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Hysteresis Design of Magnetic Materials for Efficient Energy Conversion

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Designing magnetic softness in nanocrystalline alloys with exceptionally high Fe content

Magnetically soft nanostructures have been obtained by crystallization of melt-spun amorphous precursors [1-4]. Unlike conventional crystalline alloys, the magnetic softness in these nanocrystalline alloys is due to the exchange-averaging effect [3] of the local anisotropy (K_1). This has set alloy development free from a traditional prerequisite of reducing intrinsic K_1, which usually requires a large amount of nonmagnetic additives, resulting in a reduction of the saturation polarization (J_s). Thus, nanocrystalline soft magnetic alloys stand out with a great potential of realizing both high J_s and low core losses. These properties will improve the efficiency of distribution transformers and electric motors, leading to suppression of the global greenhouse gas emission from utility and transport sectors. In the first half of this talk, the exchange-averaging effect in nanostructures will be summarised by following Herzer's random anisotropy model and our extended model. The second half will focus on the latest alloy design strategy for enhancing J_s to that of Si steel, followed by examples [5] of recent Fe-B based nanocrystalline alloys (HiB-NANOPERM) with Fe content up to 97.2 mass%.

[1] Y. Yoshizawa, S. Oguma and K. Yamauchi, *New Fe based soft magnetic alloys composed of ultrafine grain structure*, J. Appl. Phys. **64** (1988) 6044.

[2] K. Suzuki, N. Kataoka, A. Inoue, A. Makino and T. Masumoto, *High saturation magnetization and soft magnetic properties of bcc Fe-Zr-B alloys with ultrafine grain structure (Rapid publication),* Mater. Trans. JIM **31** (1990) 743.

[3] K. Suzuki and G. Herzer, Ch. 13 in Advanced magnetic nanostructures, eds. D. Sellmyer and R. Skomski (Springer, New York, 2006) pp. 365. *"Soft magnetic nanostructures and applications"*

[4] M. A. Willard and M. Daniil, *Handbook of Magnetic Materials*, Vol. 21 (Elsevier, 2013), p. 173.

[5] K. Suzuki, R. Parsons, B. Zang, K. Onodera, H. Kishimoto, T. Shoji and A. Kato, *Nanocrystalline soft magnetic materials from binary alloy precursors with high saturation magnetization*, AIP Adv. **9** (2019) 035311; https://doi.org/10.1063/1.5079778