Reduction of heavy rare earths in Nd-Fe-B-based magnets by diffusion source and application area optimization

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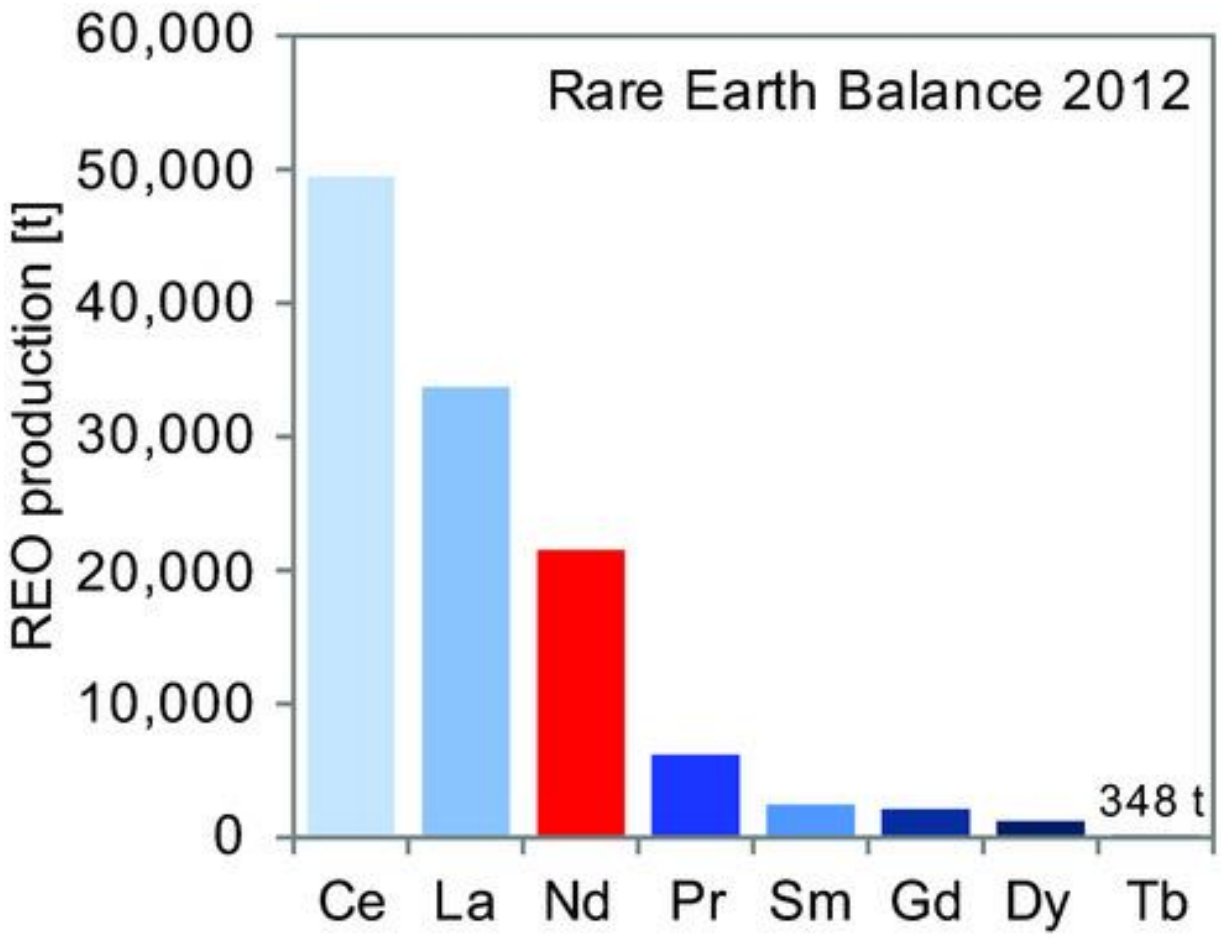
What is the best GBDP HRE source?



