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Recent R&D Trends in Rare earth permanent magnets

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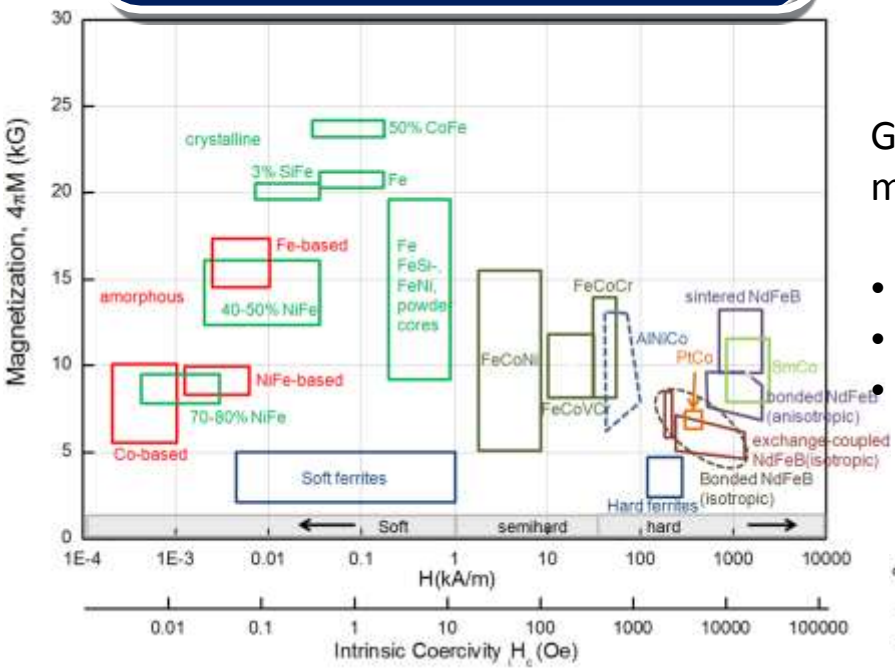
Introduction

Characteristic of magnetic materials



Generally, the magnetic materials are classified by the magnitude of the coercive force.

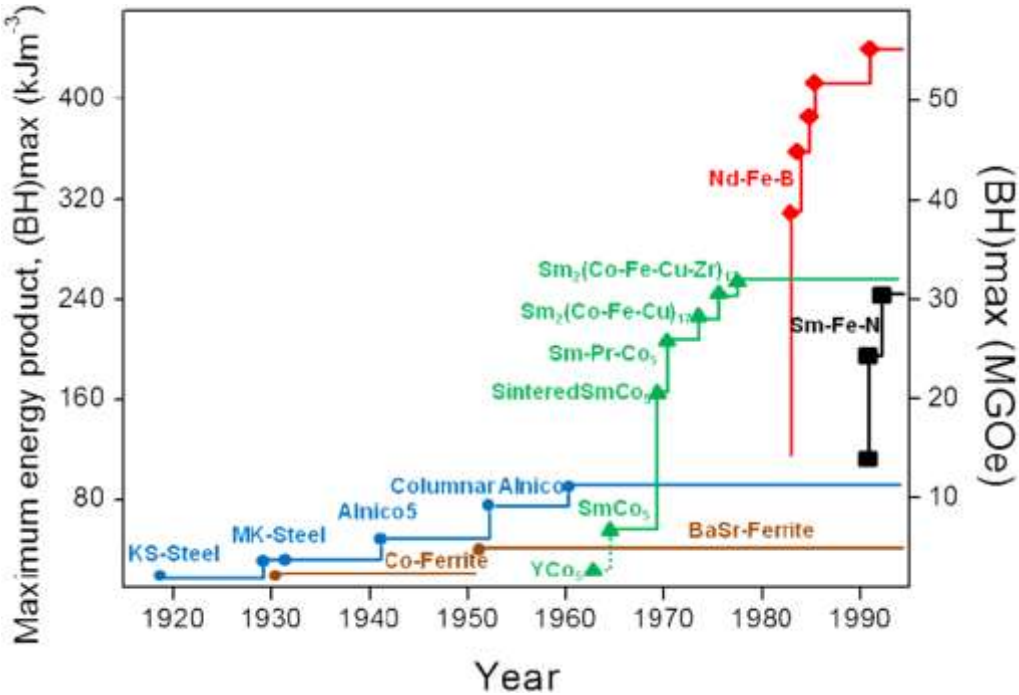
- **Soft magnet** : 1 kA/m(13 Oe ↓)
- **Semi-hard magnet** : 1~40 kA/m(13 ~ 52 Oe)
- **Hard magnet** : 50 kA/m(65 Oe ↑)

- After the **KS-steel** was developed, More than 10 kinds of permanents magnets have been developed.

