The 28th International Workshop on Rare Earth and Future Permanent Magnets and Their Applications (REPM 2025), Tsukuba, Japan, July 27-31, 2025

[O14] Theory & Simulations

Micromagnetic Simulations of Hot-deformed Nd-Fe-B Magnets Subjected to Eutectic Grain Boundary Diffusion Process

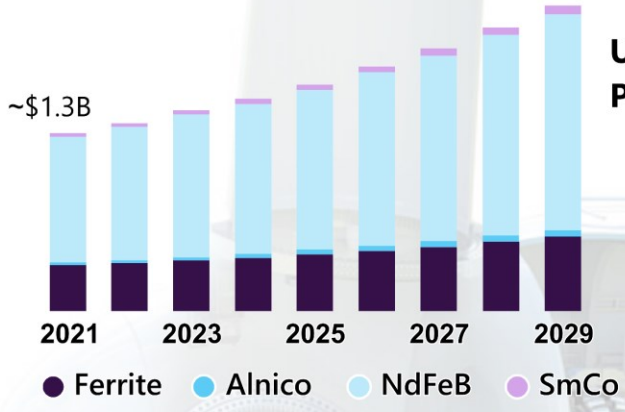
Anton Bolyachkin, Xin Tang, Nikita Kulesh, Hossein Sepehri-Amin

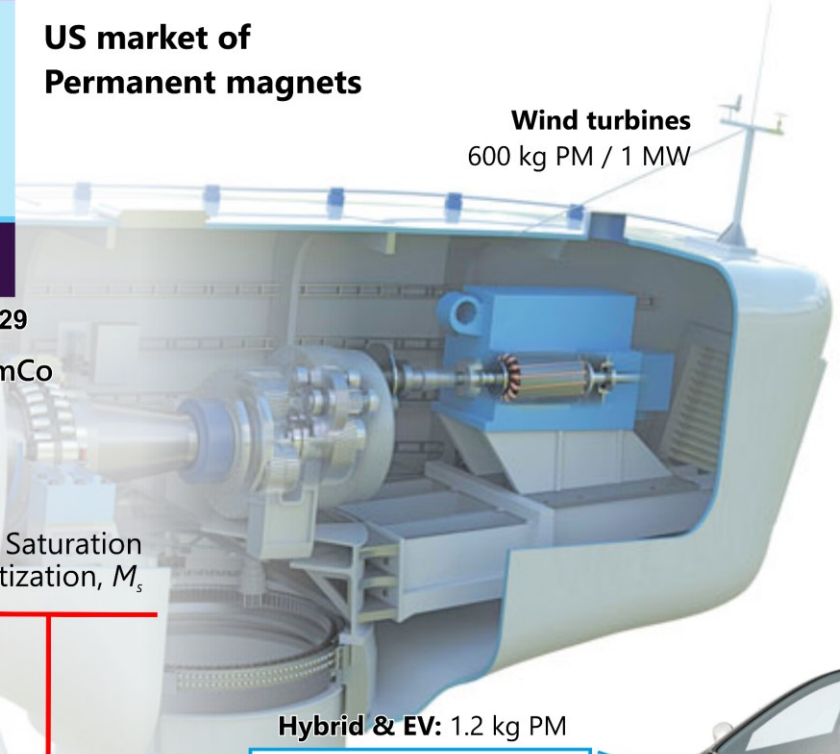
National Institute for Materials Science

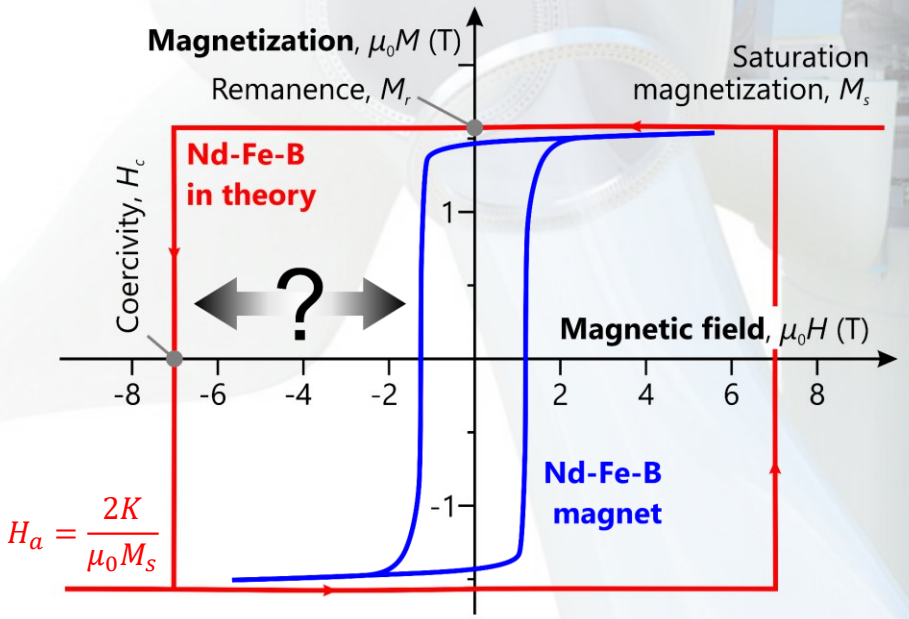
Research Center for Magnetic and Spintronic Materials

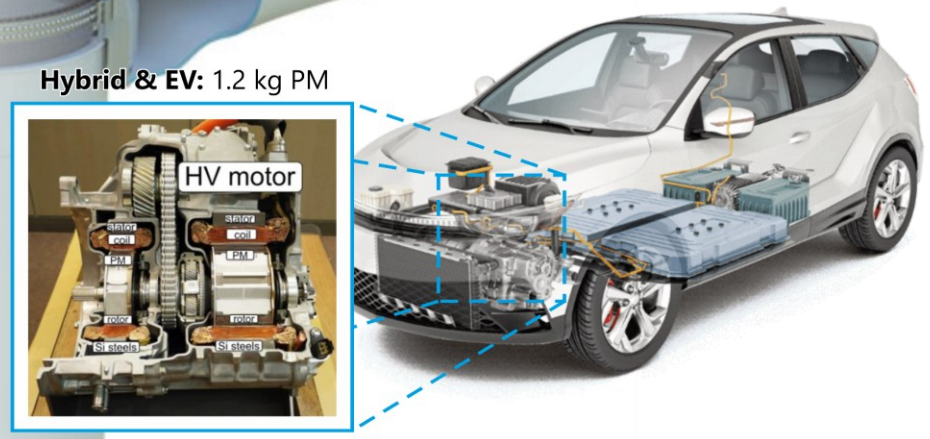
Green Magnetic Materials Group

Nd-Fe-B Permanent Magnets

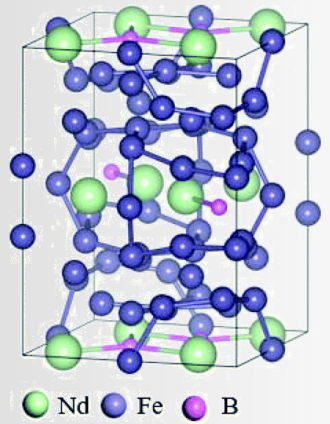








$Nd_2Fe_{14}B$



P42/mnm (136)

