Permanent (and Soft) Magnetic Materials for Accelerators

Workshop on Special Compact and Low Consumption Magnet Design, CERN, Geneva 26.-28.Nov. 2014

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Outline

- Homogeneous magnets for undulators
- Cryogenic applications: PrFeB
- Improvements of actual NdFeB alloys
  - by alloy composition
  - by grain boundary diffusion
- New soft magnetic alloys

Magnets for scientific applications on industrial scale

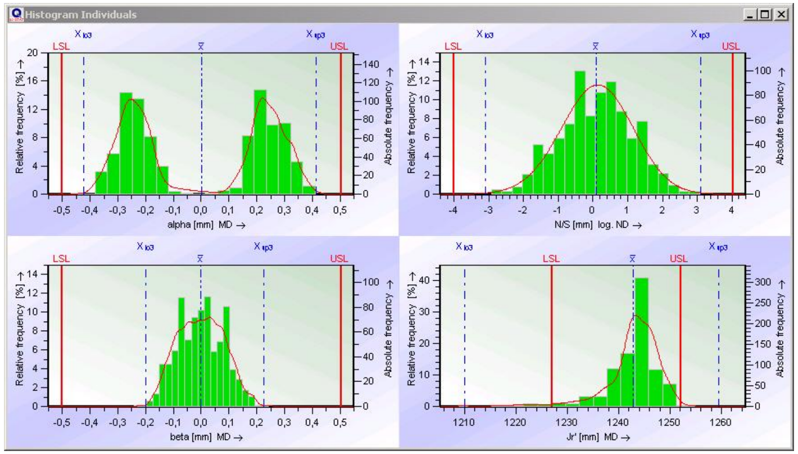
- Undulator applications need extreme homogeneities
- actual FEL-projects request material quantities on industrial scale
- Vacuumschmelze delivers:
  - Soft magnetic components
  - Precise permanent magnets
  - Assemblies

Permanent magnet structures for E-XFEL U40 and U68

- 70 undulators U40, 21 undulators U68, each 5m long in 10 substructures of 1 m length
- Total of more than 35000 permanent magnets and VACOFLUX® pole-pieces

<u>Homogeneity</u> of the permanent magnets:

- Variation of magnetic moment: <= +/- 1%
  for the whole order (more than 10 tons of PM-material)
- Angular deviation Alpha, Beta: <= +/- 0.5 °
- h/c-effect: <= +/- 2%



Material properties for cryogenic applications

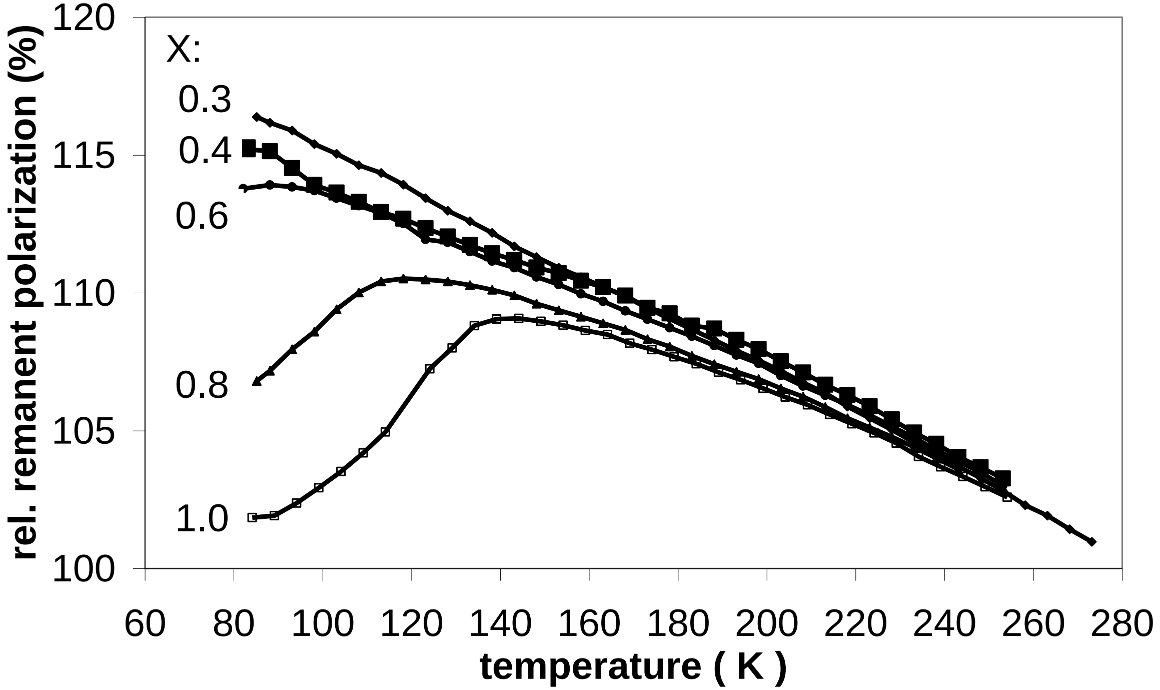
With decreasing application temperature:

