Regulation of Grain Boundary Structure in NdFeCoB Magnets through Grain Boundary Diffusion of DyAlCu Alloy

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Introduction and Background

Sintered NdFeB magnets, known for their superior magnetic properties, are widely applied in motors, generators, and communication devices. However, their inherent low Curie temperature (~312 ℃) and negative remanence temperature coefficient (-0.12%/℃) restrict high-temperature performance. Traditional modifications include Co substitution to enhance thermal stability, though excessive Co reduces saturation magnetization. Heavy rare earth (HRE) elements (Dy/Tb) improve coercivity but compromise remanence (B_r) and energy product ((BH)max). Grain boundary diffusion (GBD) efficiently enhances coercivity via local introduction of HRE compounds (e.g., DyF_3) or non-rare earth alloys (Cu, Al), minimizing magnetic degradation. Critical unresolved issues include microstructural deterioration in high-Co magnets and unclear Co distribution mechanisms under GBD. This study investigates GBD effects on Nd-Fe-Co-B magnets using $Dy_{70}Al_{10}Cu_{20}$ alloy, focusing on magnetic property optimization, microstructure evolution, and Co distribution mechanisms.

Material and Methods

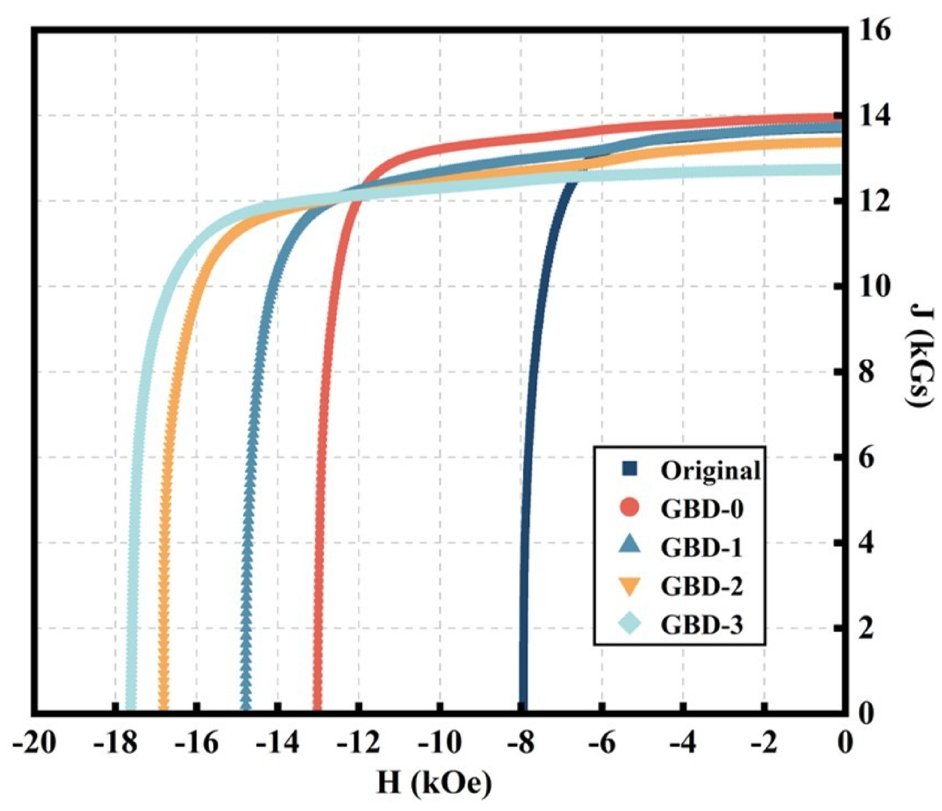
Sintered Nd-Fe-B magnets were fabricated (composition: $(Pr,Nd)_{31.2}Co_{12}Cu_{0.2}Fe_{bal}Al_{0.3}Zr_{0.1}B_1$ wt.%) via powder metallurgy: strip casting (SC), hydrogen decrepitation (HD), jet milling (JM), magnetic alignment (2 T), cold isostatic pressing (220 MPa), and sintering (1030℃). Cylindrical samples (Φ8×4 mm) were machined.

$Dy_{70}Al_{10}Cu_{20}$ alloy discs (Φ8×0.3 mm) were arc-melted, polished (SiC paper), and ultrasonic-cleaned (ethanol). Magnets, sandwiched between alloy discs, were placed in alumina crucibles.Grain boundary diffusion (GBD) was conducted in a vacuum furnace: samples were heat-treated at 880–940℃ for 5h, followed by secondary annealing at 480℃ for 2h. Non-diffused magnets underwent identical thermal cycles as controls.