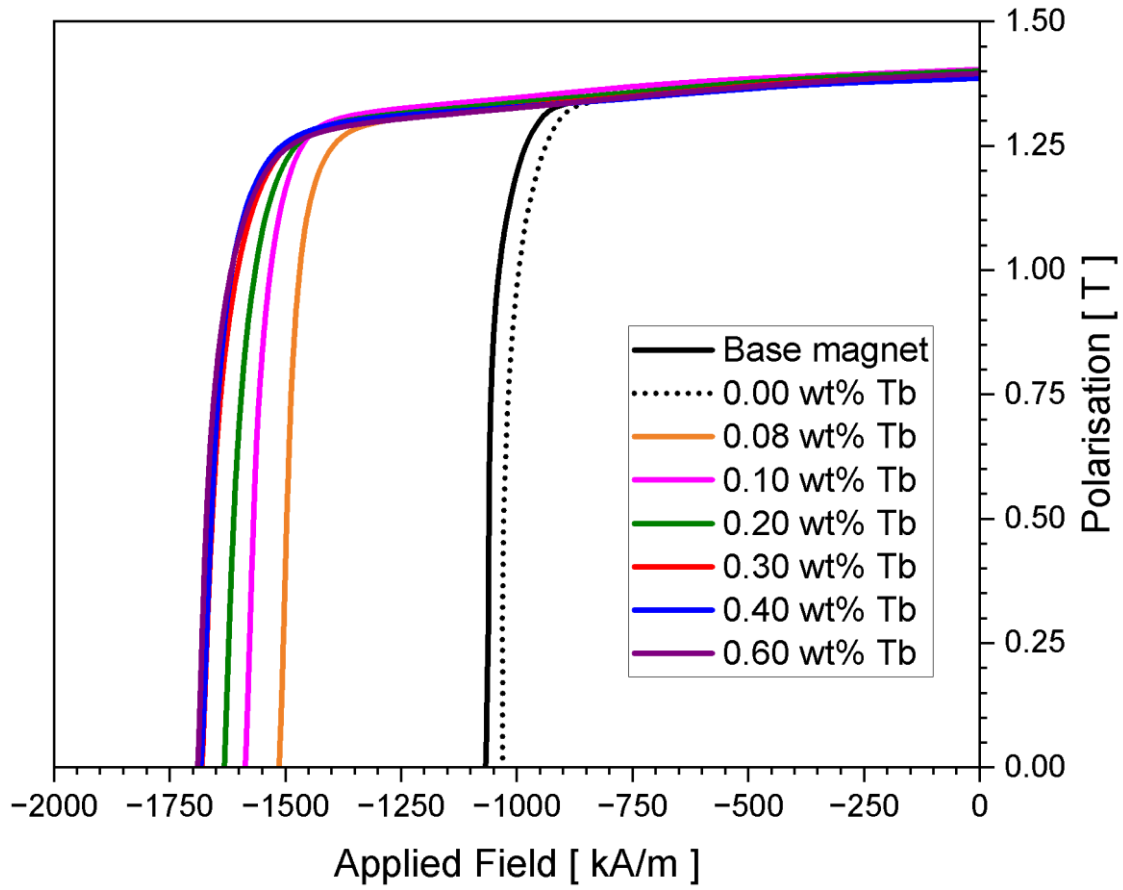
- Rare earth balance: 1 kg of Nd oxide produces 0.02 kg of Tb oxide
- **The highest ΔH_c per HRE** amount in the GBDP alloy: complex low-melting alloys **$Tb_{10}Pr_{60}(CuAlGa)_{30}$**