a = 0.8797 nm

c = 1.2226 nm

Intrinsic properties

$\mu_0 M_s = 1.61$ T

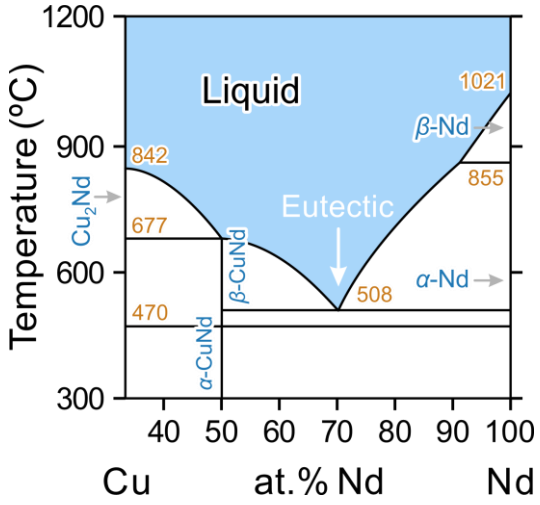
$K = 4.36$ MJ/m^3

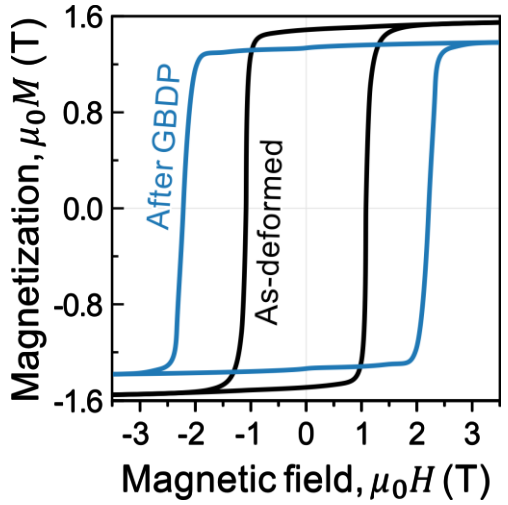
$\mu_0 H_a = 6.7$ T

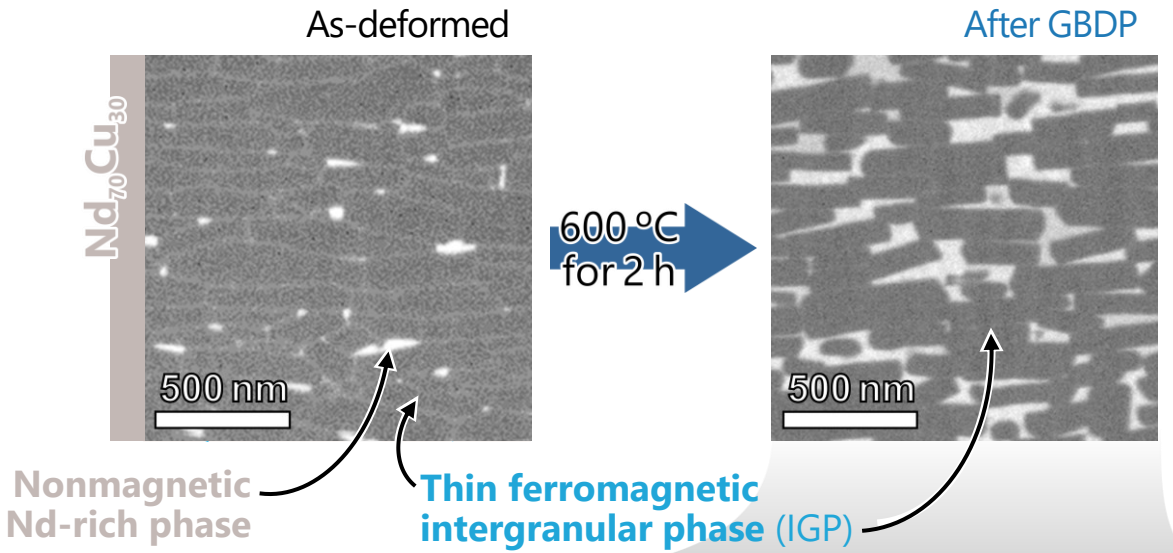
$A = 8$ pJ/m

$T_c = 585$ K

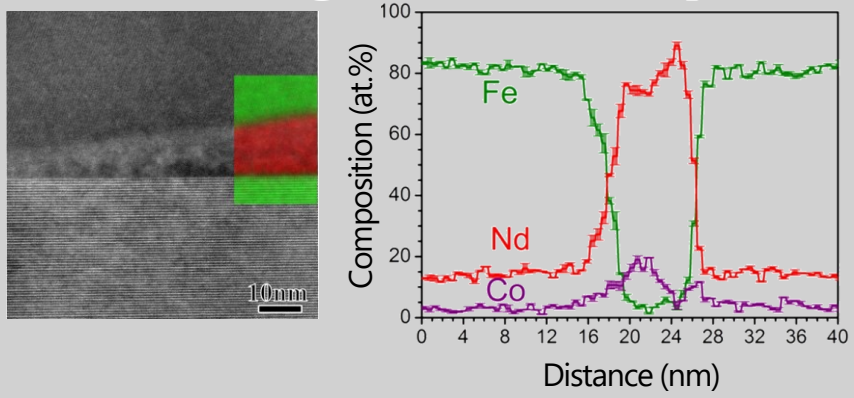
Grain Boundary Diffusion Process (GBDP)





