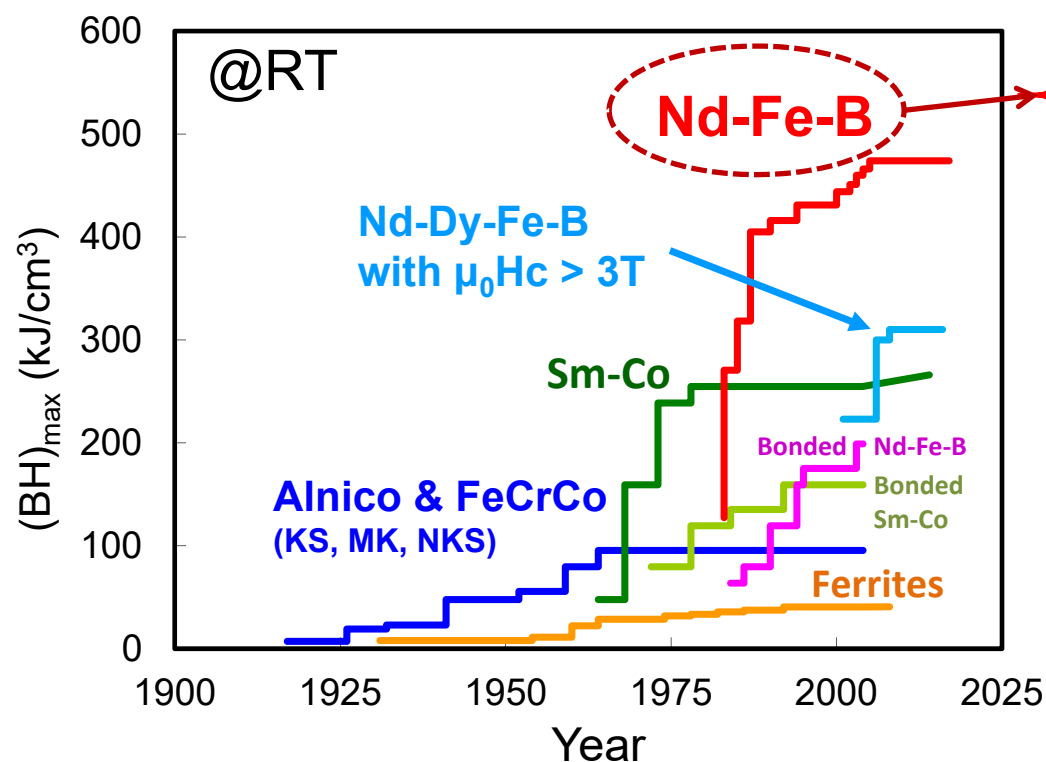


Element Strategy Initiative Center for Magnetic Materials (ESICMM)

Director-general
Satoshi Hirosawa
National Institute for Materials Science
Tsukuba, Japan

The quest for high energy-density permanent magnets

Development of permanent magnets



Automobile parts



<http://www.meank-magnet.com>

Hard Disc Drives



<https://www.google.co.jp>

HEV, EV



High coercivity
Nd-Dy-Fe-B

<https://automobiles.honda.com/>

Further Requirements from Society

Permanent magnets for the next generation applications

- ❑ Dy-free Nd-Fe-B (realized by 2016)
- ❑ Permanent magnet with superb performance at high-temperatures
- ❑ Emerging applications
- ❑ Quest for development of new permanent magnet free from critical elements



Global Wind Report 2016



<https://www.cyberdyne.jp/>



Ehang

<https://jp.techcrunch.com/>



NASA's X-57 Maxwell

<http://findmarketreport.com/nasas-x-57-maxwell-the-agencys-first-all-electric-x-plane-and-first-crewed-x-planed-in-two-decades/7774/>

Our Goals:

- Goal 1:** Realization of ultimate permanent magnet materials
- Goal 2:** Realization of permanent magnet materials based on new Fe-rich compositions
- Goal 3:** Establishment of basic science of permanent magnet materials
- Goal 4:** Dissemination and transfer of ESICMM's outputs into industry.

Topics: Generation and control of coercivity

A basic ingredient for generating coercivity: **Barriers!**

ESICMM studies:

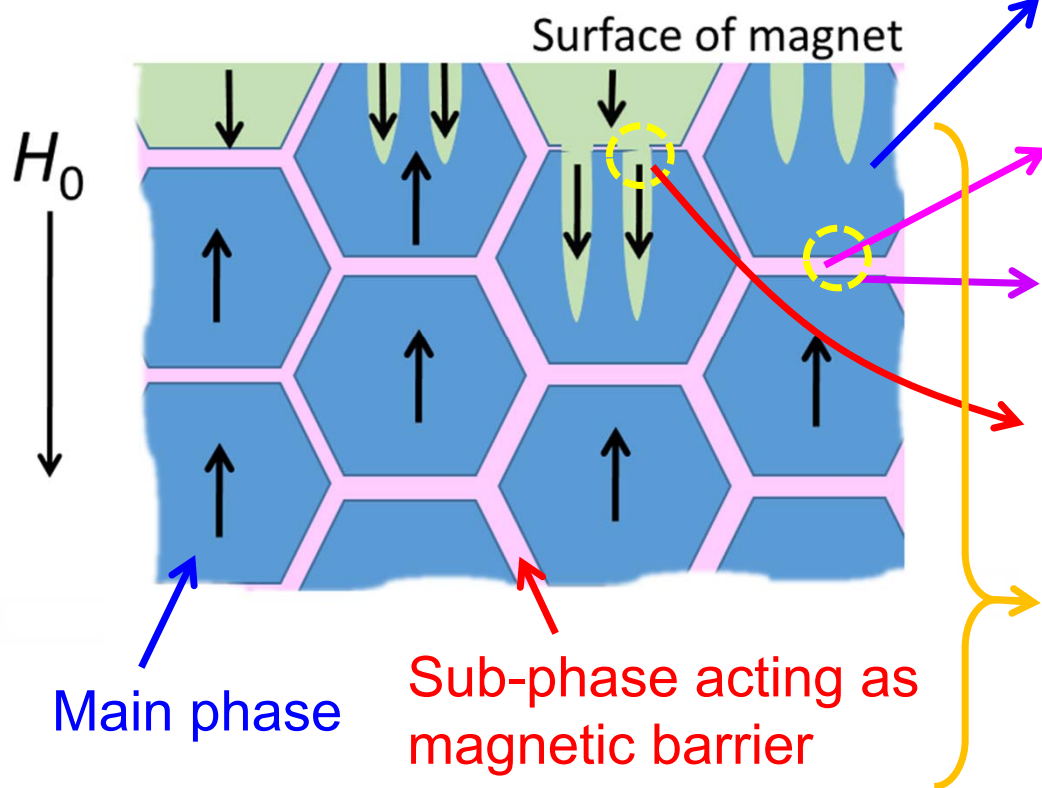
Crystal structure and magnetic properties of main phase