- **Large increase of coercivity of REFeB-material → enhanced stability**
- **Remanence of REFeB-material increases → more flux for the application**

- **But: We need to overcome the spin-flip-transition of NdFeB at 140 K**

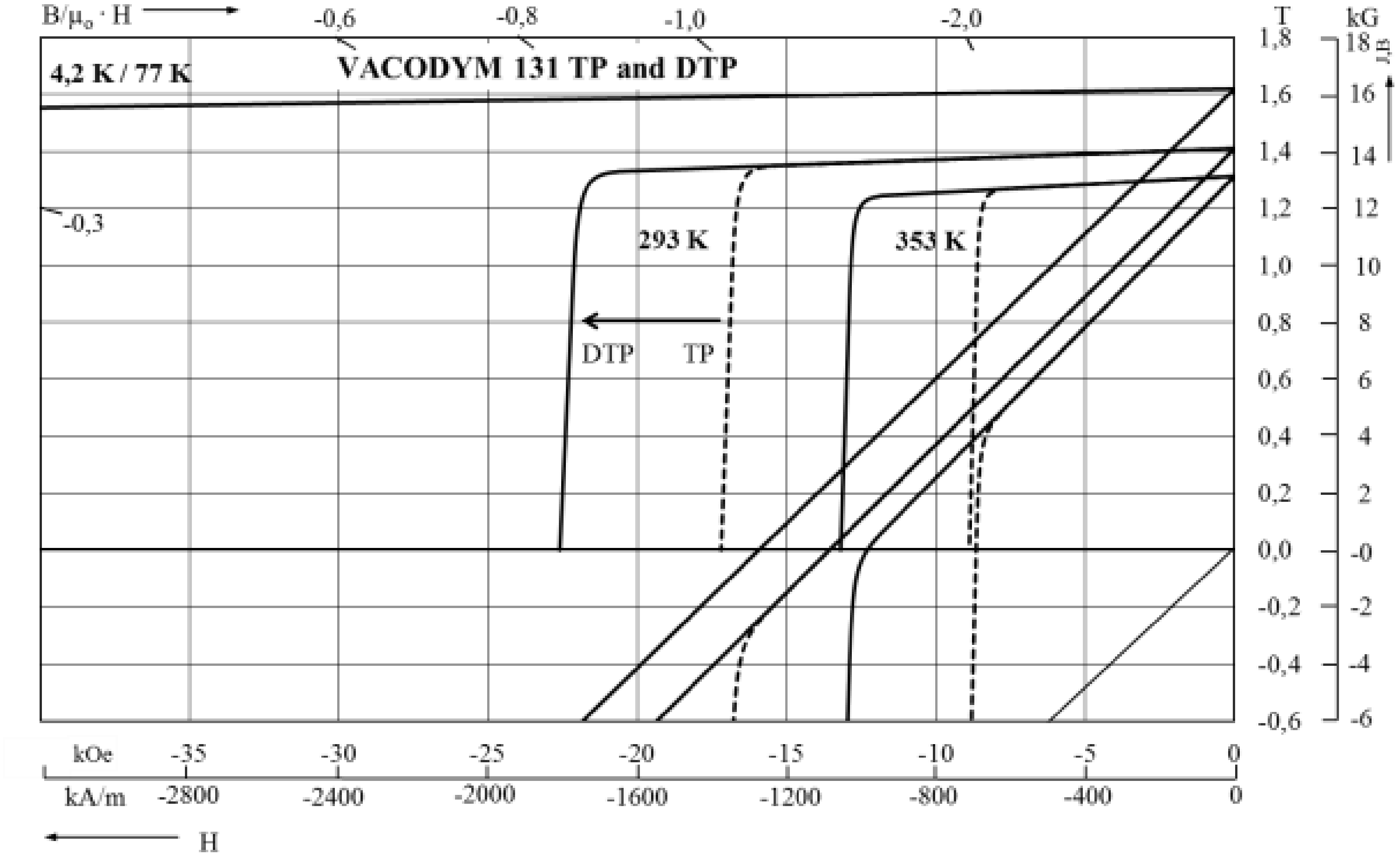
→Solution: use PrFeB-material !