Results

Magnets with various coating thicknesses were labeled as follows: GBD-0 (0 mm), GBD-1 (0.03 mm), GBD-2 (0.09 mm), and GBD-3 (0.15 mm). Among them, GBD-3 exhibited optimal performance, increasing the coercivity from 7.94 to 17.63 kOe, which represented a significant enhancement of 122%.All magnets exhibited significantly improved remanence temperature coefficients compared to commercial sintered NdFeB magnets, demonstrating enhanced thermal stability.

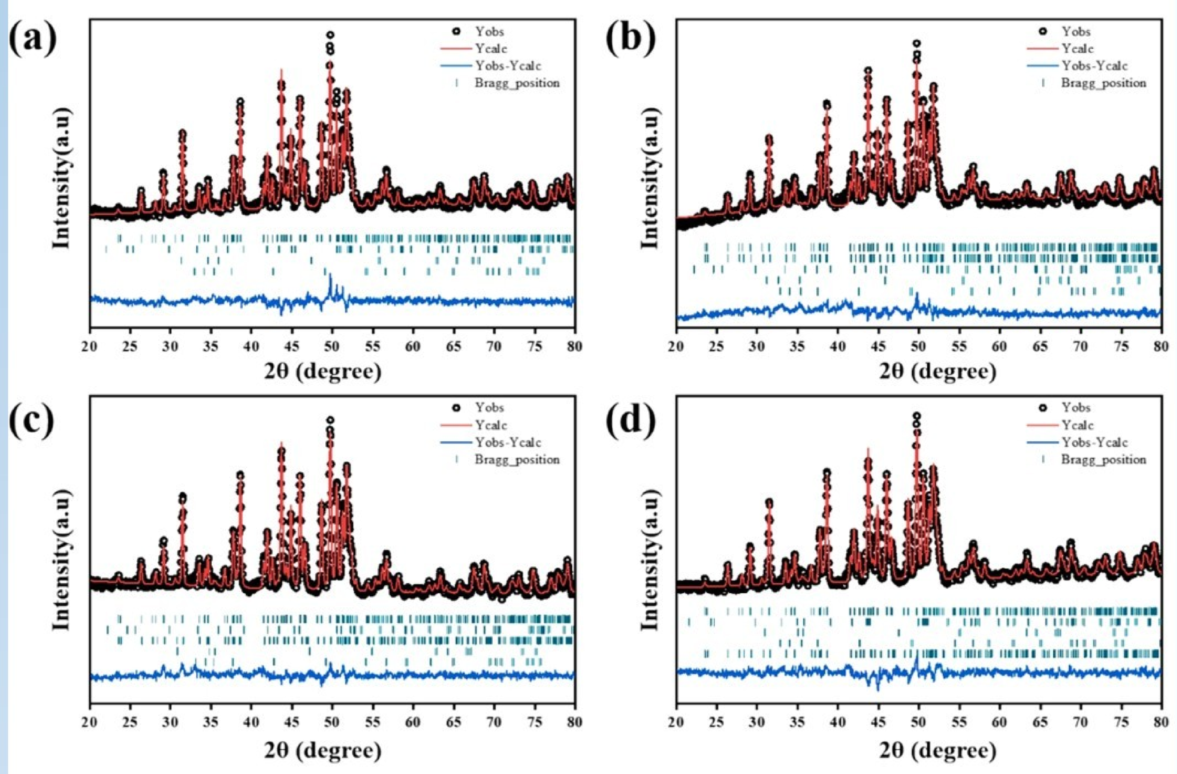
Magnetic Properties



	B_r	H_{cj}	$(BH)_{max}$	$\alpha_{(20\text{-}100℃)}$	$\beta_{(20\text{-}100℃)}$
	kGs	kOe	MGOe	%/℃	%/℃
Original	13.7	7.94	43.06	-	-
GBD-0	13.95	13.02	46.17	-0.086	-0.78
GBD-1	13.7	14.79	43.09	-0.075	-0.73
GBD-2	13.4	16.81	41.65	-0.068	-0.71
GBD-3	12.74	17.63	39.6	-0.063	-0.63

