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Upscaling the Novel 2 Powder Method for the Manufacturing of Heavy Rare Earth-Lean Permanent Magnets

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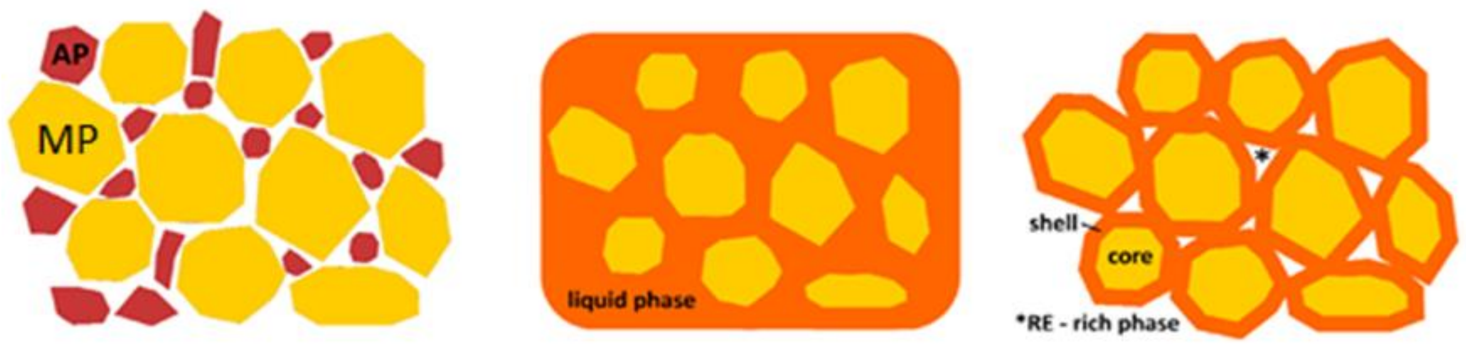
The 2-powder method* is a novel way to enrich $(Nd/Pr)_2Fe_{14}B$ grains with a shell of high magnetic anisotropy. Thus preventing the nucleation of reversed domains in large sintered blocks without magnet size limitation and at the same time, the minimization of the total heavy rare earth (HRE) content in the large magnet volume. Here, two powders with differences in particle size and chemical composition were blended and sintered together. The powder with the smaller average particle size (AP - anisotropy powder) includes HREs like Dy or Tb and therefore, shows a significantly higher magneto crystalline anisotropy than the second powder with larger average particle size (MP - main phase powder). Further, the average particle size of the MP is at least 50 – 100 % larger than the particle size of the AP. During sintering, the anisotropy powder will turn into the liquid phase first, because of the higher surface energy of smaller particles. This results in a homogeneous distribution of the HREs around the 2-14-1 grains and finally forms a core shell structure. Therefore, by use of the 2-powder method, size independent HRE-lean magnets can be produced, which is not the case for the grain boundary diffusion (GBDP) and no additional diffusion treatment after the normal sintering procedure is necessary, making the 2-powder method useful to integrate in the commercial used mass production for high performance didymium-based sintered magnets.