of sub-phases

Grain boundary and interfaces

Theory of coercivity

Thermodynamics



ESICMM

The core research center for
permanent magnet

in the Element Strategy Initiative
under auspices of MEXT since 2012

Industrial Advisors

from

ShinEtsu

TDK

Hitachi Metals

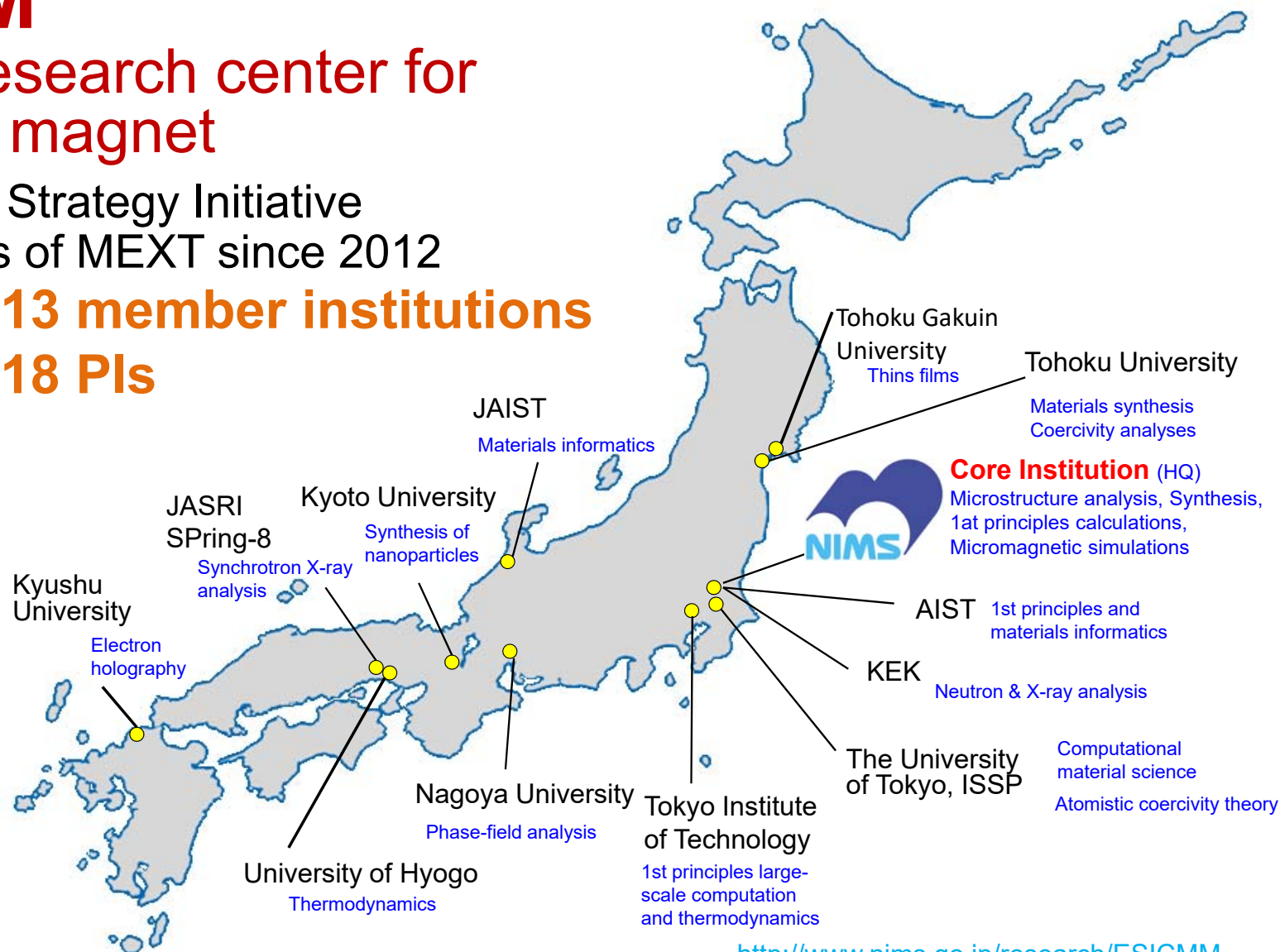
Daido Steel

Aichi Steel

Toyota

Hitachi

13 member institutions
18 PIs



<http://www.nims.go.jp/research/ESICMM>

Theory Group



T. Miyake
(AIST)
Theoretical search
of new matter



S. Tsuneyuki
(ISSP)
Common Platform



Y. Gohda
(TITech)
First-principles
structural studies



H. Tsuchiura
(Tohoku Univ.)
Theoretical study of
coercivity



S. Miyashita
(ISSP)
Statistical physics
of coercivity



T. Tadano
(NIMS)
First-principles
lattice dynamics

Thermo- dynamics



T. Abe
(NIMS)
Computational
phase diagrams



T. Koyama
(Nagoya U.)
Phase-field
analysis

Principal Investigators 18PI (including 3GL and 6 PI from NIMS)