- Since the advent of the **rare earth magnets** , performance of permanent magnet was quickly developed.

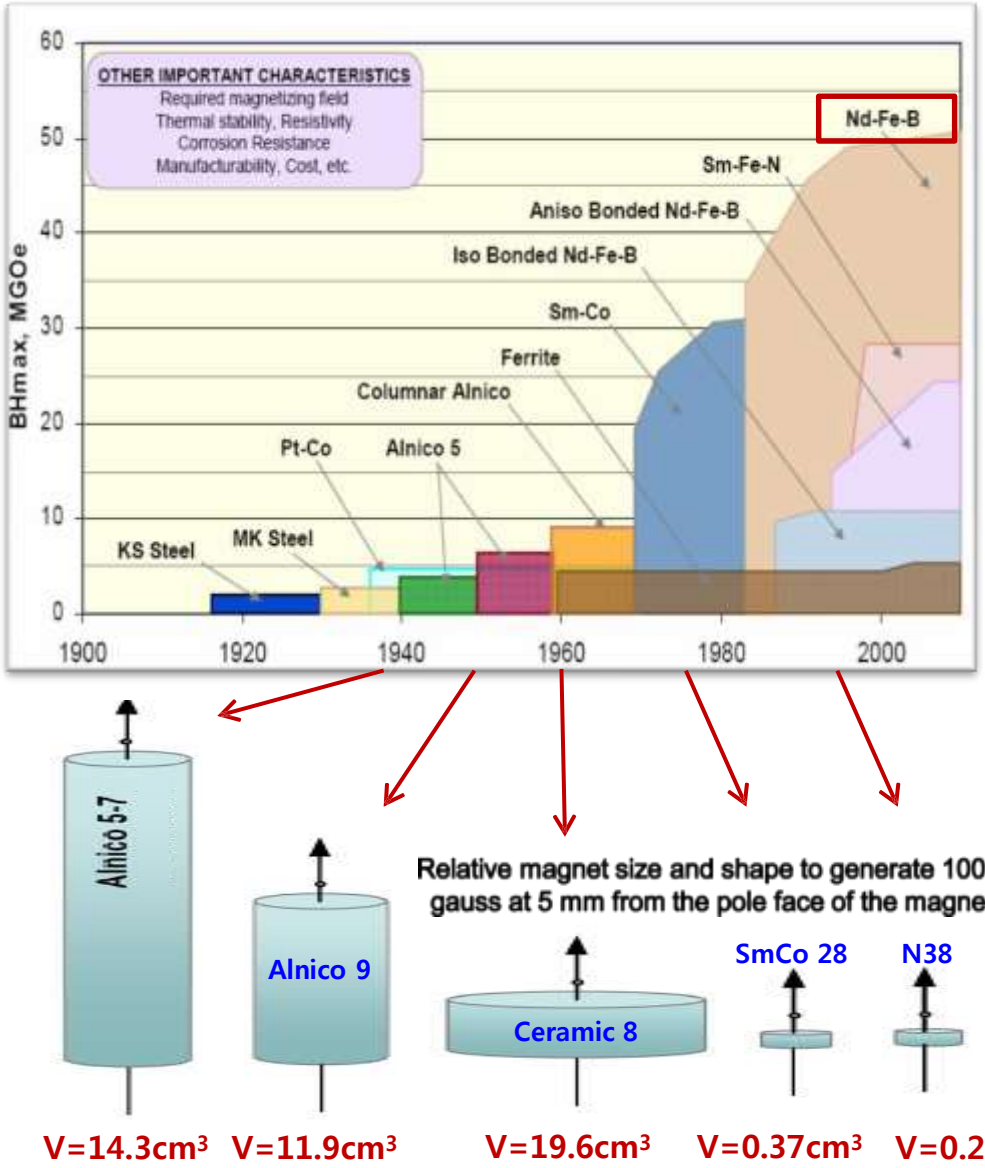
- Maximum energy product of NdFeB magnet is **60 times** greater than KS-steel.