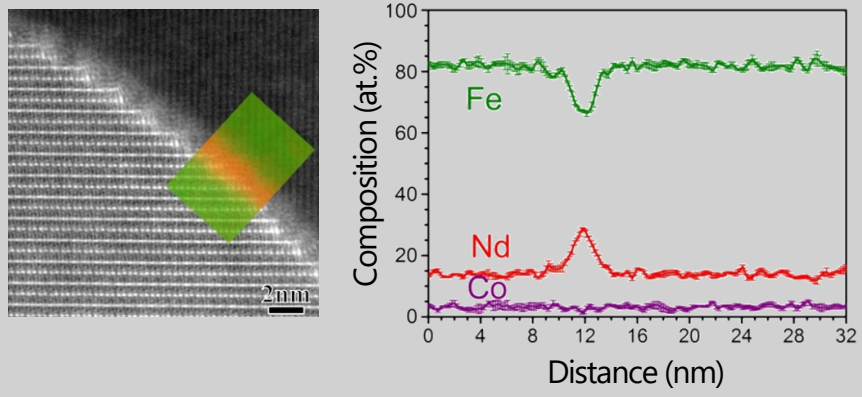


Nonmagnetic Nd-rich phase



vs.

Thin ferromagnetic IGP

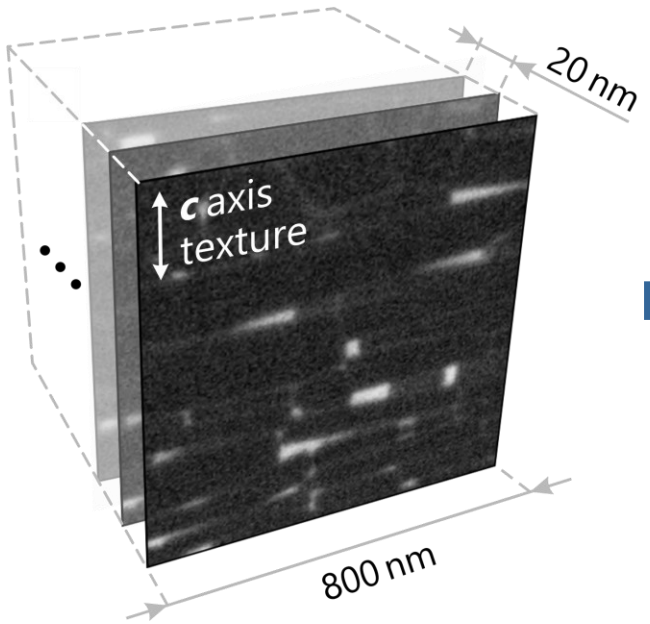


H. Sepehri-Amin *et al.* Scripta Mater. 63 (2010) 1124
H. Sepehri-Amin *et al.* Acta Mater. 61 (2013) 6622

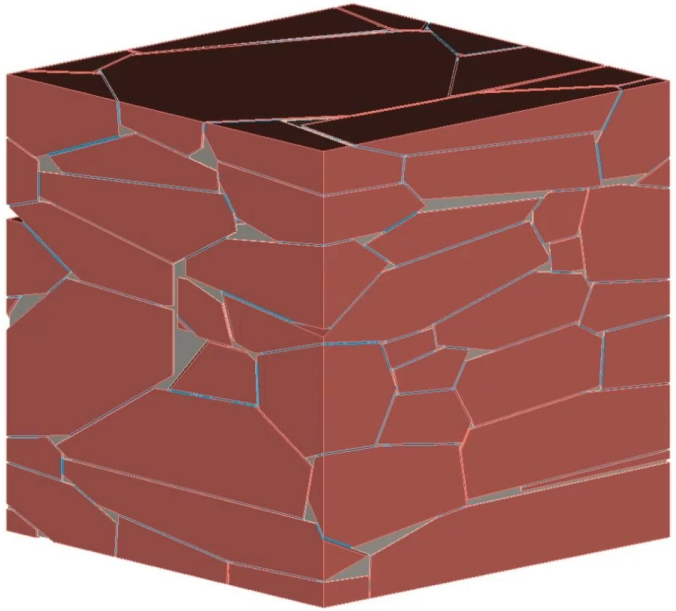
What is the effect of remaining grain connectivity on coercivity?

Hot-deformed Nd-Fe-B Magnets: Advanced FEM

FIB-SEM tomography

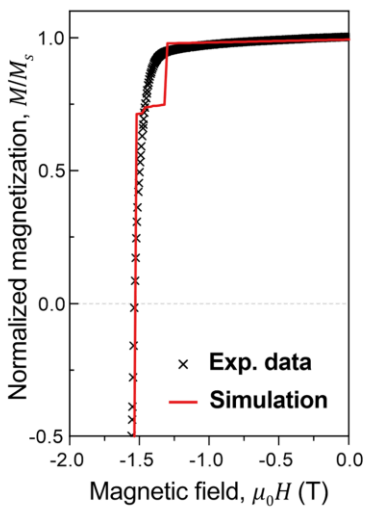


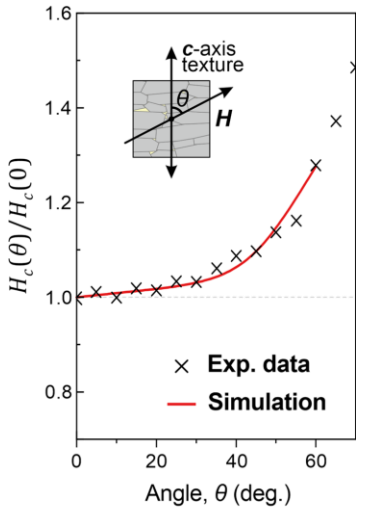
3D Finite Element Model



Can be tuned

93.3 vol.%	$Nd_2Fe_{14}B$ grains
3.9 vol.%	thin IGP (3.5 nm)
2.8 vol.%	triple junctions