Head Office



S. Hirosawa
Director-
general



C. Mitsumata
Planning
Manager

Advisors (alphabetical)

(Industry)

(Academia)

Y. Enomoto (Hitachi)
T. Iriyama (Daido Steel)
C. Mishima (Aichi Steel)
H. Nakamura (Shin-Etsu)
T. Nishiuchi (Hitachi Met.)
M. Sagawa (NDFEB)
T. Shoji (Toyota)
K. Suzuki (TDK)

H. Akai (IPPS)
Y. Murakami (KEK)
T. Oguchi (Osaka Univ.)
K. Ozaki (AIST/MagHEM)
A. Sakuma (Tohoku Univ.)
J. Suzuki (J-PARC)
M. Takata (IMRAM)

Analysis Group



K. Hono
(NIMS)
Multi-scale-multi-
aspect analyses



T. Nakamura
(JASRI)
Synchrotron X-ray
analyses



K. Ono
(KEK)
Neutron and X-ray
analyses



S. Okamoto
(Tohoku Univ.)
Magnetization
process



K. Sodeyama
(NIMS)
Materials
informatics

Synthesis Group



S. Sugimoto
(Tohoku Univ.)
Novel multi-phase
magnetic materials



T. Teranishi
(Kyoto Univ.)
Synthesis of magnetic
meso particles



YK. Takahashi
(NIMS)
Thin film synthesis
of novel materials



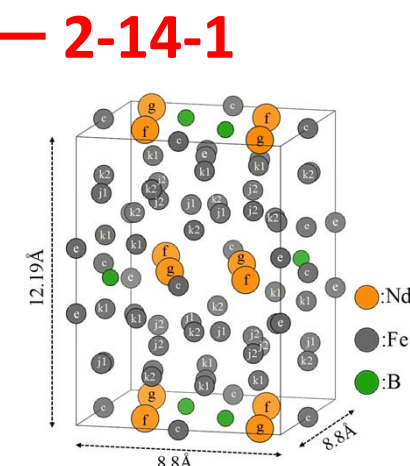
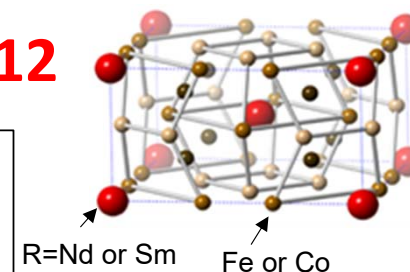
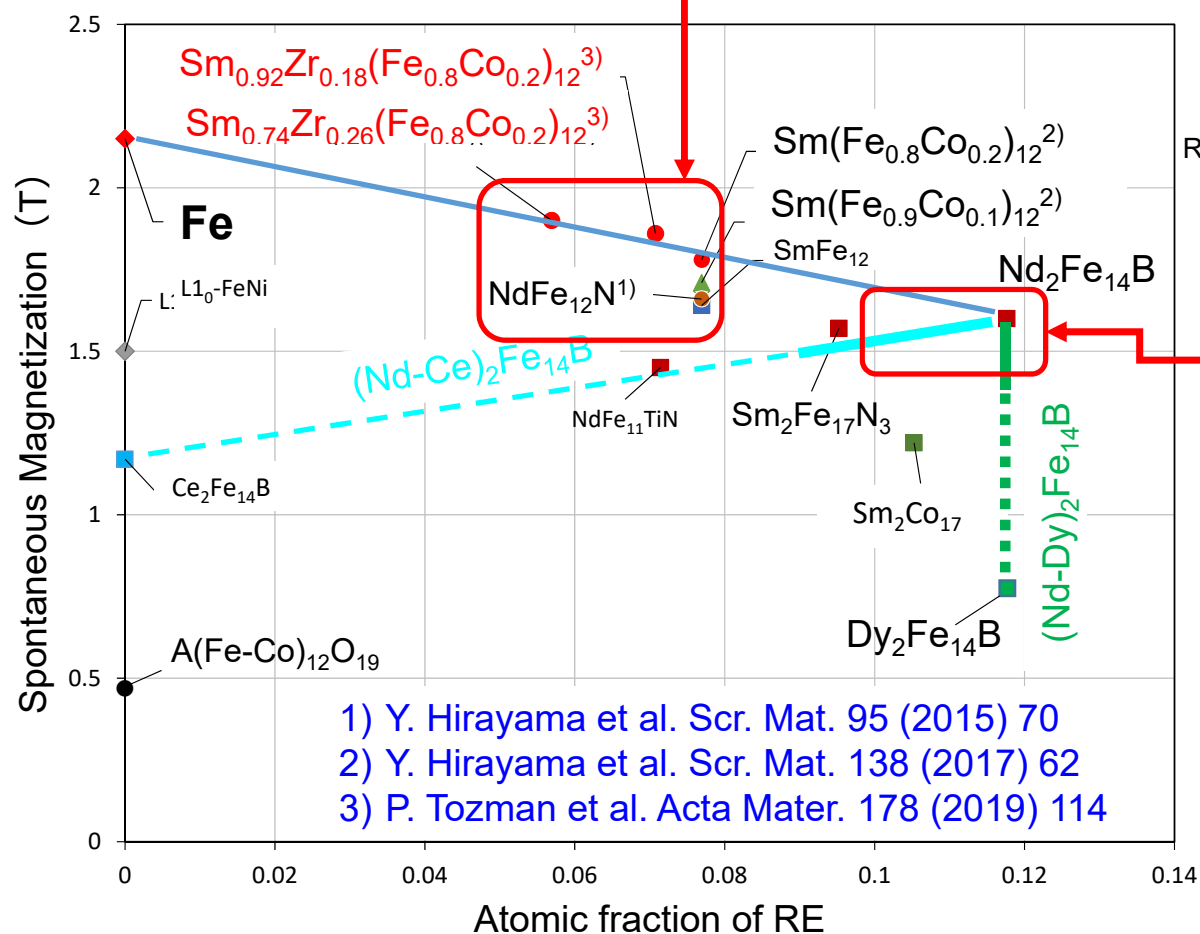
T. Ohkubo
(NIMS)
Synthesis of bulk
magnetic materials