Development progress



Introduction

Development progress



Magnetic field strength

△V ~ 98% (1940 -1995)

- More smaller
- Light weight
- Energy efficiency

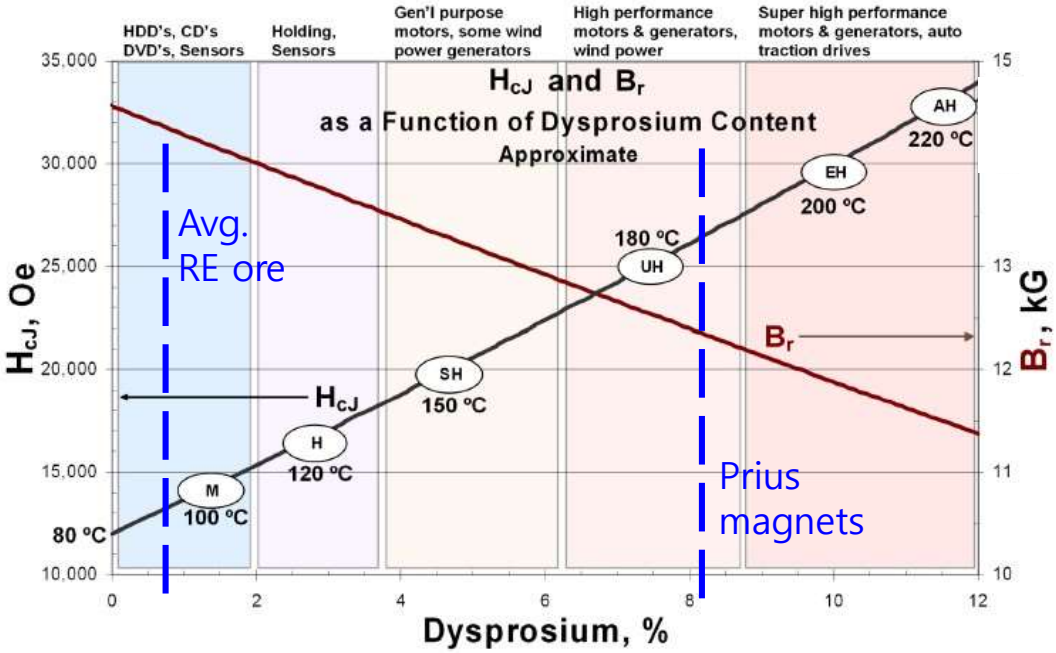
Introduction

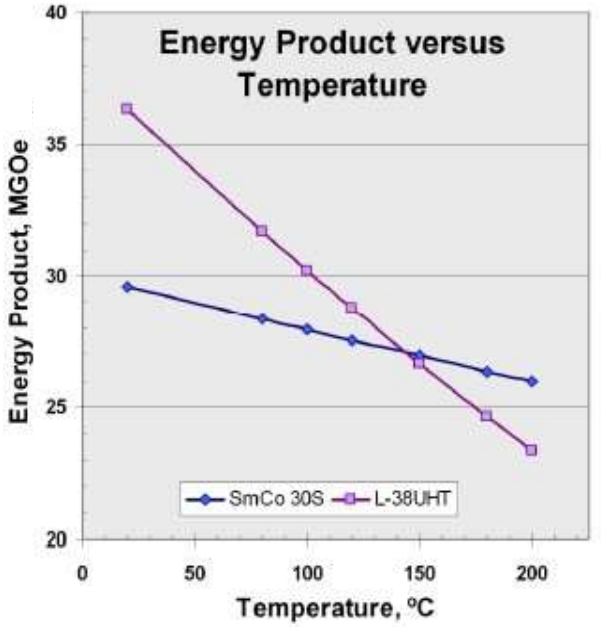
Nd- Fe- B system

$Nd_2Fe_{14}B$ + Nd rich

- Invented by Sagawa & Croat in 1982
- Saturation magnetization, M_S=16 kG
- Anisotropy field, H_A=73 kOe
- Energy products, $(BH)_{MAX}$=64 MGOe
- Curie temperature, T_C=315 °C

Therefore the development of high coercivity Nd-Fe-B permanent magnet is a challenging issue.





* Add Dy and Tb for improvement of $_iH_c$

- However, remanence and energy products become lower.
- HRE(heavy rare earth metal) is relatively expensive and being limited in quantity.

-> Hence, a new technology that can increase the coercivity of Nd-Fe-B sintered magnet using Dy-less or Dy-free process is necessary.