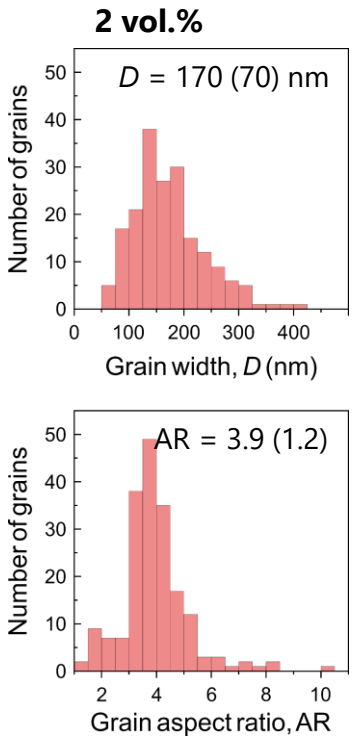
Estimated parameters | $\mu_0 M_{IGP}$ = 0.8 T, A_{IGP} = 2.0 pJ/m; $\mu_0 M_{TJ}$ = 0.4 T, A_{TJ} = 0.5 pJ/m

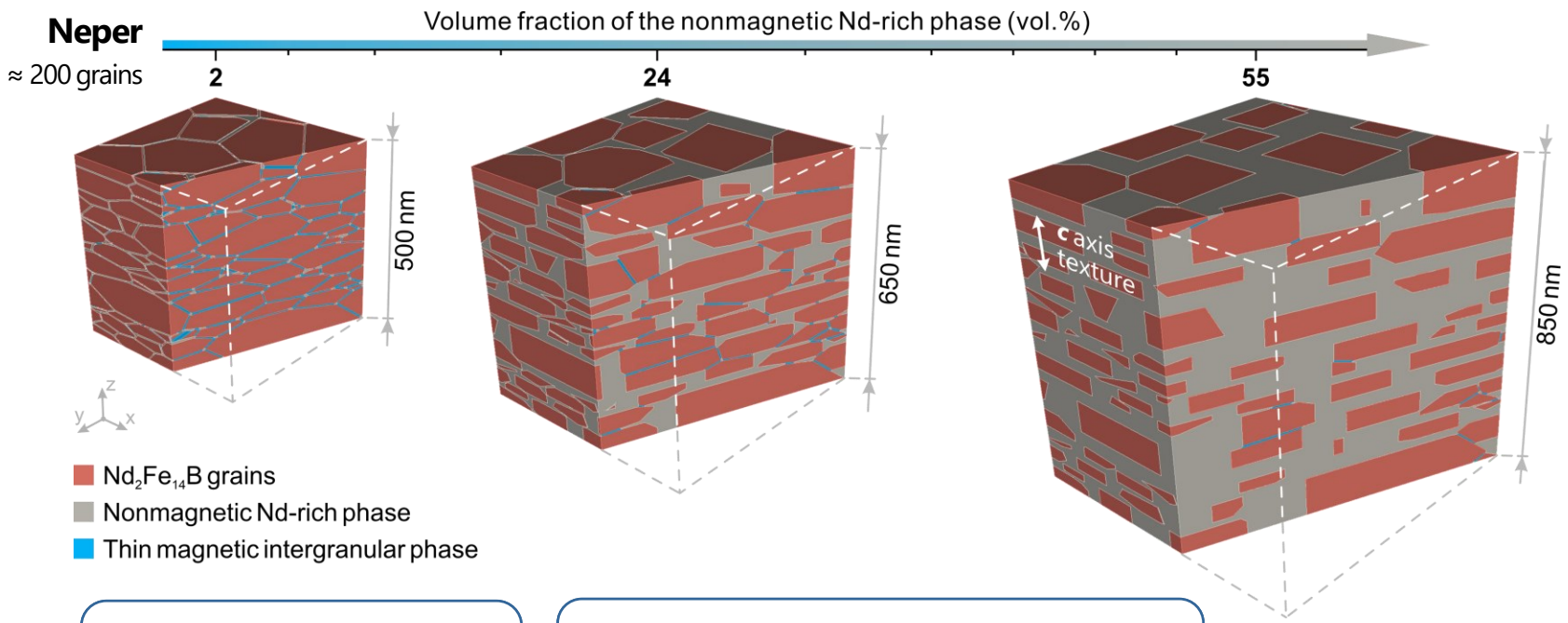
! Tomography-based model of sintered Nd-Fe-B magnets

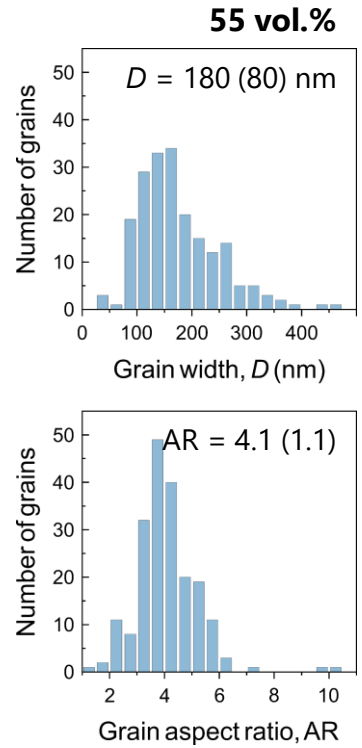
14:15 - 14:30 **[O15-3]** Nikita Kulesh

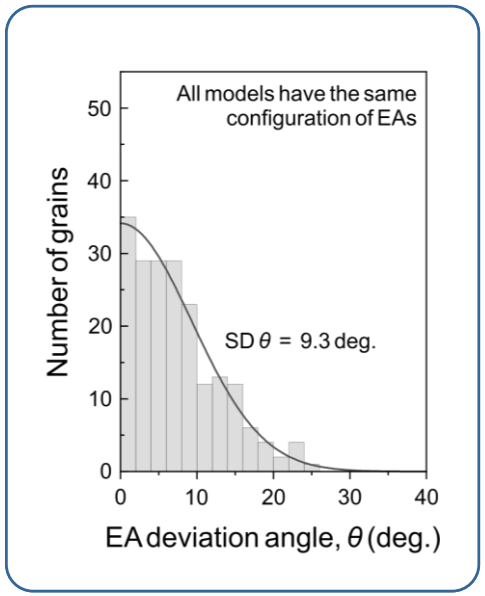
A. Bolyachkin *et al.*, npj Comp. Mat. 10 (2024) 34