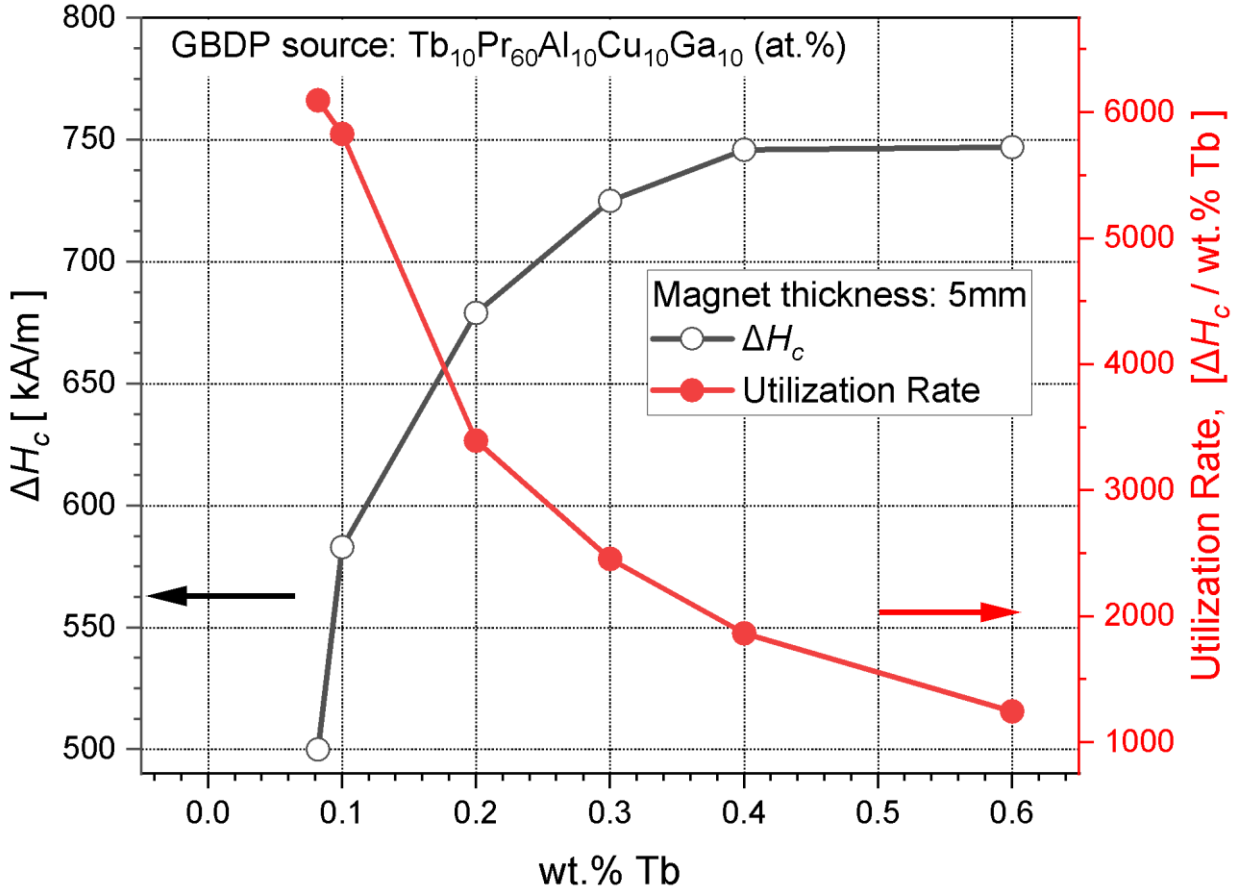
Experimental:

- Produced by melt spinning, applied on commercial N50 grade sintered magnets followed by a two-step heat treatment

Gauß, R., Homm, G. and Gutfleisch, O. (2017),. J. Ind. Ecol. 21: 1291-1300.