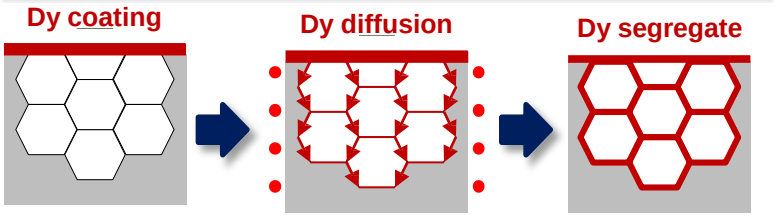
Research Trend – Dy less

Alloy design of rare earth magnet

Nd-Dy-TM-B

- Need to contain much Dy to increase Coercivity
- Dy content of magnet for HEV(8~10 wt%), compressor(5~6 wt%)
- Cost of Dy is 10 times higher than Nd

Grain Boundary Diffusion Process



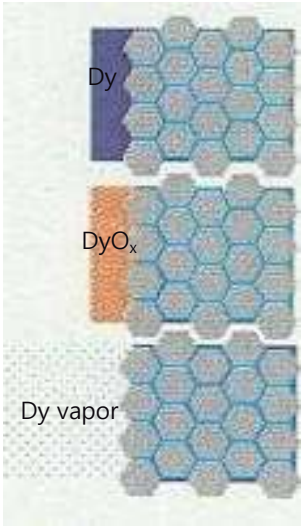
Dy coating on Nd-Fe-B magnet

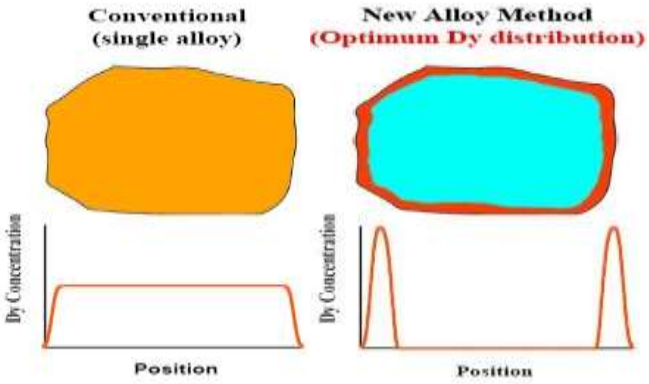
Dy diffusion during heat treatment

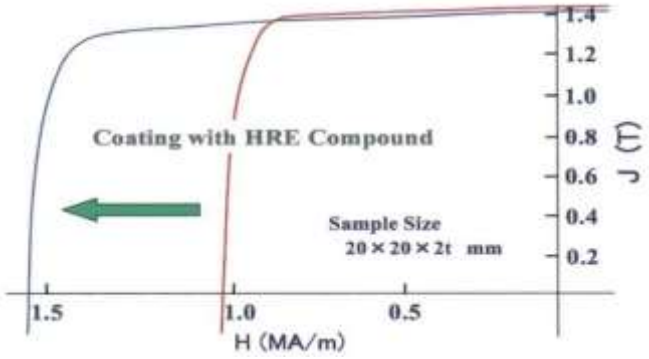
Dy segregation along grain boundary

**Sources of Dy : Dy film, compounds, vapor*

- Deposition of Dy film
- Dy compounds
- Dy vapor



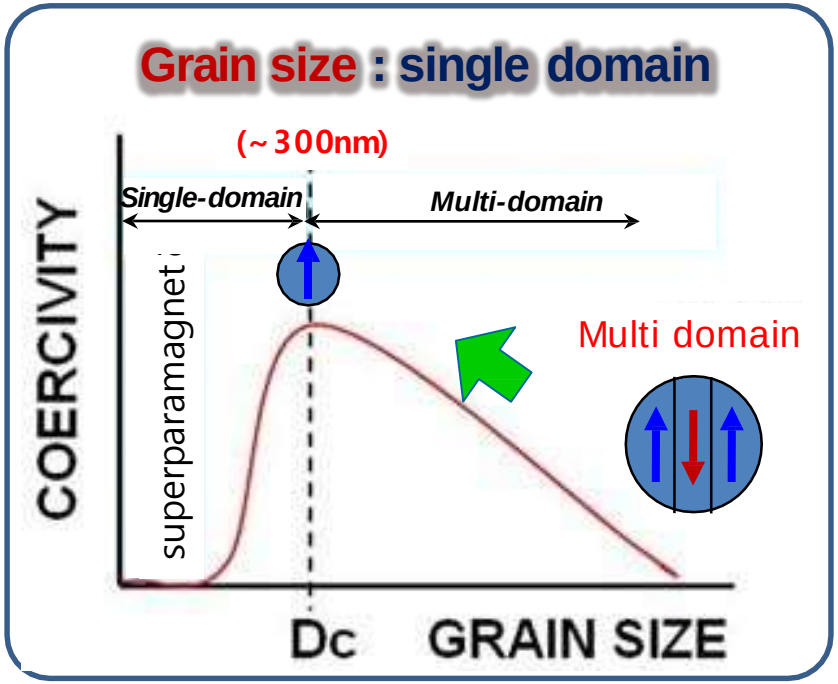