2 –Powder Method*

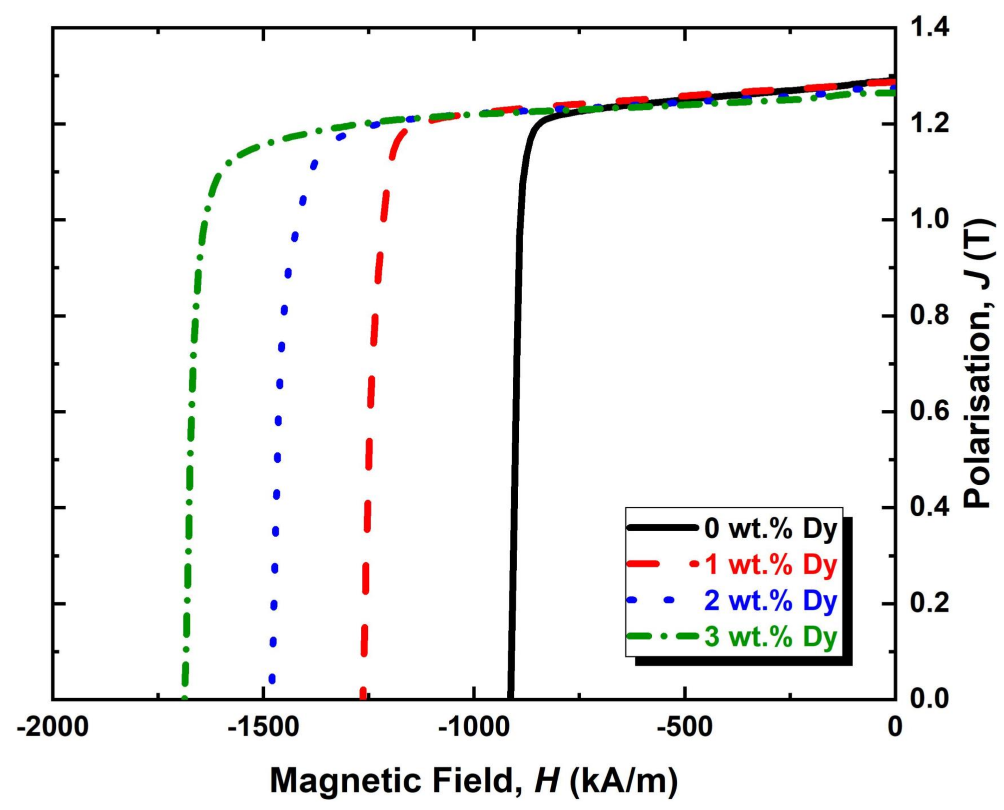
- Blending of two different $RE_2Fe_{14}B$ powders with different particle size distributions
- Heavy rare earth free main phase powder (**MP**) with ideally at least 50 - 100 % higher average particle size
- Blended with a HRE (such as Dy) containing anisotropy powder (**AP**)
- During the sintering process the smaller **AP** particles turn earlier into the liquid phase and surround the **MP** particles
- Formation of a core-shell structure



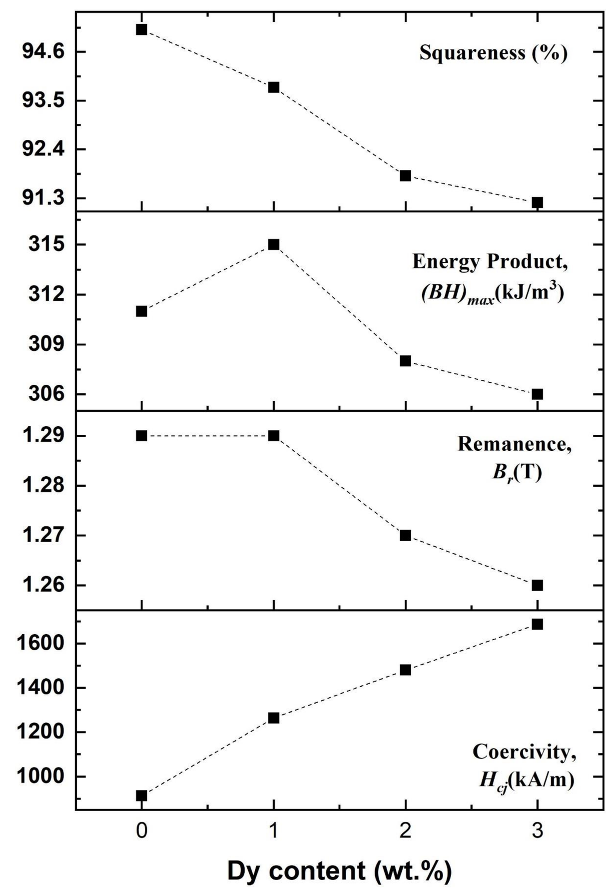
Löwe, K., *Grain boundary engineering in sintered Nd-Fe-B permanent magnets for efficient utilization of heavy rare earth elements.* Dissertation 2016: Darmstadt.