Grain boundary diffusion process optimization

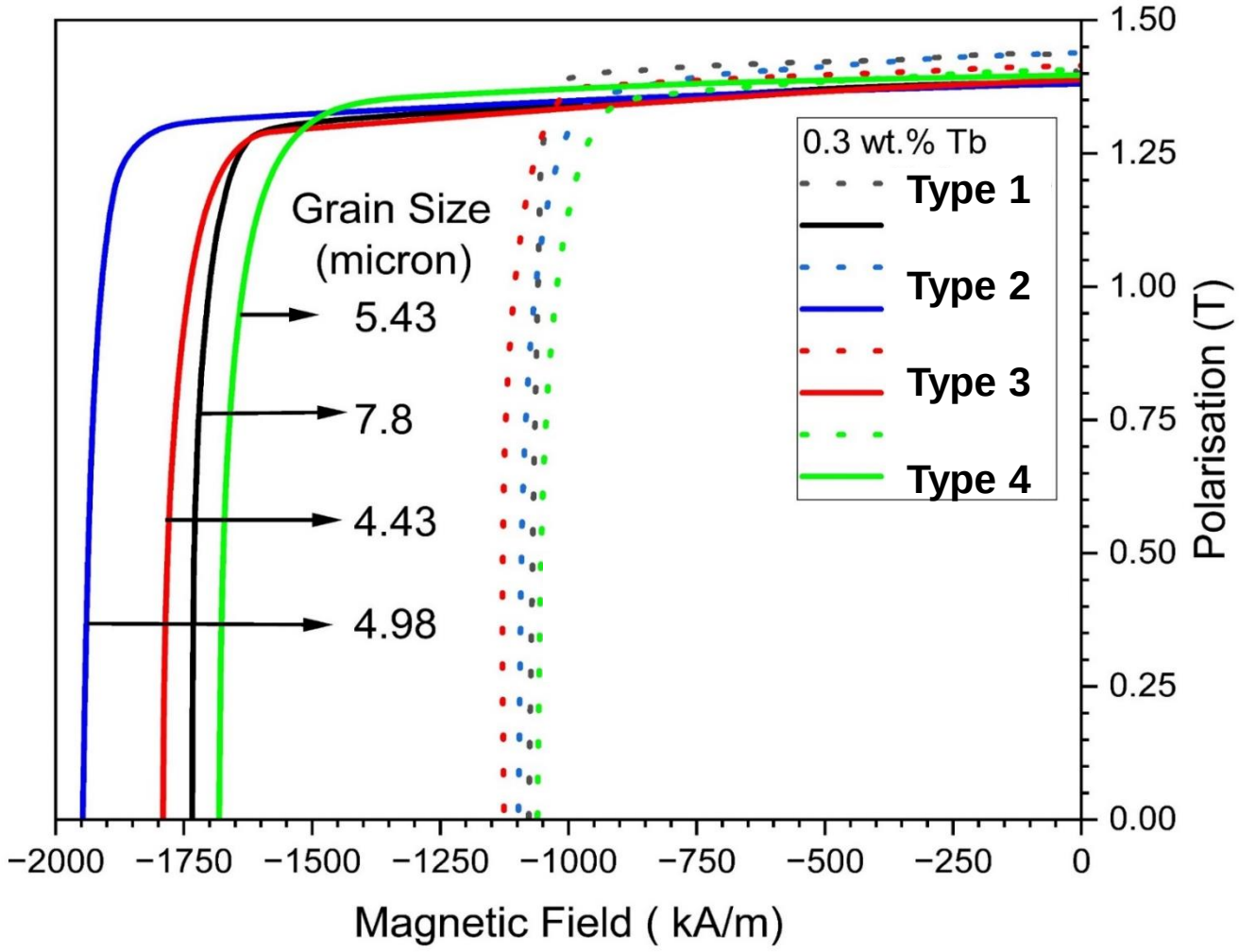


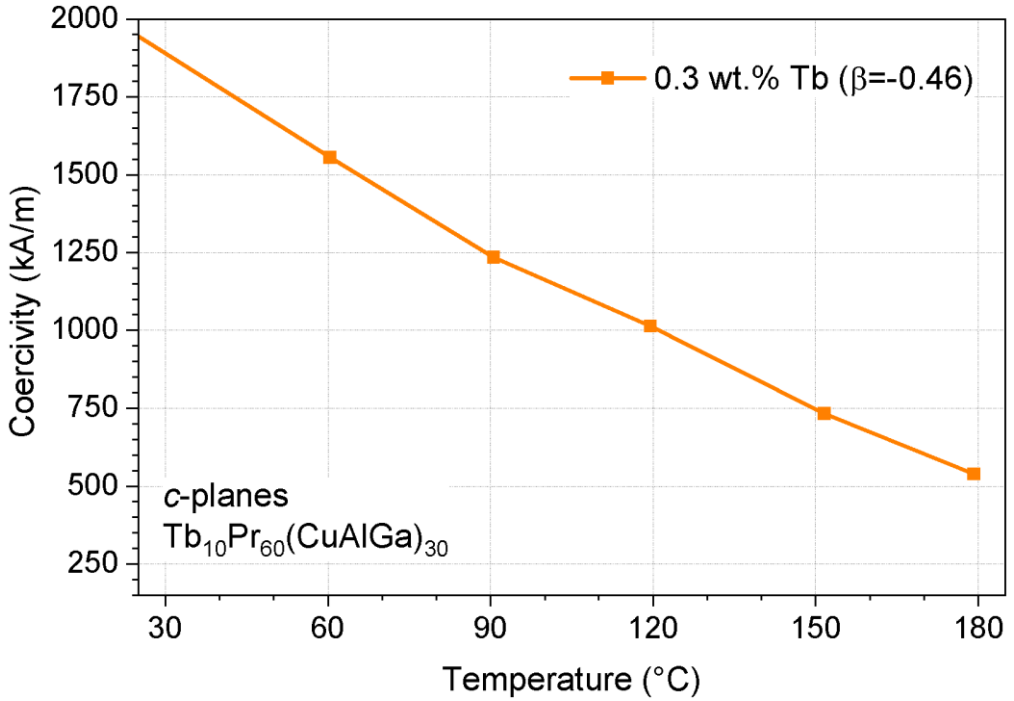


Coercivity enhancement saturates and HRE utilization decreases for high Tb amounts

*Commercial grade VD722HR NdFeB-based sintered magnets from Vacuumschmelze GmbH

The influence of the initial magnet (N50 grade)