Coercivity, 6 kOe↑ Dy, 2-3wt%↓

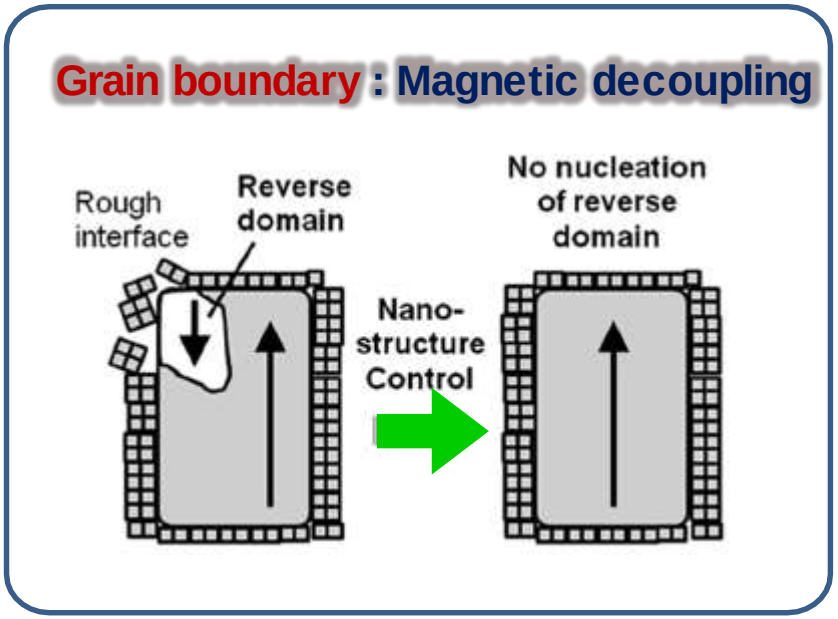
reported by Shin-Etsu Chemical in 2005

Research Trend – Dy free



The crystal magnetic anisotropy is increased.

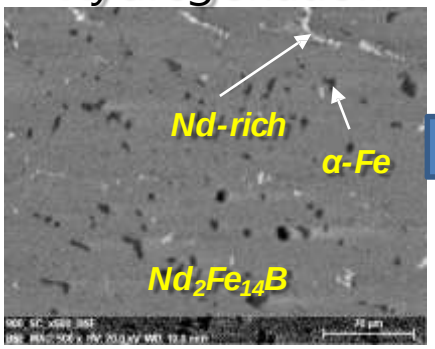
Method : HDDR, Melt spinning



Control the reverse domain by interface defect and magnetization reversal by the grain growth.

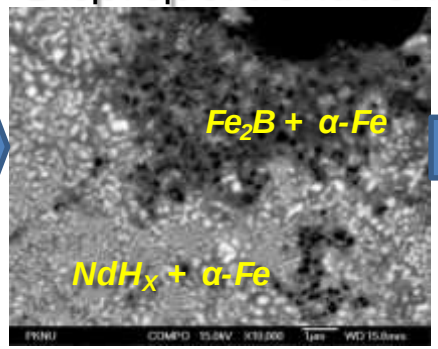
Research Trend – Dy free

Hydrogenation



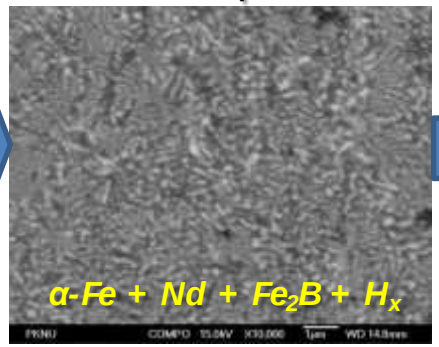
Hydrogen reaction during heat treatment

Disproportionation



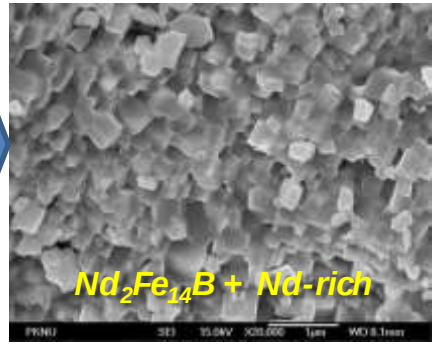
Decomposition(NdH_2, Fe, Fe_2B) by hydrogen reaction