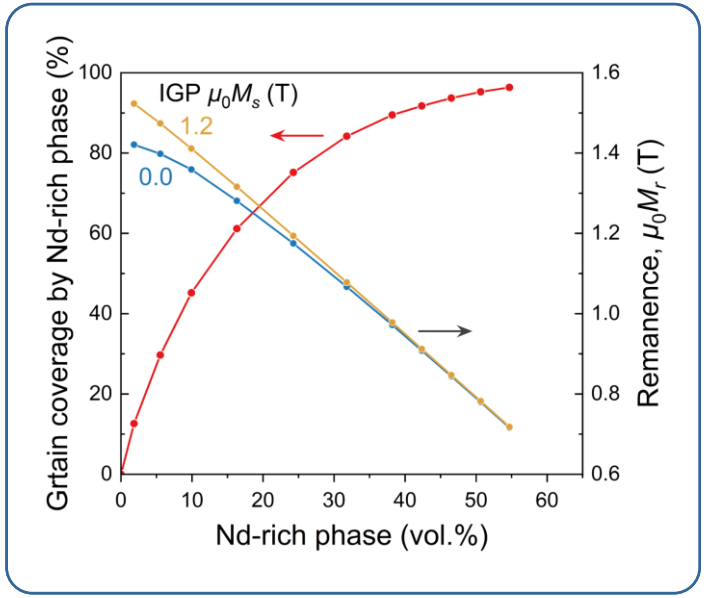
GBDP Imitation











A. Bolyachkin *et al.*, Scripta Mater., 247 (2024) 116095

Simulated Demagnetization Curves

Grains:

$\mu_0 M_s$ = 1.61 T,

A = 8 pJ/m,

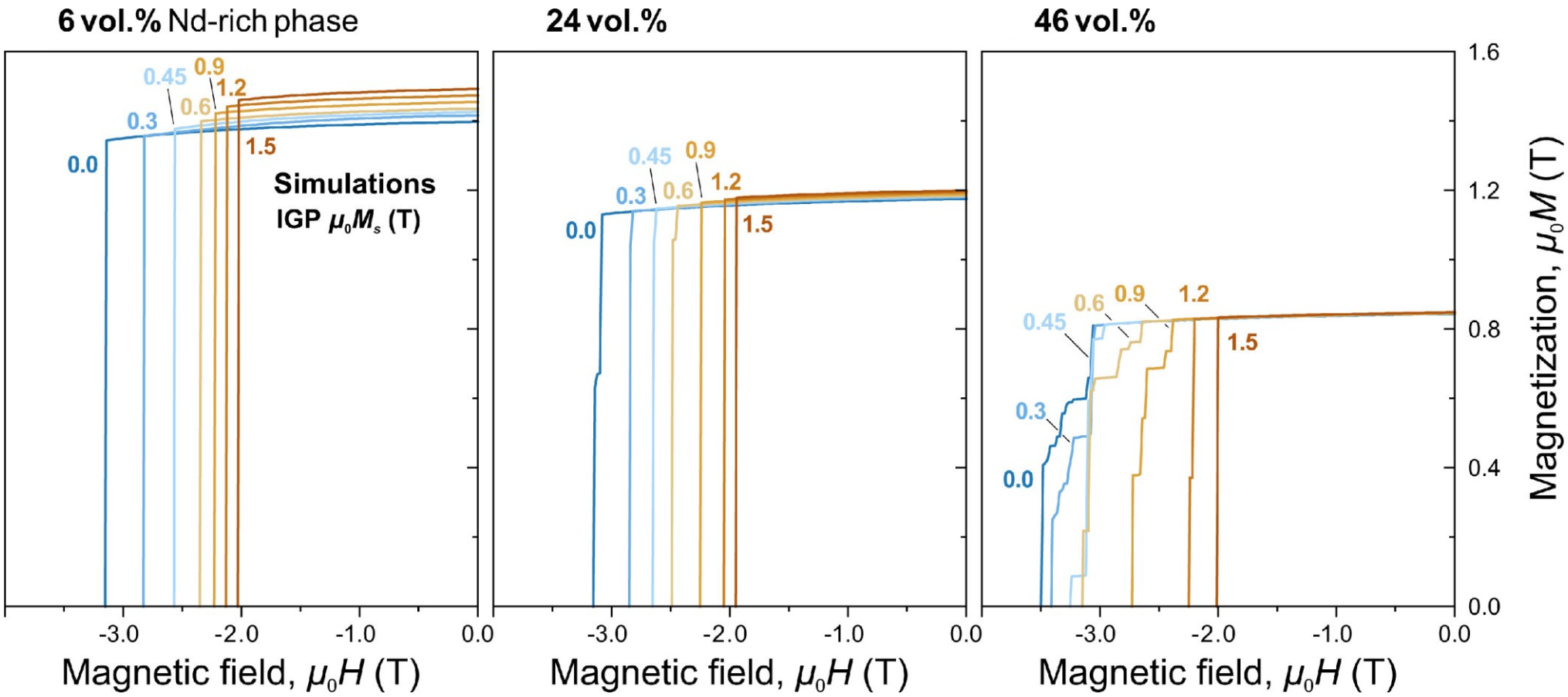
K = 4.36 MJ/m^3

Thin IGP:

M_s is varied,

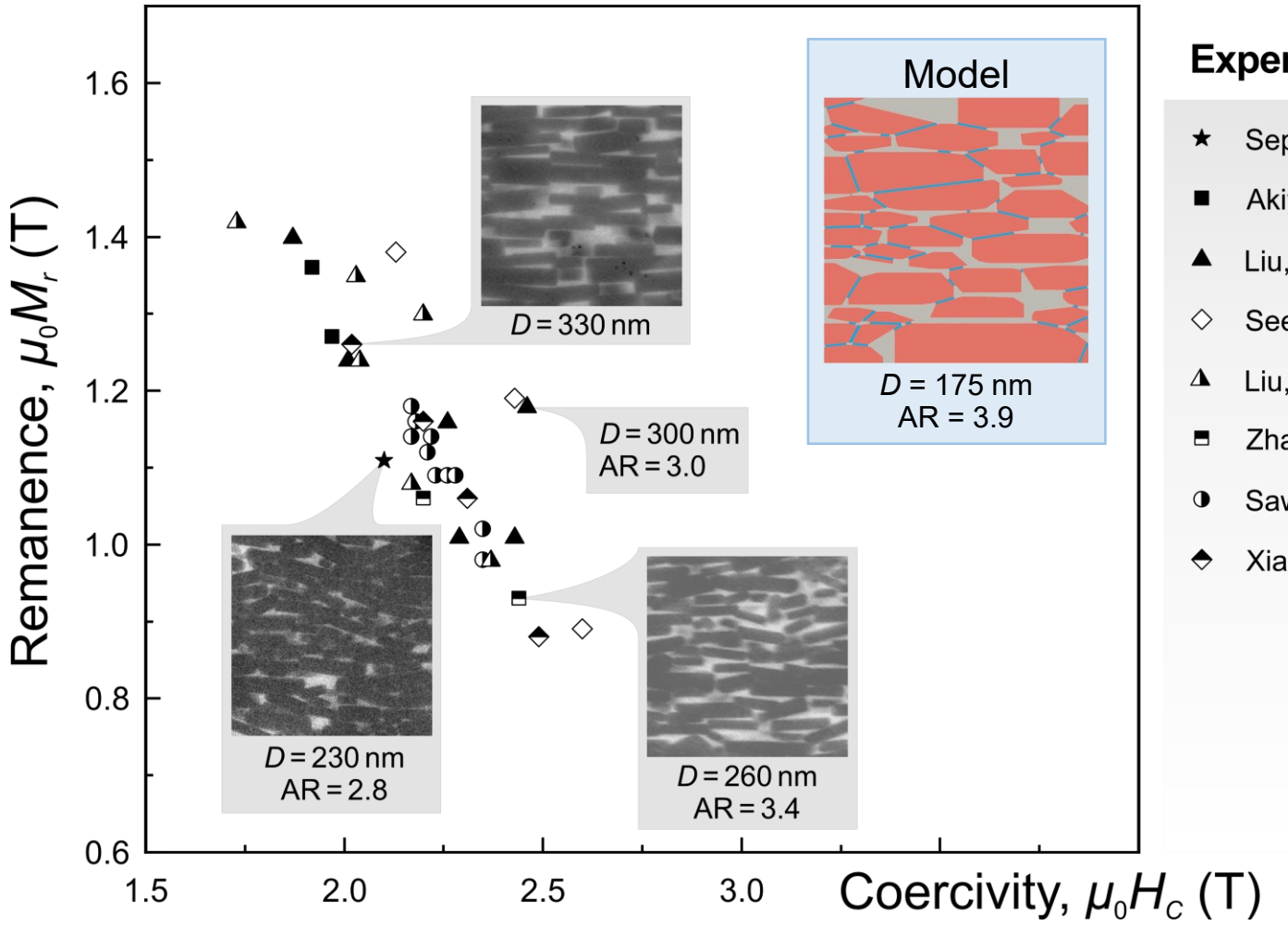
$A \propto M_s^2$,

K = 0 J/m^3



Simulations *via* **b4vex** [AIP Adv. 7 (2017) 045310]

