [1,2]. Thus, it is important to understand the relationship between the large coercivity enhancement and the  $\text{Nd}_6\text{Fe}_{13}\text{Ga}$  phase.

In this study, high-temperature synchrotron XRD measurements were performed at BL02B2, SPring-8 [3], on an isotropic Ga-containing Nd-Fe-B as-sintered magnet. We identified the constituent crystalline phases in the magnet and quantitatively determined their volume fractions by Rietveld analysis. Figure 1 shows the temperature dependence of the volume fractions of each phase, together with the coercivity as a function of annealing temperature. At elevated temperatures, we found that the volume fraction of the dhcp-Nd phase goes to zero just below the annealing temperature at which the coercivity rapidly increases (about 400 °C), whilst the temperature-dependent volume fraction of the  $\text{Nd}_6\text{Fe}_{13}\text{Ga}$  phase exhibits a dome-like shape between 400 and 750 °C which is in remarkable agreement with the annealing temperature range in which the coercivity is drastically enhanced.

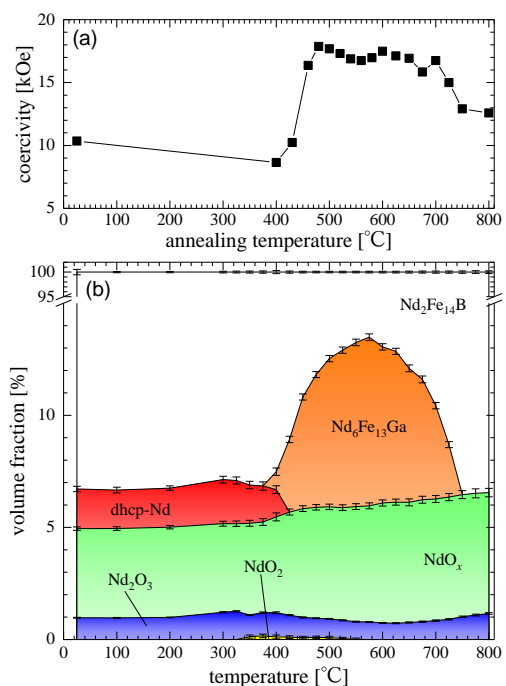


Figure 1: (a) Annealing temperature dependence of the coercivity. (b) Temperature-dependent changes in the volume fractions of phases that comprise the magnet.

## References

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- [2] Y. Enokido *et al.*, Mater. Trans. **57**, 1960 (2016).
- [3] S. Kawaguchi *et al.*, Rev. Sci. Instrum. **88**, 085111 (2017).