Desorption



Remove hydrogen during heat treatment

Recombination



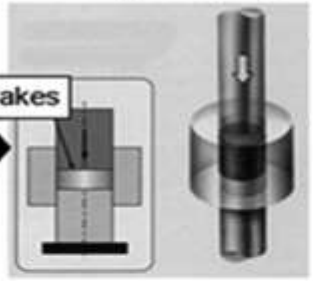
Recombination $Nd_2Fe_{14}B$ phase

Grain size : 50-300nm

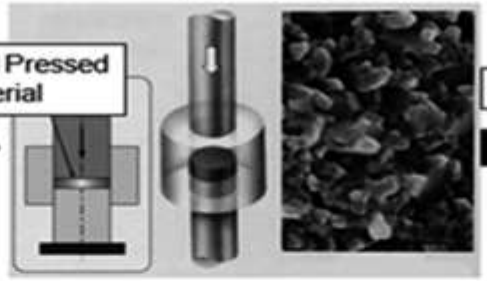
Melt spinning

Grain size : 20-50nm

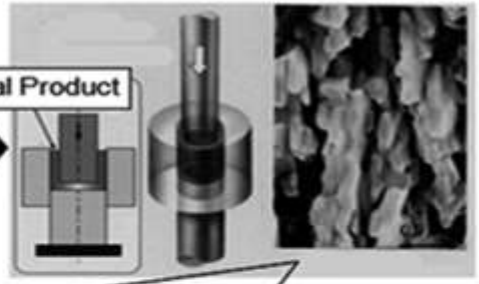
Cold pressing

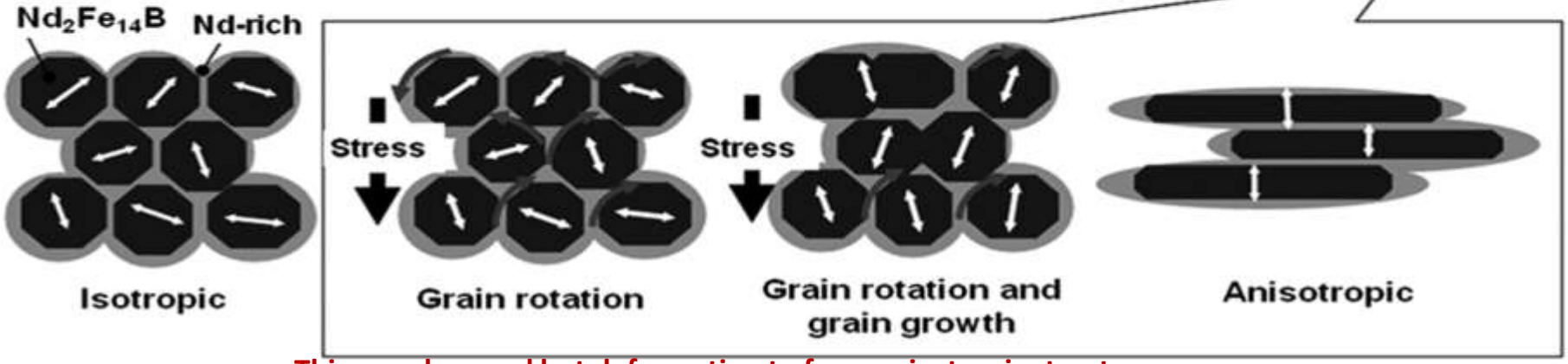


Hot pressing



Hot forming





This powder need hot deformation to form anisotropic structure

Application of Nd magnets

IT

2 g

Automobile

1.2 k g

Renewable energy

1 t

(Nd,Dy)-Fe-B magnet

$Fe_{65.5}Nd_{22}Dy_{11}B_1Al_{0.3}Cu_{0.1}O_{0.1}$ (mass.%)

High performance magnets are used in IT, Automobile and Wind generators.

Thanks for your attention ...