H. Nakamura
(Kyoto Univ.)
Synthesis and
analysis of ferrites

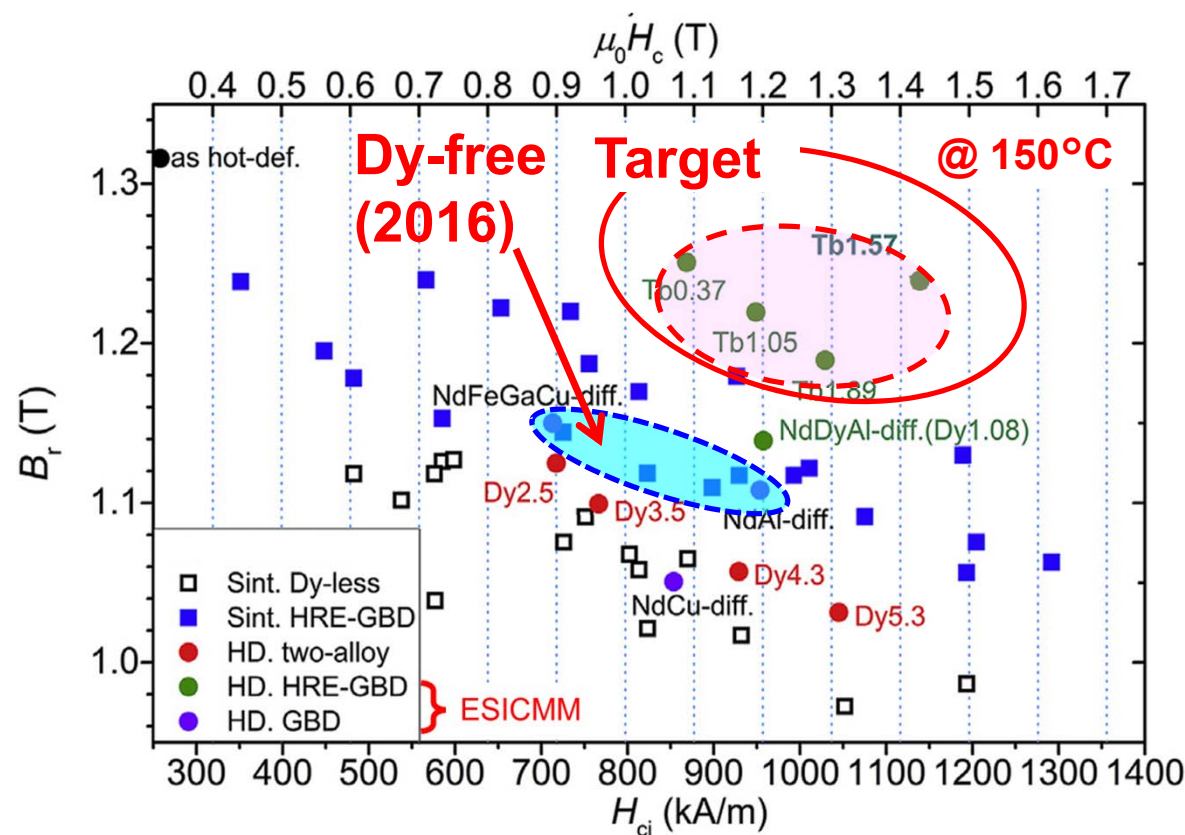
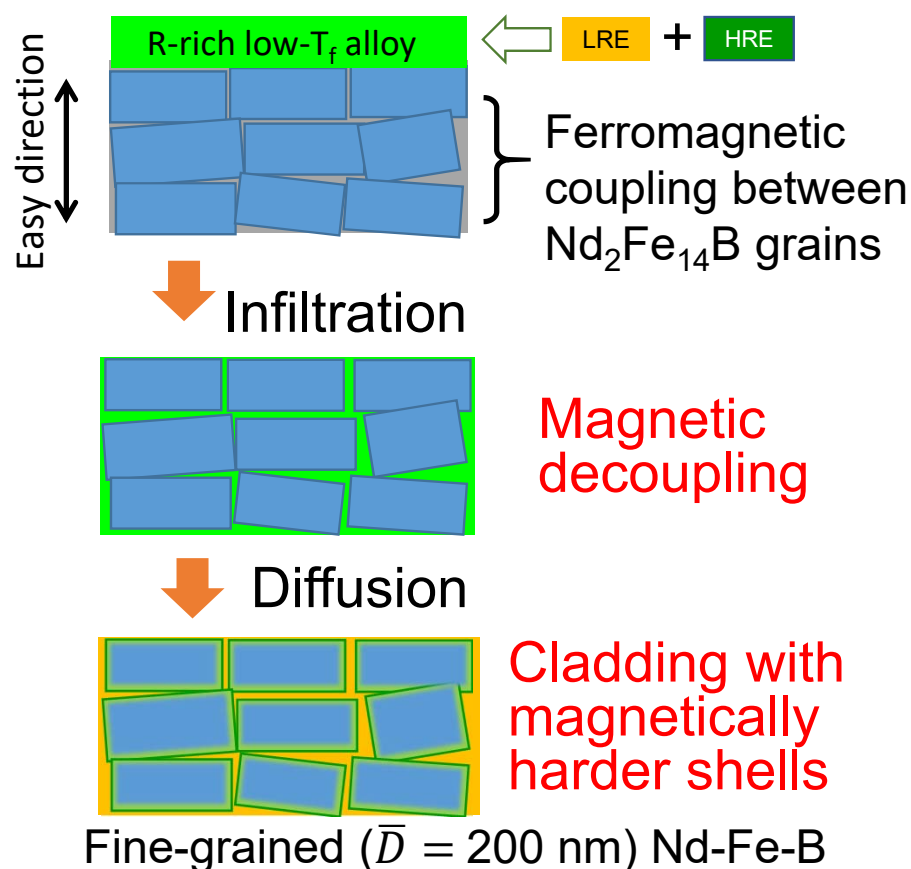
Target materials for ultimate permanent magnet