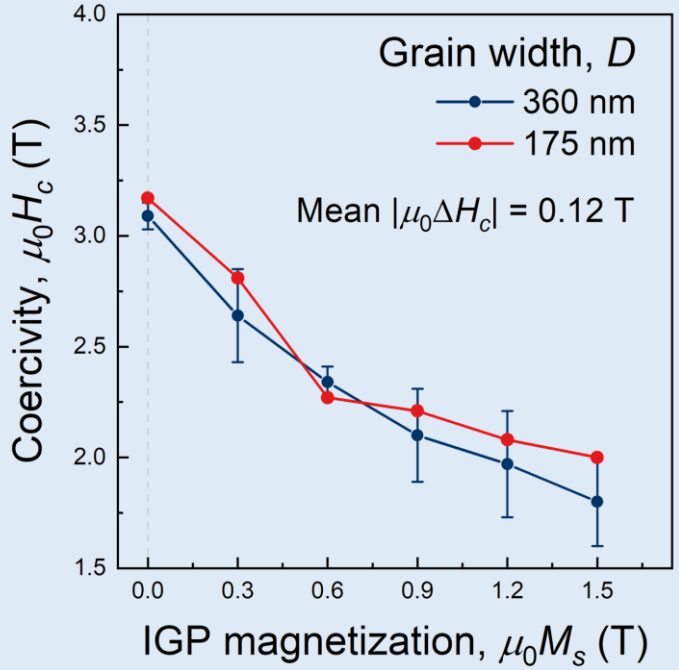
M_r vs. H_c Tradeoff



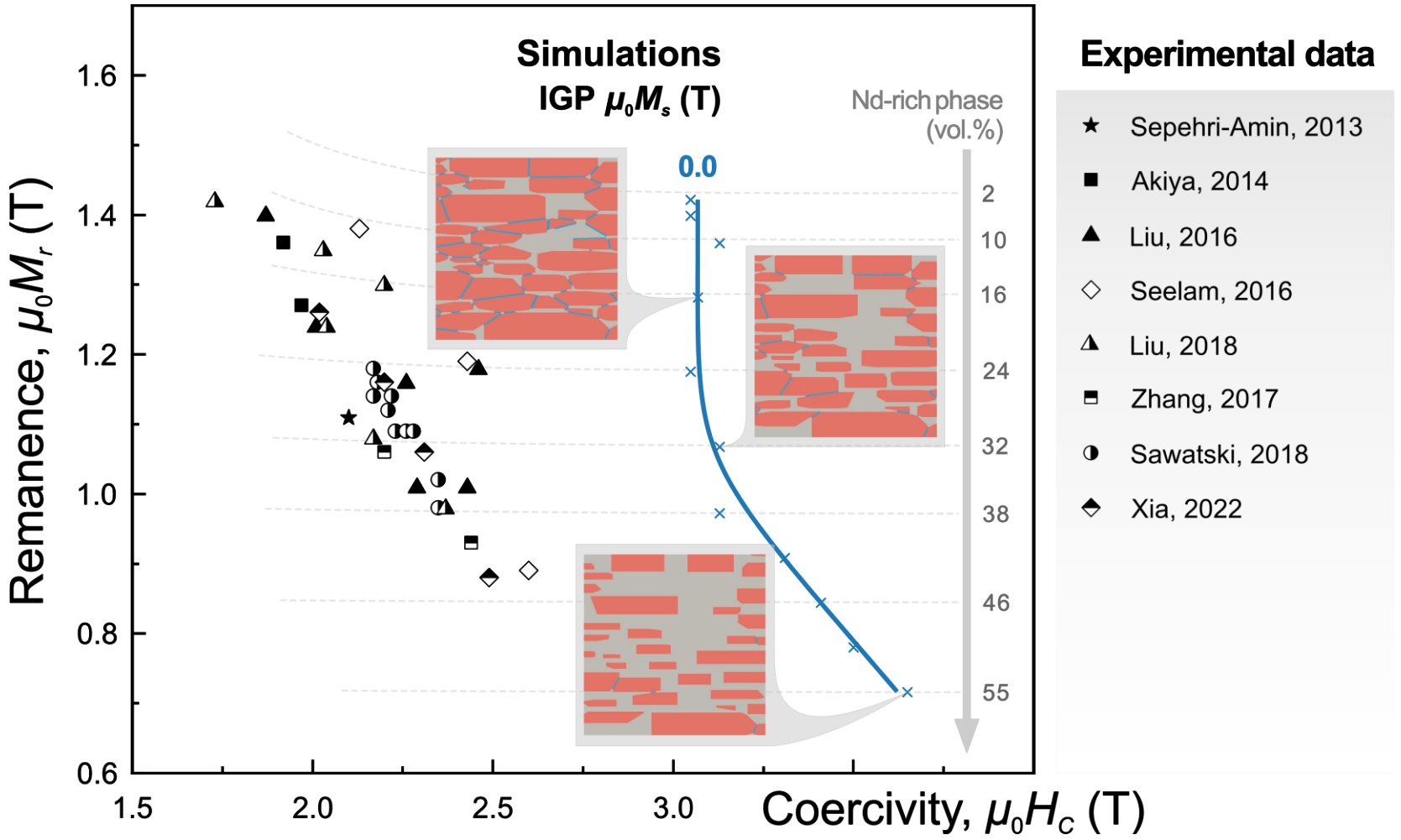
Experimental data

- ★ Sepehri-Amin, 2013
- ■ Akiya, 2014
- ▲ Liu, 2016
- ◇ Seelam, 2016
- ◭ Liu, 2018
- ⬒ Zhang, 2017
- ◑ Sawatski, 2018
- ◆ Xia, 2022