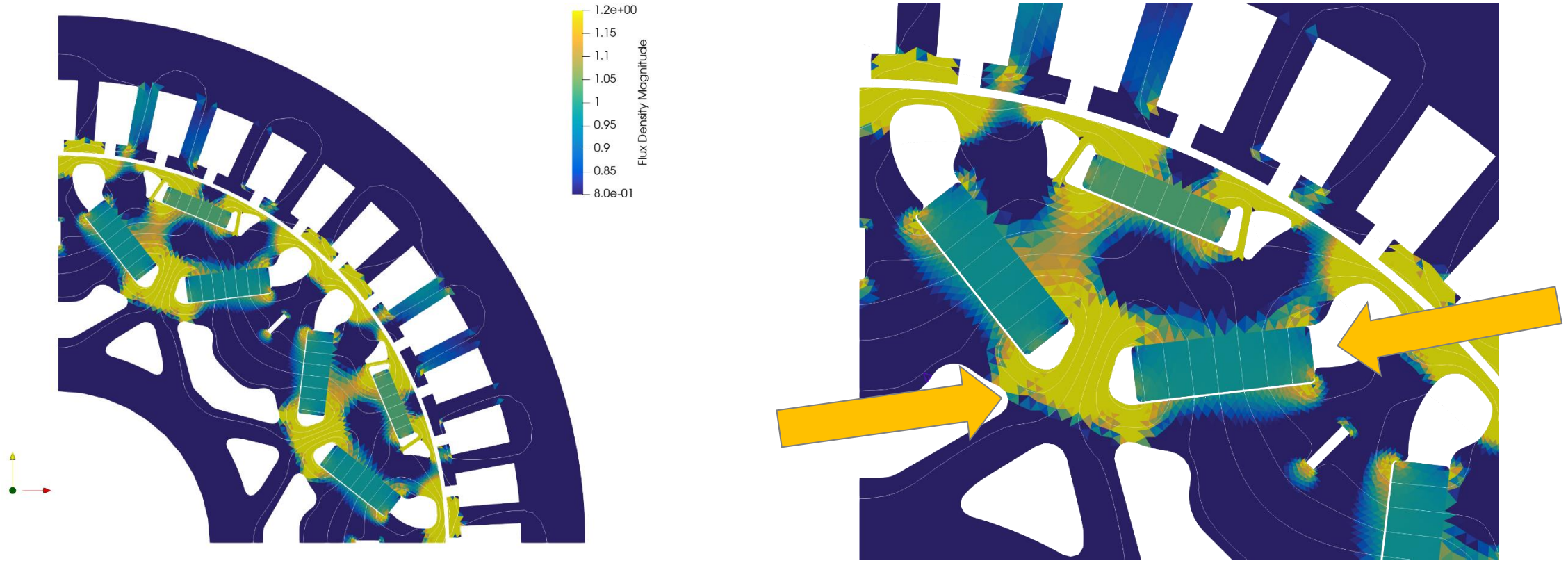




J_r =1.4 T, H_c=1990 kA/m (2.5 T)