Permanent Magnets for Undulators at Cryogenic temperatures



Open circuit remanent polarization of $(Nd_xPr_{1-x})_2Fe_{14}B$ relative to the remanent polarization at 283 K, as a function of temperature, measured parallel to the alignment direction on samples of $B/\mu_0H = -1.78(+/-0.04)$ for various x values. [2]

VACODYM® 131 for use at Cryogenic temperatures



Demagnetization curves of VACODYM® 131 TP and DTP at cryogenic temperatures, room temperature and elevated temperature

Improvements of actual NdFeB-based alloys

- Radiation damage of permanent magnets correlates to temperature stability over large ranges of potential radiation doses
- Stability at elevated temperatures depends on
  - Load line (depends on geometry and external fields)
  - Coercivity of the material
- Coercivity is increased by heavy rare-earth (HRE-) content

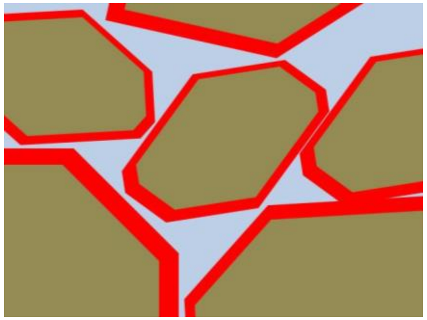
Possible solutions:

→ Place the HRE at the location, where it works most effectively

→ Use of more effective HRE-elements

Optimised coercivity by Dy-diffusion-process

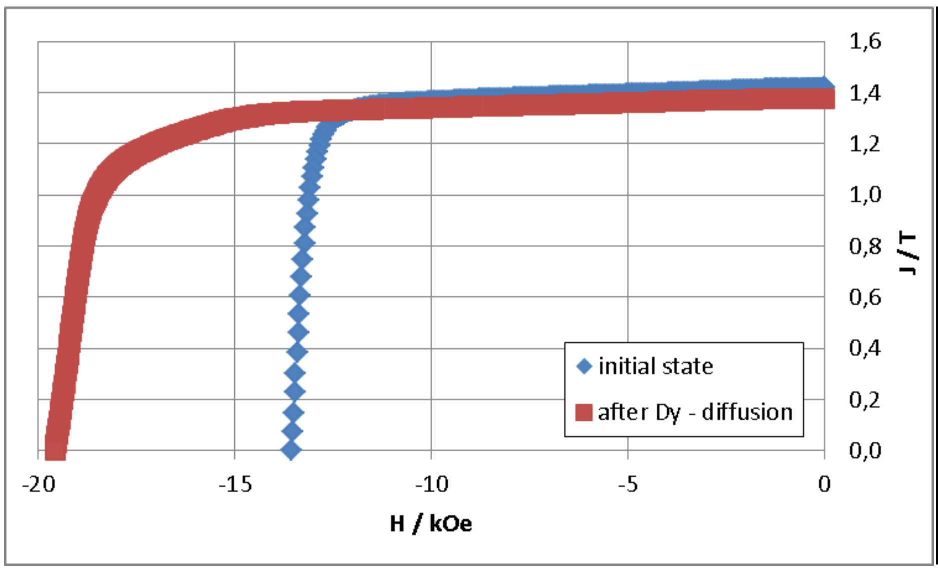
- Additions of Dy to pure NdFeB are used to increase coercivity
- They slightly reduce remanence
- The use of Dy is optimised by placing it to the grain boundaries in a diffusion process instead of additions to the base alloy