Selected groups of hard magnetic materials
after screening research (2012 -2016)



Development toward “ultimate Nd-Fe-B”

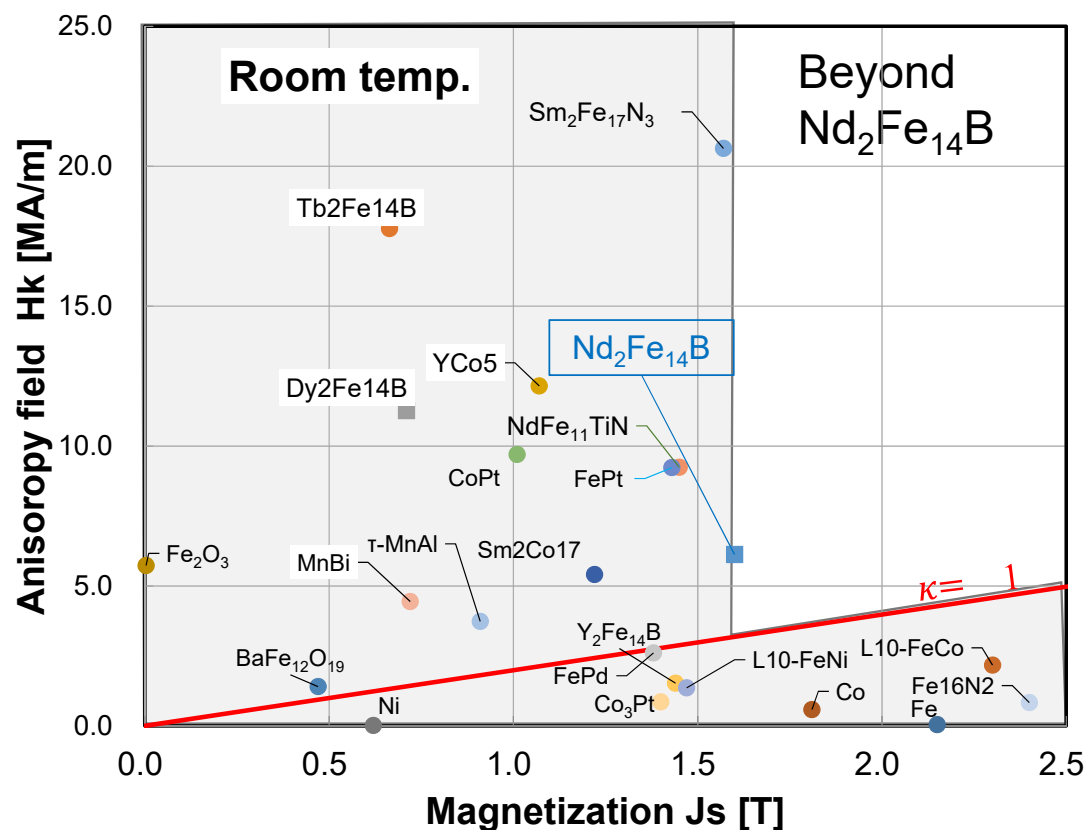
- ✓ Grain-boundary-infiltration process to hot-deformed Nd-Fe-B
- ✓ Dy-free Nd-Fe-B-Co-Ga with 2 tesla coercivity at RT (suitable up to c.a, 150°C)
- ✓ Superb performance at 150 °C with Nd₆₀Tb₁₀Cu₃₀-infiltration alloy



