Observation of the demagnetization process of HDDR Nd-Fe-B sintered magnets by soft X-ray magnetic circular dichroism microscopy

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Nd-Fe-B based magnets have dominated the high-performance permanent magnet market since their development in 1984. Among other applications, wind turbines and motors for electric-powered cars have experienced rapid growth due to the necessity to reduce the dependence on fossil fuels. Magnets used in these applications have to sustain high demagnetization fields under temperatures up to 200 °C, and so, as the temperature coefficient of coercivity of Nd-Fe-B magnets is large, a high coercivity ($\mu_0H_c \sim 3.0$ T) at room temperature (RT) is needed. As Nd-Fe-B sintered magnets present a relatively low coercivity ($\mu_0H_c \sim 1.2$ T) at RT, partial substitution of Nd with heavy rare earth (HRE) elements such as Dy or Tb is commonly used to improve the coercivity and thermal stability. In the attempt to reduce the use of the very scarce HRE, efforts are being made to improve the coercivity of HRE-free Nd-Fe-B sintered magnets by tuning the microstructure reducing the grain size of the main $Nd_2Fe_{14}B$ phase and improving the grain boundary phase of the sintered magnet. To obtain grain sizes below 1 µm, the hydrogenation-disproportionation-desorption-recombination (HDDR) and hydrogen decrepitation processes have been explored. Recently, Xu *et al*. [1] reported an unexpectedly low coercivity, of just 1.3 T, in sintered magnets with ultrafine grain sizes obtained by HDDR and the pressless sintering process (PLP) compared to those made from He jet-milling and PLP, with a coercivity of 2.14 T, while both had a similar particle size of ~1 µm. They found that HDDR processed PLP magnets presented a thinner grain boundary together with a lower concentration of non-magnetic elements in the grain boundary, which would promote the propagation of the reversal magnetic domains, and thus, reduce the coercivity.

To gain a deeper insight into the reason for the diminished coercivity on HDDR processed PLP magnets, in this work, we have analyzed the evolution of the magnetic domains on the fractured surface of four types of Nd-Fe-B-based magnets with different sizes of grains by soft X-ray magnetic circular dichroism (XMCD) microscopy. These include a hot deformed magnet with plate-like grains of ~0.37 µm with a thickness of ~100 nm in the c-axis direction, and three PLP magnets obtained from a N_2 jet-milled powder (~3 µm), a He jet-milled powder (~1 µm), and a HDDR powder (~0.8 µm), which is made by both HDDR and He jet-milling. The XMCD microscopy showed that, while the 3µm, the 1µm, and the hot deformed magnet demagnetization processes were mainly driven by nucleation and propagation of the reversal domains with a preference for the domain propagation in the hot deformed magnet, in the HDDR processed magnet, the nucleation of magnetic reversal domains dominates throughout the whole demagnetization process. Moreover, the nucleation field for the HDDR processed magnet is greatly reduced compared to the other magnets studied.

References

1) X.D. Xu *et al.*, Acta Mater. 151 (2018) 293–300.