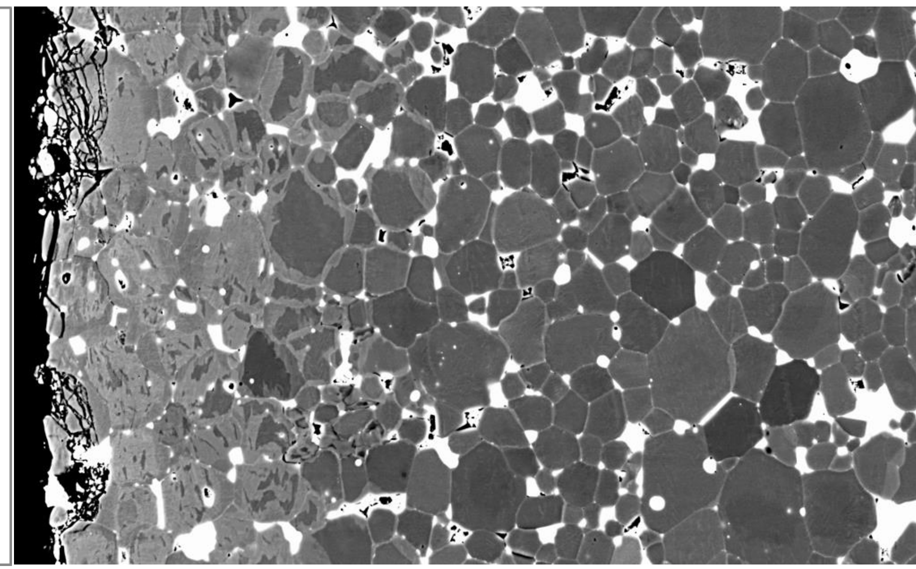


- For a given coercivity and remanence the amount of Dy needed is minimised
- The effectiveness is restricted to limited dimensions (thickness of the magnet)

Optimised coercivity by Dy-diffusion-process

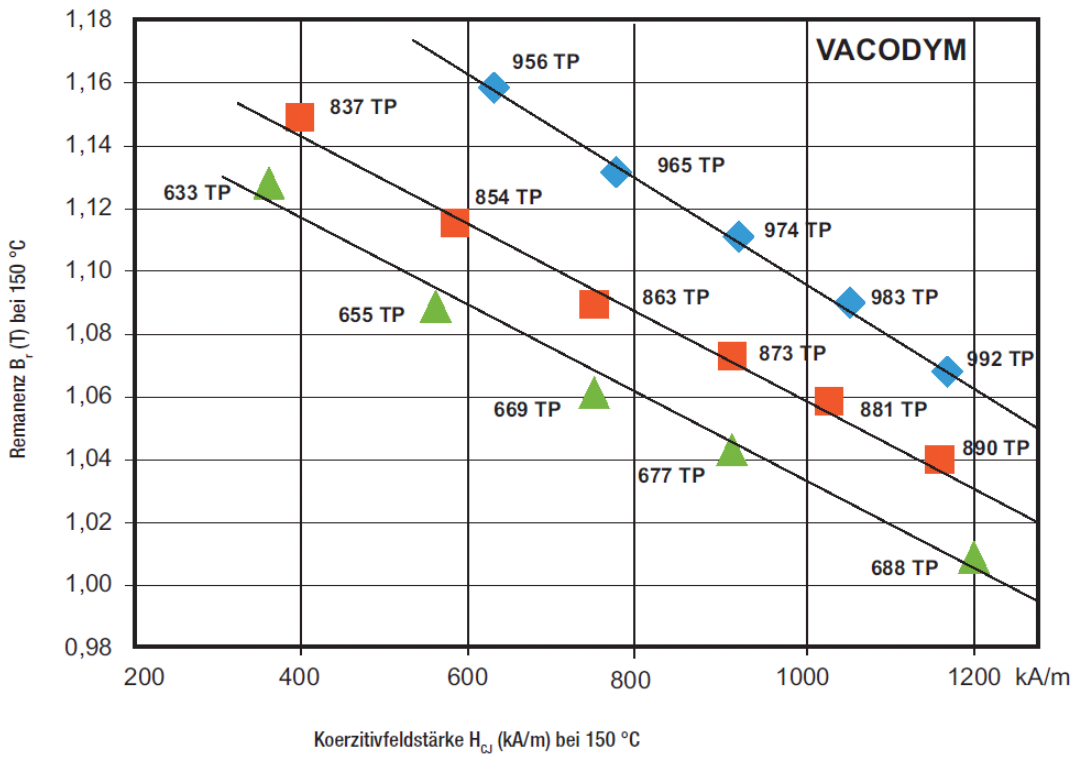
- Δ HcJ as high as by diffusion treatment after sputter coating
- Micrograph depicts Dy rich grains near surface which are responsible for the loss of B_r