The effect of grain size

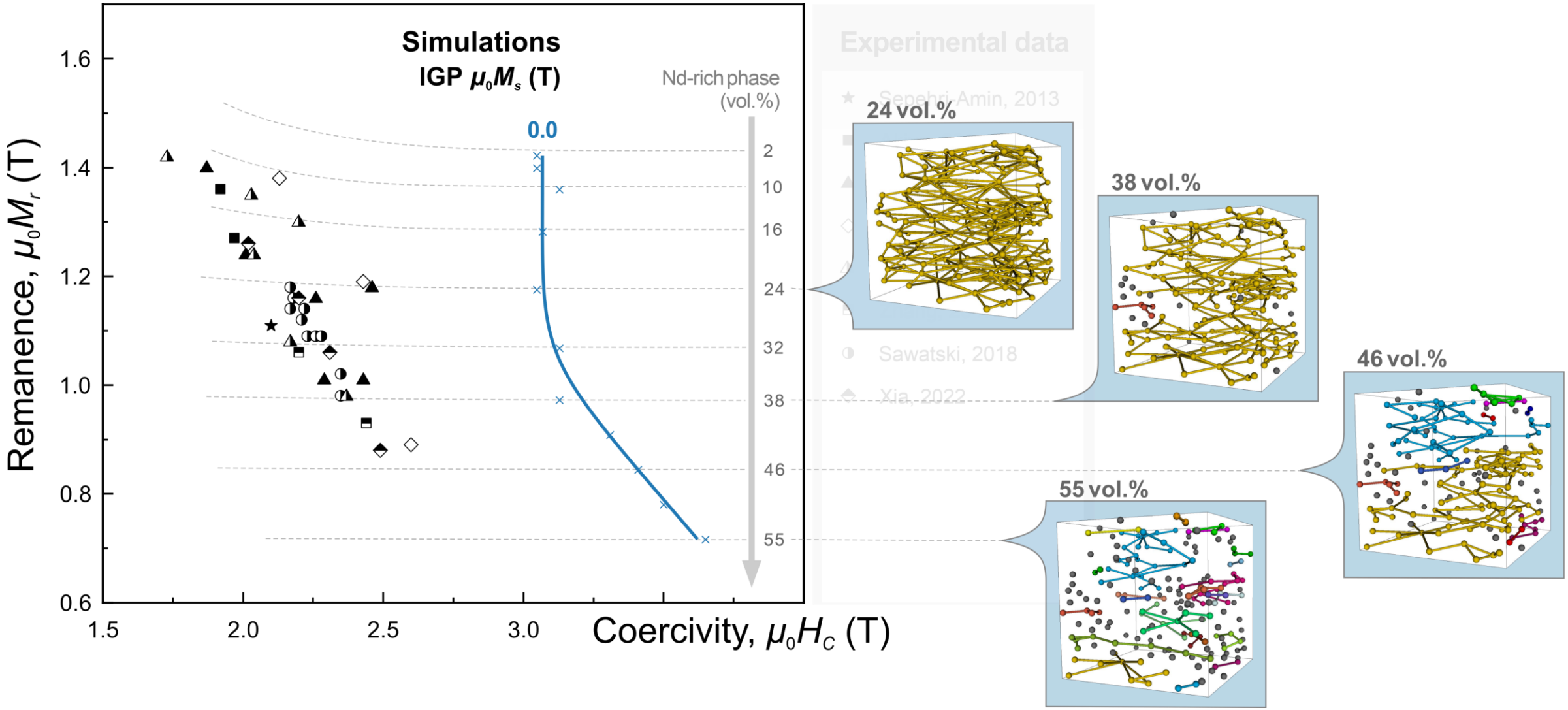


M_r vs. H_c Tradeoff

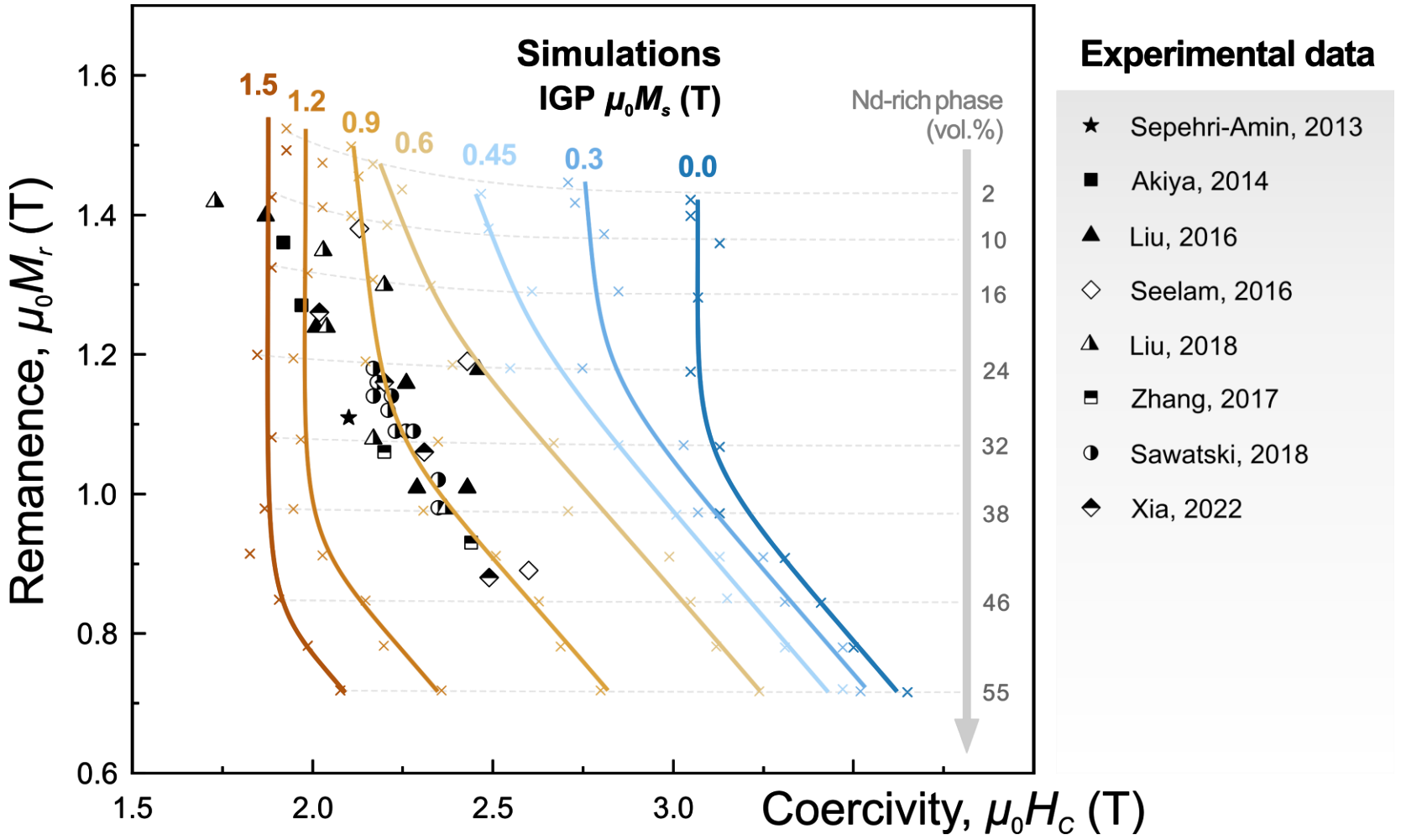


Note: EAs of the corresponding grains are the same throughout the models

M_r vs. H_c Tradeoff



M_r vs. H_c Tradeoff



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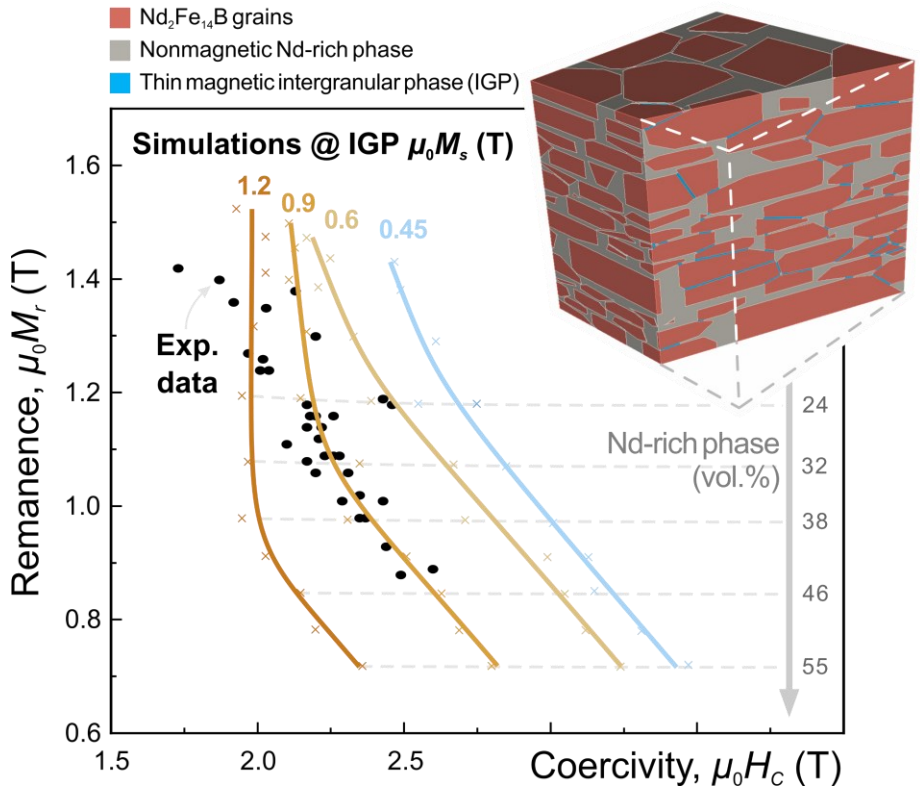
- Xia, 2022

Assumption: the chemical composition of thin IGP (and thus its M_s) doesn't change much during GBDP

Summary

- The M_r vs. H_c tradeoff of hot-deformed Nd-Fe-B magnets after the grain boundary diffusion process using a Nd-based eutectic alloy can be described by micromagnetic simulations
- Magnetization of the thin intergranular phase is estimated to be 0.9 ± 0.1 T
- Magnetostatic interaction defines the slope of M_r vs. H_c tradeoff, while exchange coupling – the bias, at high and low Nd-rich phase content, respectively



What's NEXT?

- Accounting for the core-shell structure
- **Implementing ROM** for larger models and better statistics

A. Bolyachkin *et al.*, Scripta Mater., 247 (2024) 116095

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Thank you for your attention!

Anton Bolyachkin, PhD
bolyachkin.anton@nims.go.jp
National Institute for Materials Science, Japan