# Defect grain influence on the mechanism of coercivity and its angular dependence of exchange-coupled polycrystalline Nd-Fe-B magnet

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The coercivity mechanism of Nd-Fe-B-based magnet has been in dispute since its discovery. Considering the existence of the defect regions such as the grain boundary (GB), where $K_1$ is locally damaged or grains are largely misaligned, the nucleation model suggests that the coercivity is determined by the formation of the reversed magnetic domain at these defect regions, whereas the pinning model suggests that domain wall (DW) pinning/depinning process is dominant for the coercivity. In recent years, the finite element micromagnetic simulation method has developed into a strong tool to study the coercivity of Nd-Fe-B magnet with complex microstructure. However, even for a simple case with uniform ferromagnetic GBs, the predicted coercivity by simulation can diverge largely from experimental results, ranging from 1 T to 3.2 T [1-3]. A systematic study is necessary to clarify the physics behind these simulation results.

In this work, we focus on the exchange-coupled Nd-Fe-B magnet, based on the simulations of a three-phase micromagnetic model including the polyhedron Nd-Fe-B grains, the continuous thin ferromagnetic GBs and a defect grain on the model surface (Fig.1 (a)). It is shown that, depending on the anisotropy degradation of the defect grain, $K_1^{def}/K_1$, both pinning- and nucleation-controlled reversals can appear (Fig.1 (b)). The linear formula, $\mu_0 H_c = \alpha\mu_0 H_c - N_{eff}\mu_0 M_s$, is confirmed to be valid for both pinning- and nucleation-controlled coercivity but with different dominant factor of $\alpha$. If nucleation starts at a defect grain, $\alpha$ is directly influenced by $K_1^{def}/K_1$ as indicated by the linear relationship between $K_1^{def}/K_1$ and coercivity, whereas for pinning-controlled reversal, $\alpha$ is hardly influenced by $K_1^{def}/K_1$. The simulated angular dependence of coercivity shows strong dependence on the reversal mode (Fig.1 (c)). In a pinning-controlled reversal, the coercivity continuously increases with measurement angle $\theta$, whereas in a nucleation-controlled reversal, the coercivity decreases at small $\theta$ but increases again at large $\theta$.

To compare the simulation with experiment, 0.5%-Ga-doped sintered magnets with/without post-sintered annealing [4] are utilized to measure the angular dependence. Our simulation of pinning-controlled model agrees well with the as-sintered sample, indicating the pinning mechanism for the coercivity of this exchange-coupled magnet. In addition, the angular dependence of the post-annealed exchange-decoupled sample will be further discussed, in comparison with our simulation of magnet model with non-ferromagnetic GBs.

## References

1) J. Fujisaki, *et al.*, IEEE Trans. Magn. 50 (2014): 1-4.
2) M. Soderžnik, *et al.*, Acta Mater. 135 (2017): 68-76.
3) J. Fischbacher, *et al.*, Scripta Mater. 154 (2018): 253-258.
4) T.T. Sasaki, *et al.*, Scripta Mater. 113 (2016) 218-221.

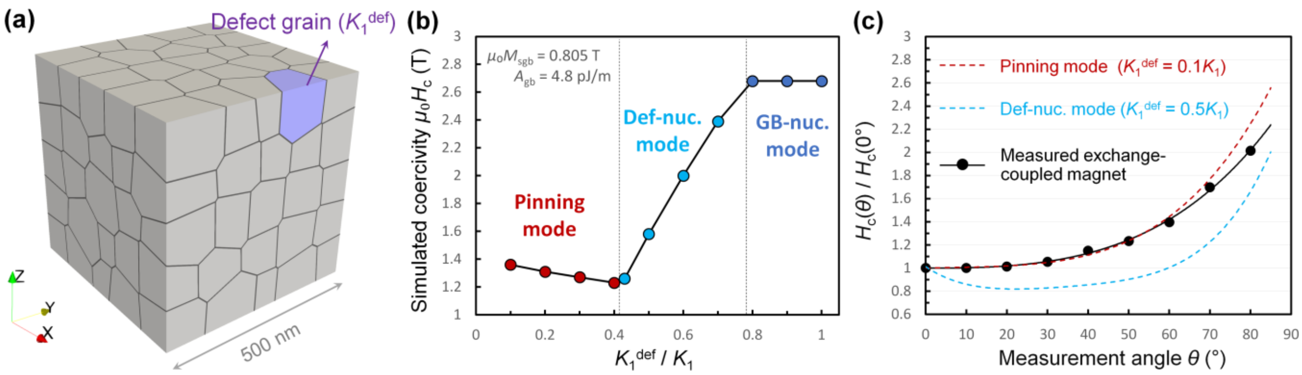


Fig.1 (a) The micromagnetic model of exchange-coupled Nd-Fe-B sintered magnet. (b) Simulated coercivity value as a function of $K_1^{def}/K_1$. (c) Comparison between simulated and measured angular dependence of coercivity.