H_c= 747 kA/m (0.94) @ 150 °C

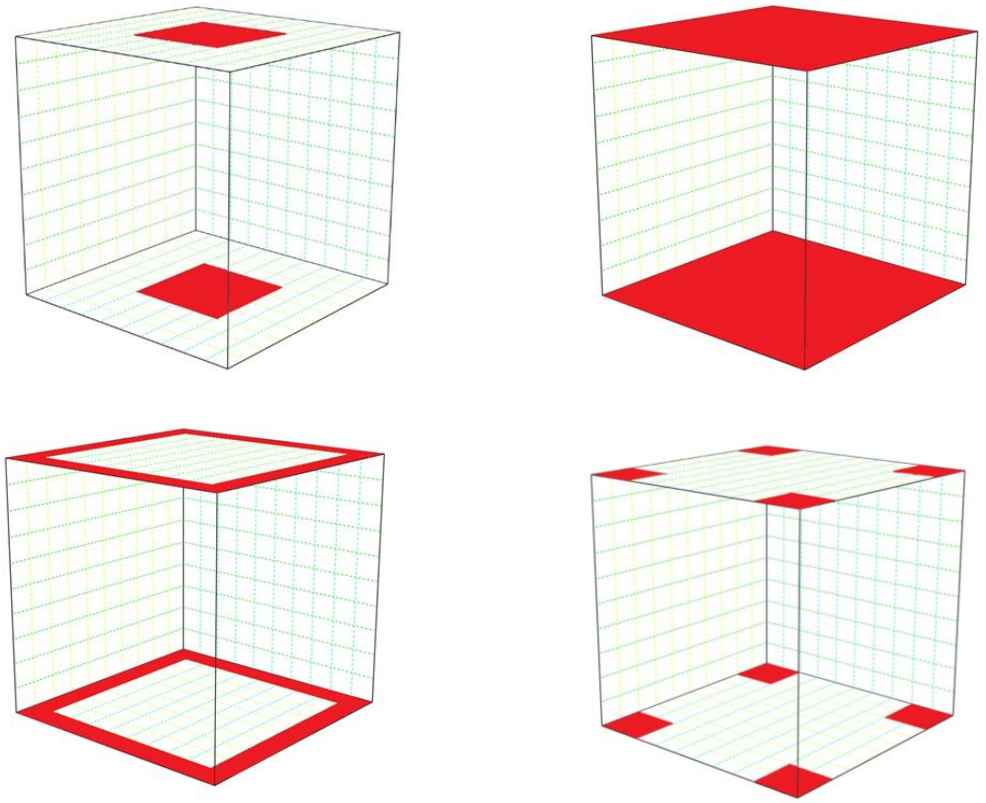
Strategic local magnetic hardening

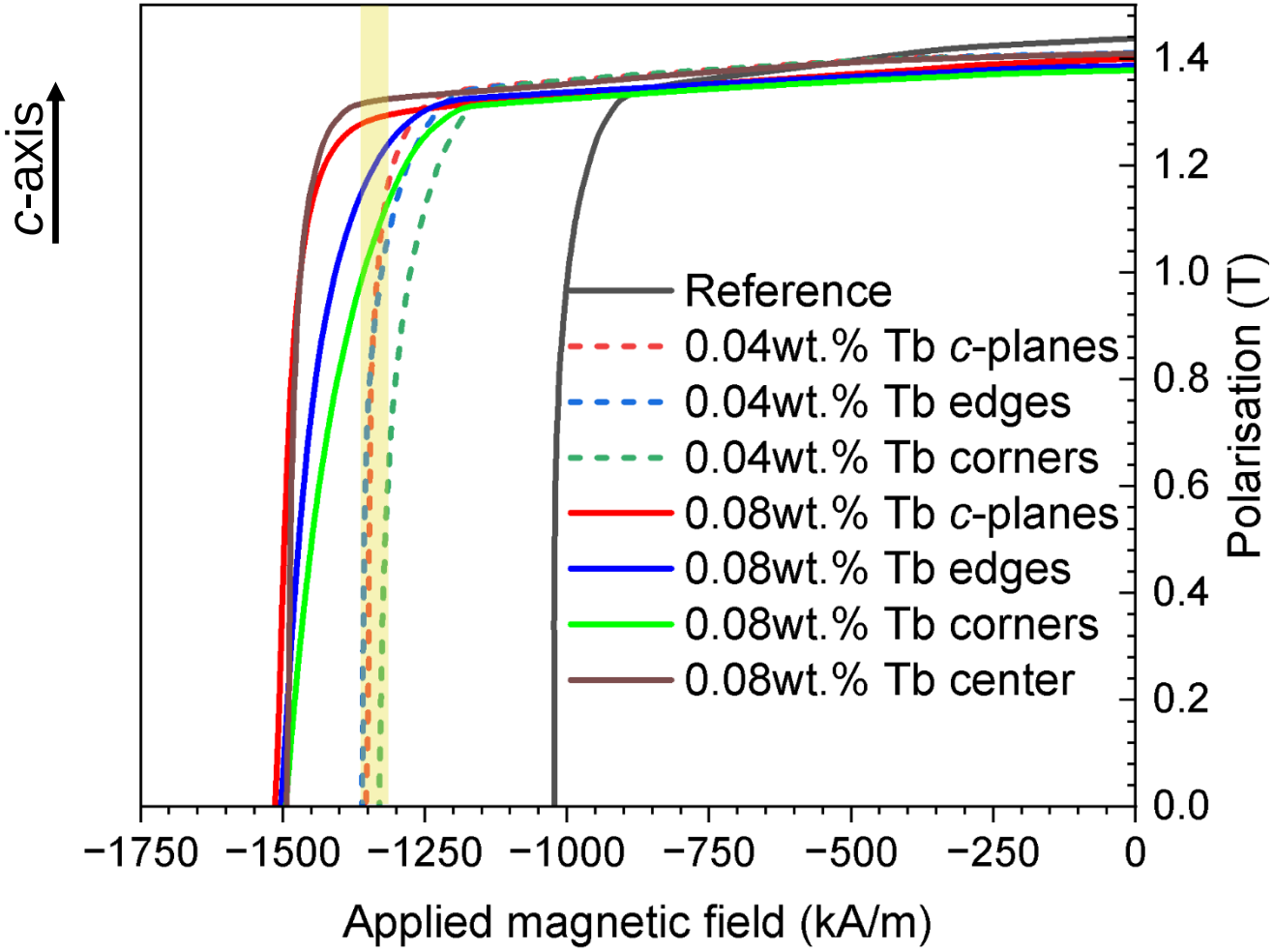


2D FE-Simulated flux density distribution for a permanent magnet traction motor from electric vehicles

The highest demagnetization at corners/edges. **Local magnetic hardening via selected area GBDP**?