J. Li *et al.* Acta Mater. 161 (2018) 171-181.

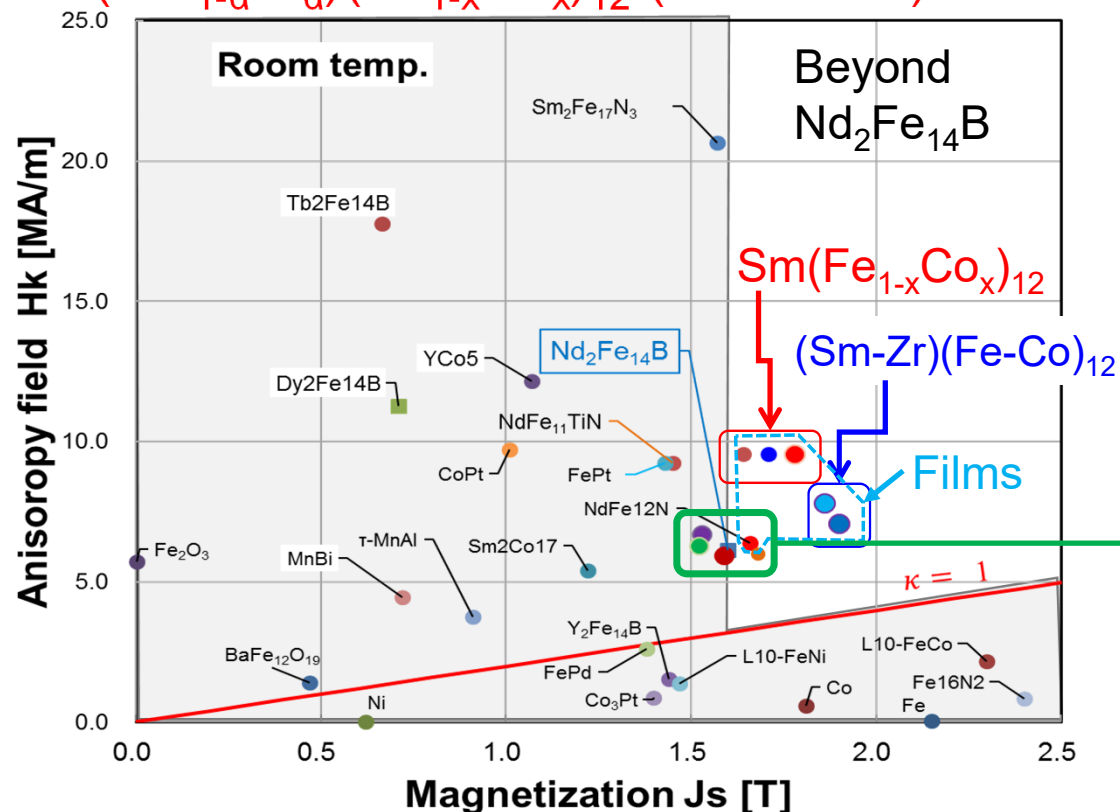
Discovery of new 1-12-type compounds

Map of hard magnetic compound in 2012



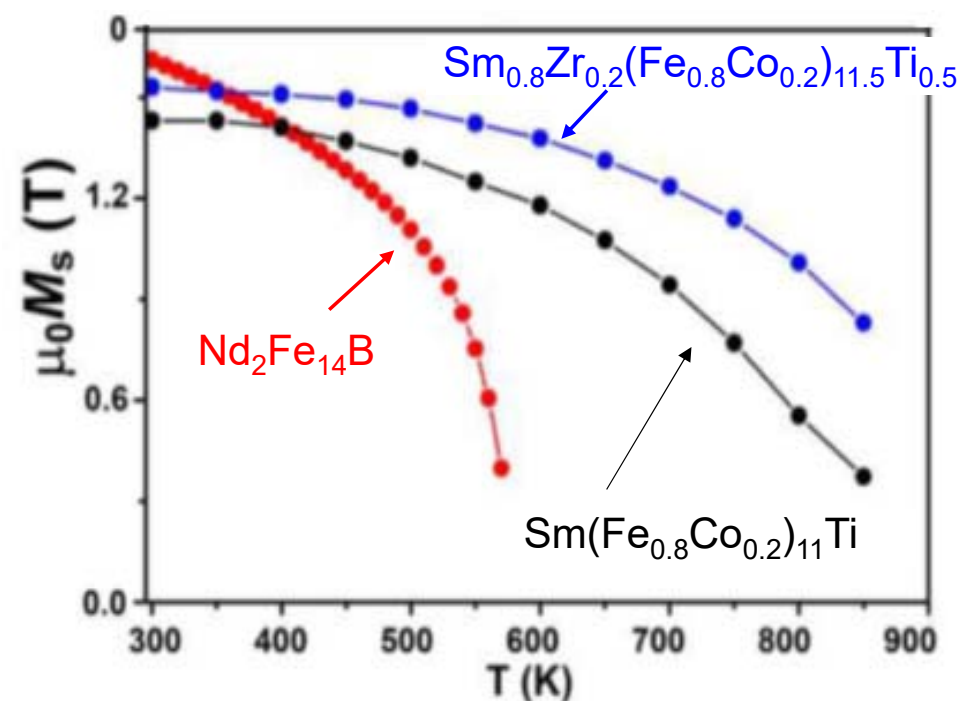
Discovery of new 1-12-type compounds

Synthesis of single-crystal NdFe_{12}N and $(\text{Sm}_{1-\alpha}\text{Zr}_{\alpha})(\text{Fe}_{1-x}\text{Co}_x)_{12}$ ($0.1 \leq x \leq 0.2$)



- ● ● Y. Hirayama et al. Scr. Mat. 138 (2017) 62
 - ● ● P. Tozman et al. Acta Mat. 153 (2018) 354
 - ● ● P. Tozman et al. Acta Mater. 178 (2019) 114
 - ● ● T. Kuno et al. AIP Adv. 6 (2016) 025221
- } ESICMM