Magnetic Properties and Microstructural Investigation

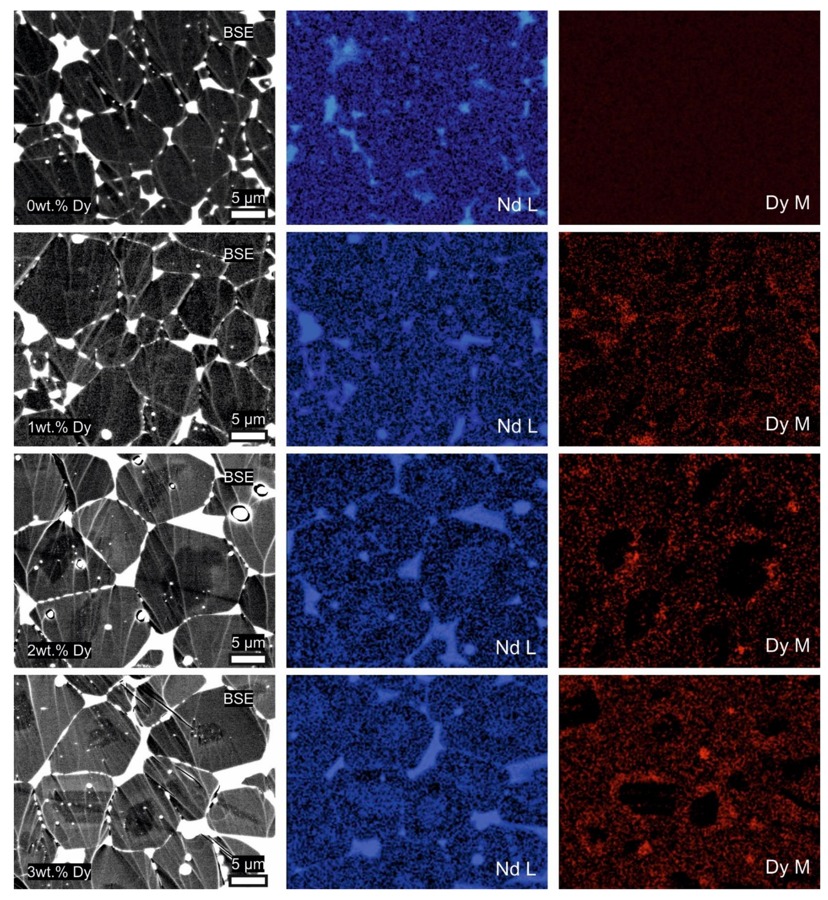
- Sintered magnets containing 0, 1, 2 and 3 wt.% Dy produced by using the 2-powder method
- Increase in coercivity of 750 kA/m without significant loose in remanence
- Homogeneous core-shell structure in the whole magnet volume



Demagnetization curves of the magnets produced by using the 2-powder method and the MP only.