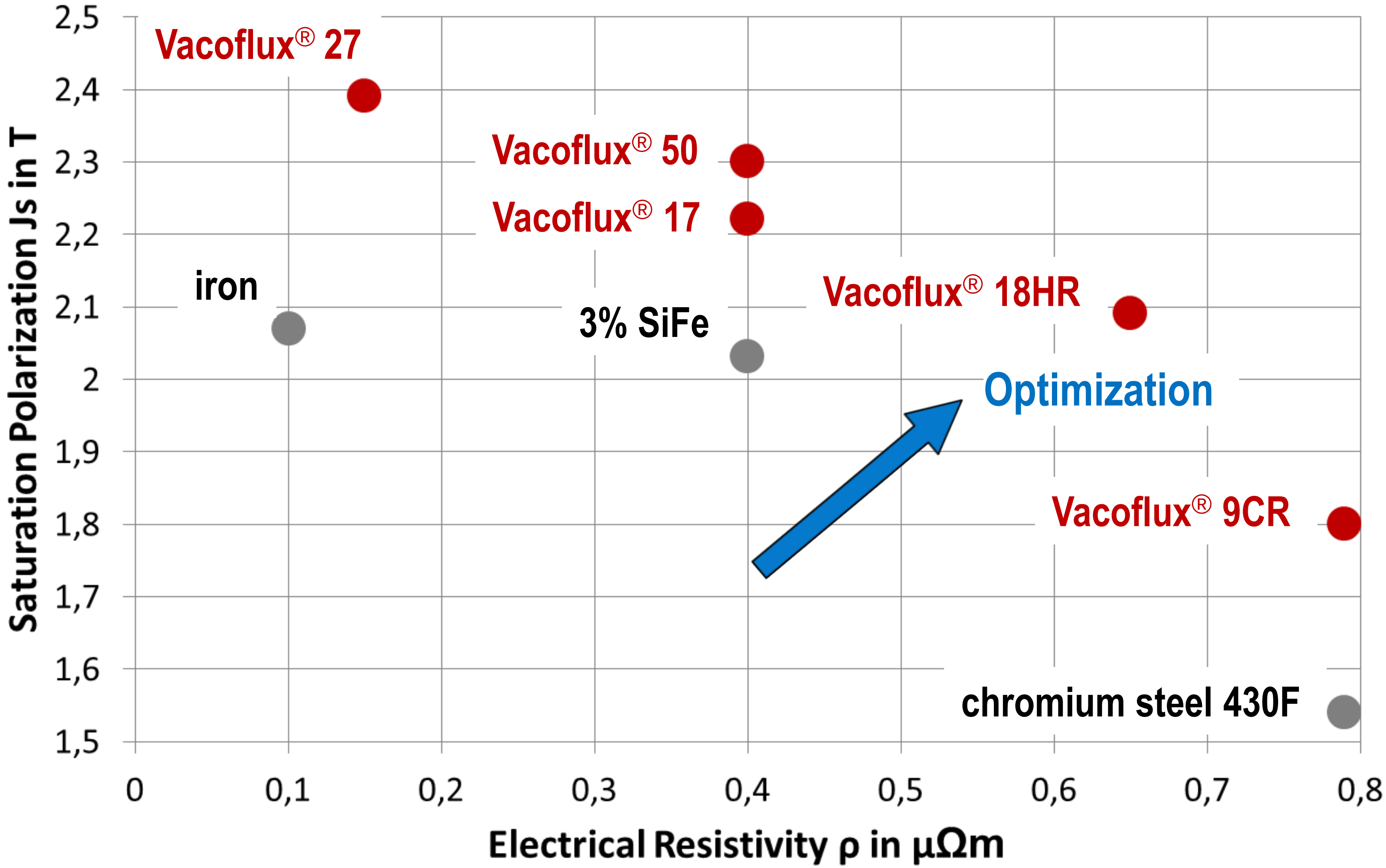


VACODYM® 9xx-series

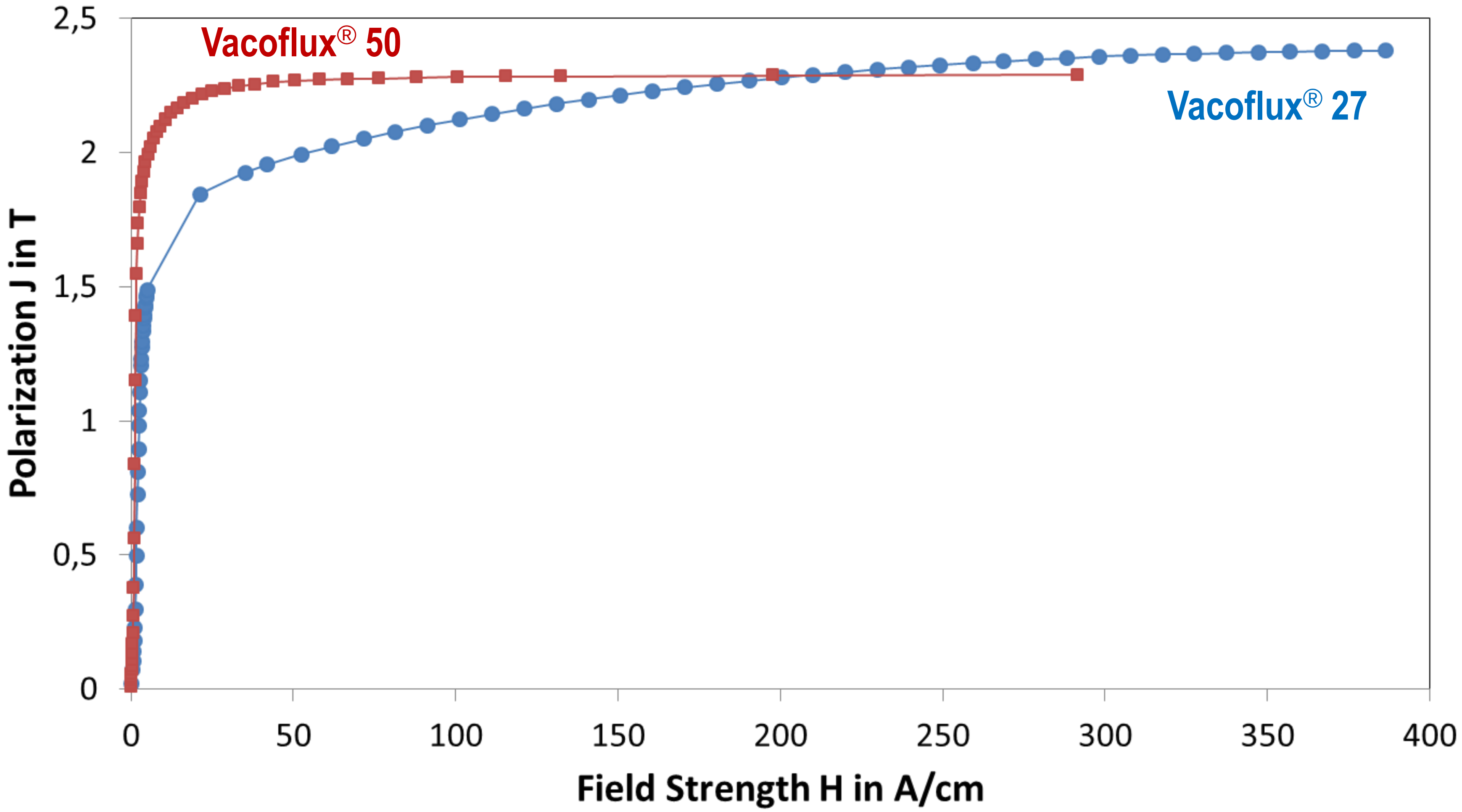
- use Tb instead of Dy as HRE-element (in the base alloy)
- optional: additional enhancements by grain boundary diffusion at the surfaces