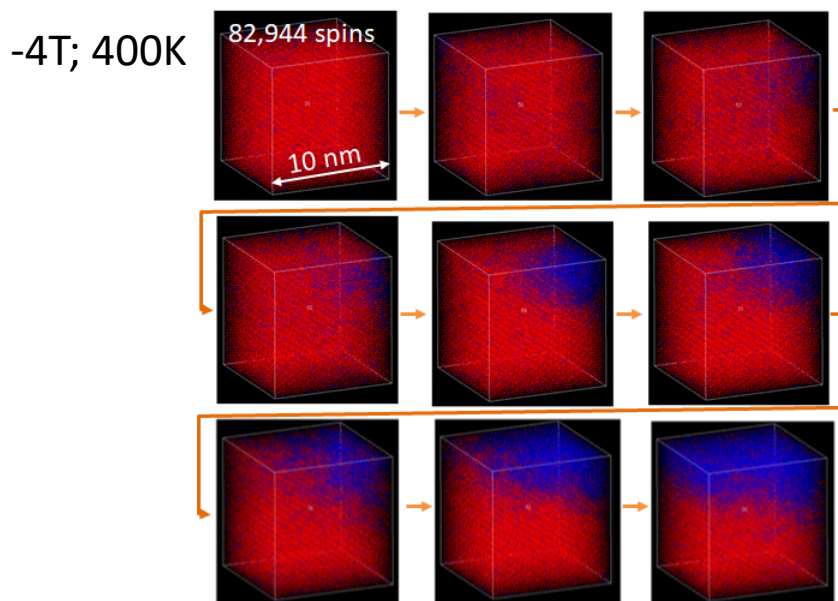
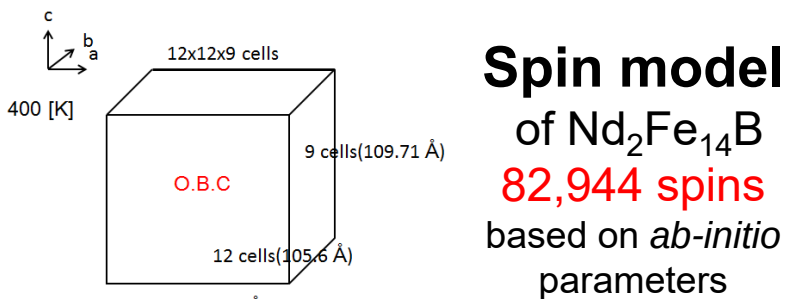
Stabilized bulk alloys



P. Tozman et al. Acta Mat. 153 (2018) 354

Atomic spin model to understand coercivity at $T > 0$

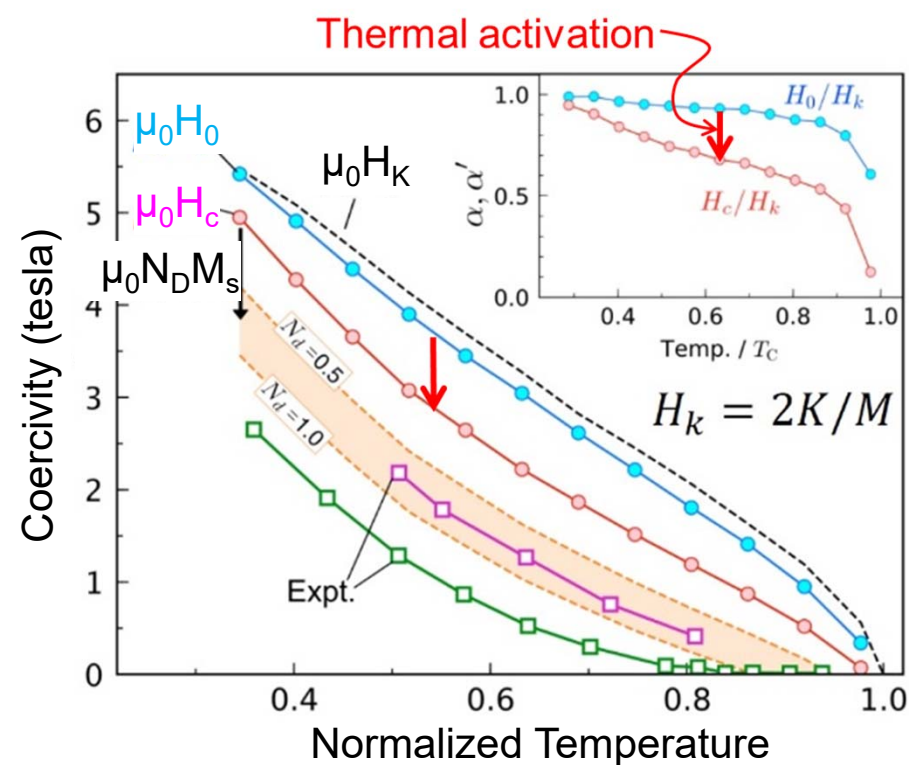
Stochastic LLG simulation



S. Miyashita, M. Nishino, et al.
 Scr. Mater. 154, 259 (2018)

Thermo-statistical analysis (Monte-Carlo)