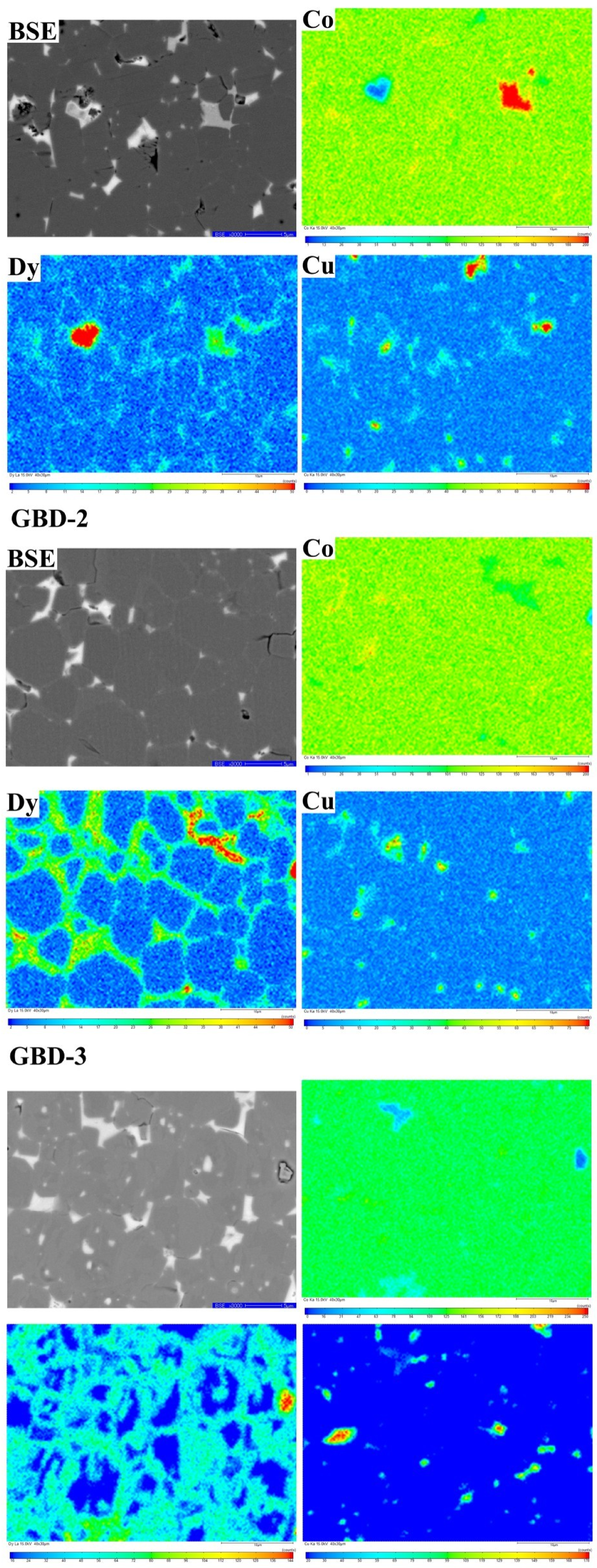
Prior to grain boundary diffusion processing (GBDP), X-ray diffraction (XRD) confirmed the presence of Nd_2Co_{17} soft magnetic phases at grain boundaries, where Co enrichment was observed. These plane-anisotropic phases were found to degrade coercivity (H_{cj}). After GBDP, electron probe microanalysis (EPMA) revealed the formation of Dy-rich shells with high anisotropy fields surrounding the $Nd_2Fe_{14}B$ matrix, which effectively enhanced Hcj. Notably, core regions maintained low Dy concentrations, preserving high remanence (B_r). The uniform distribution of Al and Cu suppressed Nd_2Co_{17} phase formation, contributing to improved coercivity. This dual mechanism of boundary hardening and soft-phase suppression demonstrates a viable strategy for balancing coercivity and remanence in high-Co NdFeB systems.

XRD Analysis



EPMA Micrograph

GBD-1



This study shows GBDP with " Heavy Rare Earth-Low Melting Point" alloys improves NdFeCoB magnets' magnetic properties, offering a theoretical basis for high-performance, temperature-stable sintered NdFeCoB magnets.

Reference

[1] *Intermetallics.*, 2024, 170, 108325

[2] *J. Magn. Magn. Mater.*, 2024, 606, 172387

[3] *J. Alloy. Compd.*, 2024, 976, 173117

[4] *Mater. Charact.*, 2025, 225, 115103