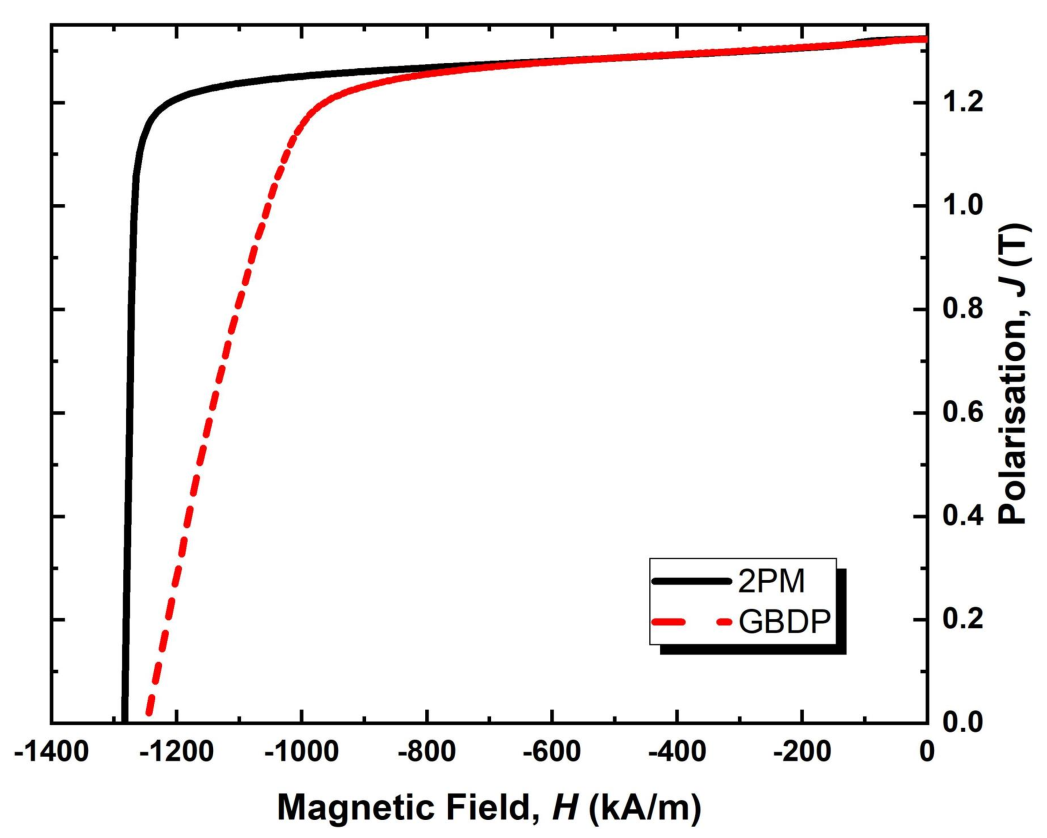
Magnetic values in dependency of the Dy content.



Secondary electron microscopy investigation of the resulting microstructure.

Comparison of the 2-Powder Method and the GBDP

Using the GBDP means additional effort in terms of cost and time namely (i) additional HRE source preparation; (ii) additional process step concerning magnet coating by dipping into a suspension, sputtering, electrophoretic deposition; (iii) additional heat treatment for HRE diffusion; (iv) only small size magnets treatment; the 2-powder method addresses all of them, demonstrating the simple integration in industrial magnet production. First, there is no additional HRE source needed, because a conventional HRE containing high anisotropy didymium alloy from magnet production of other industrial magnet grades can be used as AP. The coating step is skipped, as the powders are just blended together and the additional heat treatment is not required because the standard sintering route is used. Finally, magnets can produced independent of their size.



Comparison of the magnetic properties for 10 mm thick sintered magnets by using the 2-powder method (black curve) and the GBDP (red curve). The Dy content was adjusted to 1 wt.% for both magnets underlining that the 2-powder magnet is even useful for thick magnets. The poor squarness of the magnet treated with the GBDP indicates a not homogeneous distribution of the HREs because of the size limitation in terms of GBDP compared to the 2-powder method.

Summary

- Study of the 2-powder method as novel approach to increase coercivity without significant decrease in remanence independent of the magnets siz
- Coercivity was increased by 750 kA/m to 1687 kA/m for the samples containing 3 wt.% Dy without significant loose in remanence
- Homogeneous core-shell structure of HREs enclosing the 2-14-1 grains in the whole magnet volume was observed
- Comparison of the 2-powder method and the GBDP illustrate the advantages of the 2-powder method, that magnets independent of their size can be produced by using the conventional metallurgical processing route for sintered Nd-Fe-B based permanent magnets