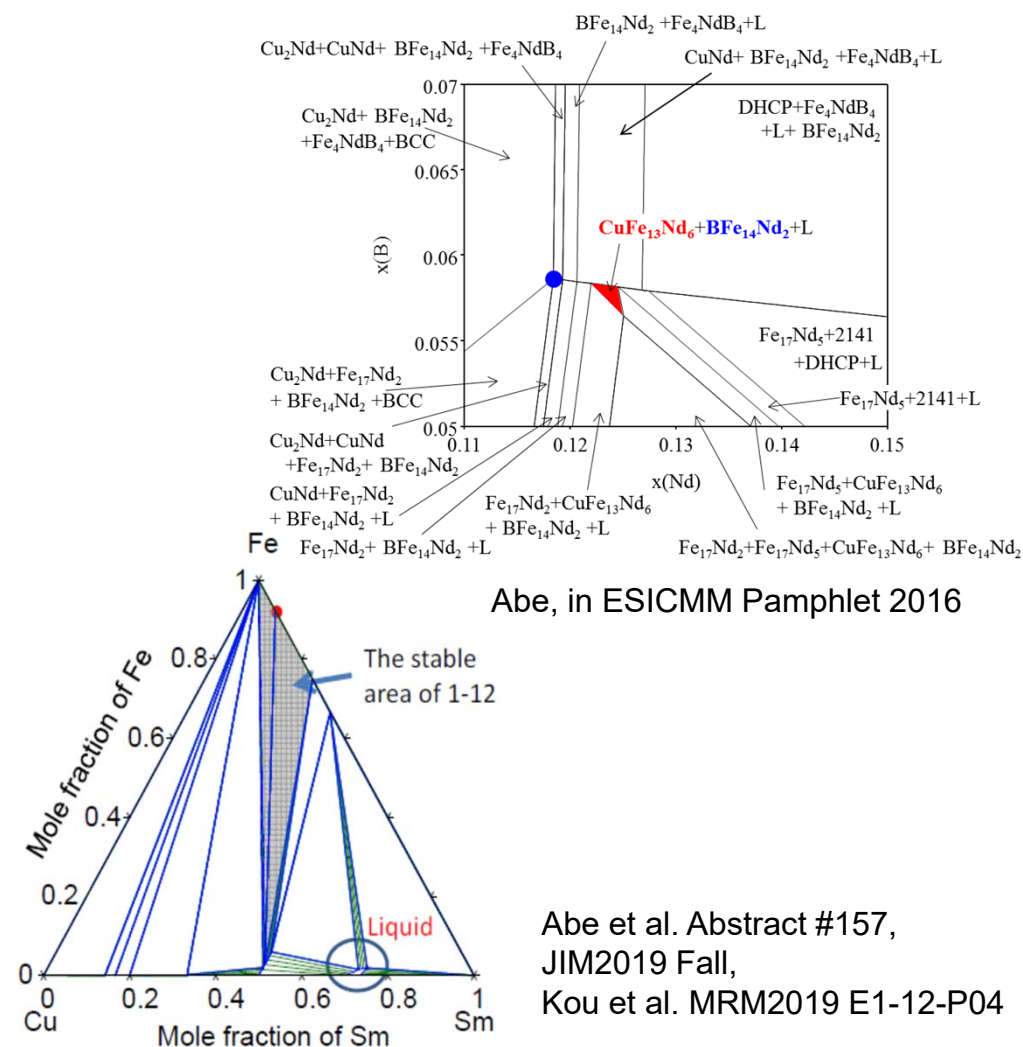
Spin model of $\text{Nd}_2\text{Fe}_{14}\text{B}$; 713,172 spins (c.a., $(21\text{nm})^3$)



Coercivity vs. temperature from energy barrier calculations,
 Y. Toga et al. submitted, presented at MRM2019, E-1-13-009

Thermodynamics Data Base

- ✓ There was no systematic database for permanent magnet alloys.
- ✓ Compilation of a thermodynamic database for Nd-Fe-B-Cu-Co-Al-Dy-Ga-O and Sm-Fe-Co-Ti-Ga-Cu-; (on-going)
- ✓ Phase diagram calculation service since June 2019



Vision : Core center for academia-industry cooperation on permanent magnets (toward Goal 4)

Our vision is to establish a matching-fund program in **NIMS-MOP** for cooperation with industry to inherit the research core and network of ESICMM.

Research Network developed in ESICMM



Dissemination ↓ Unpublished results, Phase diagrams, etc.

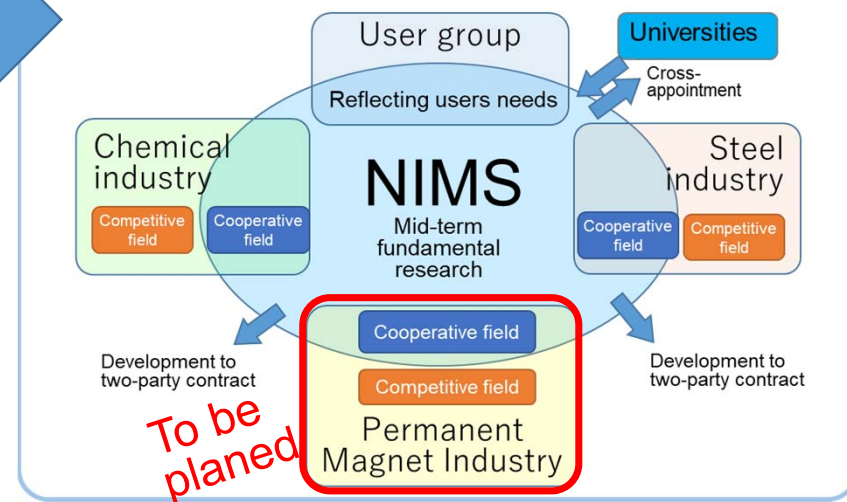


NIMS Permanent Magnet Partnership
14 member companies

NIMS M-cube Program

MOP

“Horizontal cooperation in sharable base science to strengthen innovative ability”



Summary

As the core research center for permanent magnets, ESICMM has developed:

1. Dy-free Nd-Fe-B comparable to conventional magnets basing on the new understandings,
2. New $\text{Sm}(\text{Fe-Co})_{12}$ -type family of hard magnetic compounds based on theoretical predictions,
3. Fundamental understandings for R&D of permanent magnets (thermodynamics and mechanism of coercivity)
4. Future vision for academia-industry partnership (MOP)