Soft magnetic materials: saturation vs. resistivity

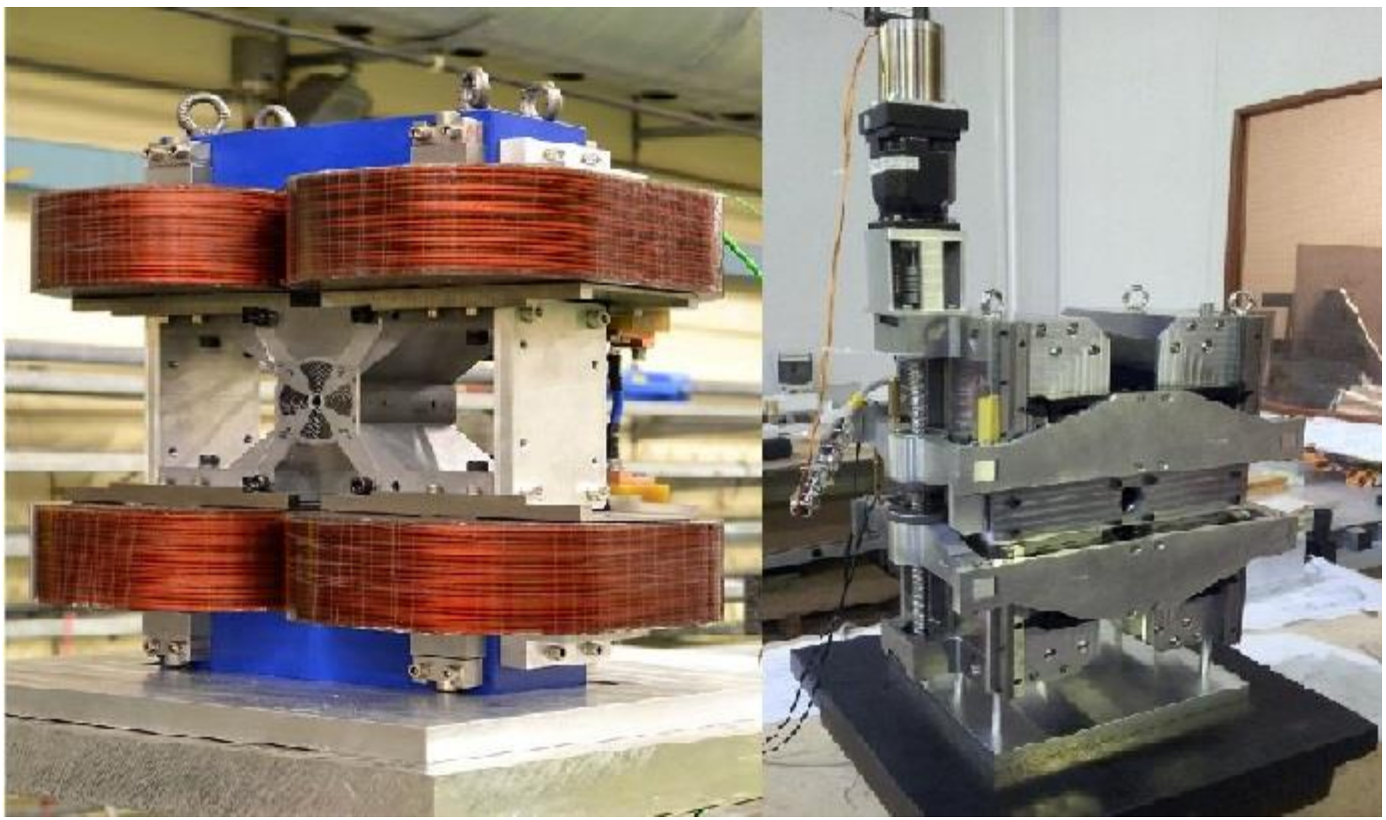


Comparison of Static Initial Magnetization Curves VACOFLUX®50 vs. VACOFLUX®27



Outlook

- Vacuumschmelze material is already implemented in various designs
- We are looking forward to your discussions on further optimisation



Thanks for your attention!