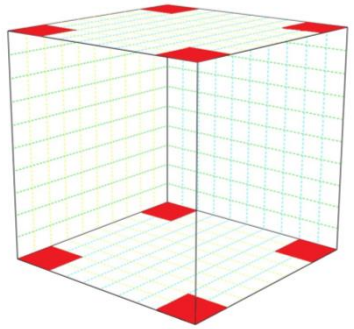
Strategic local magnetic hardening



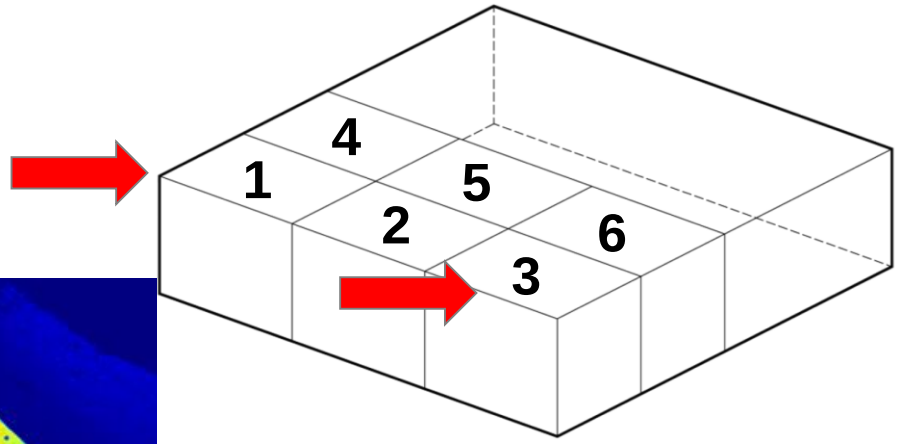


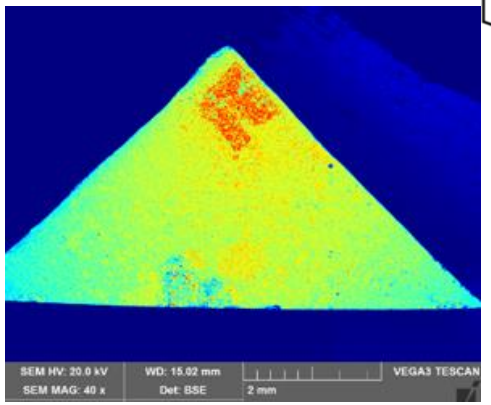
“3D GBD”, “Gen 3”..

Local magnetic hardening – how to characterize?



3D view

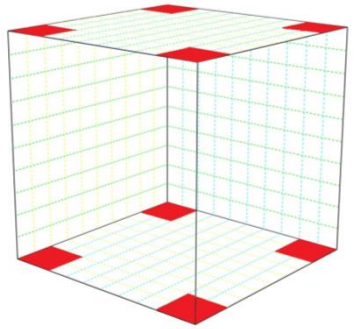




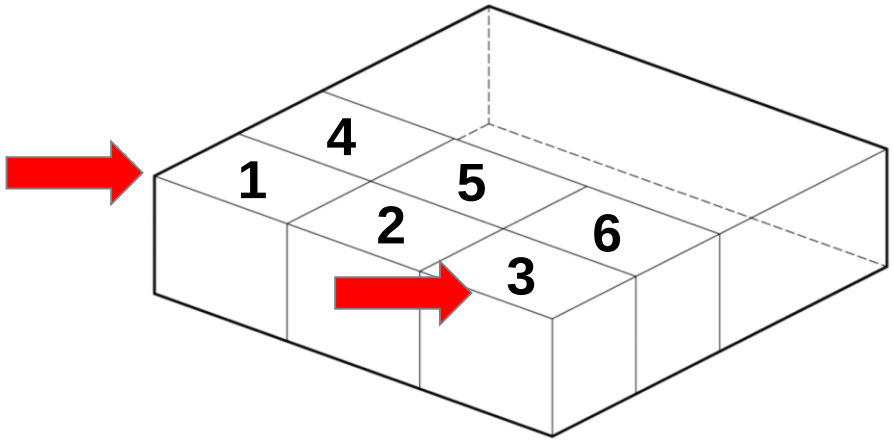
Position	H_c (kA/m)	ΔH_c (kA/m)
1	1598	587
2	1521	510
3	1592	581
4	1503	492
5	1441	430
6	1486	475
Initial	1011	

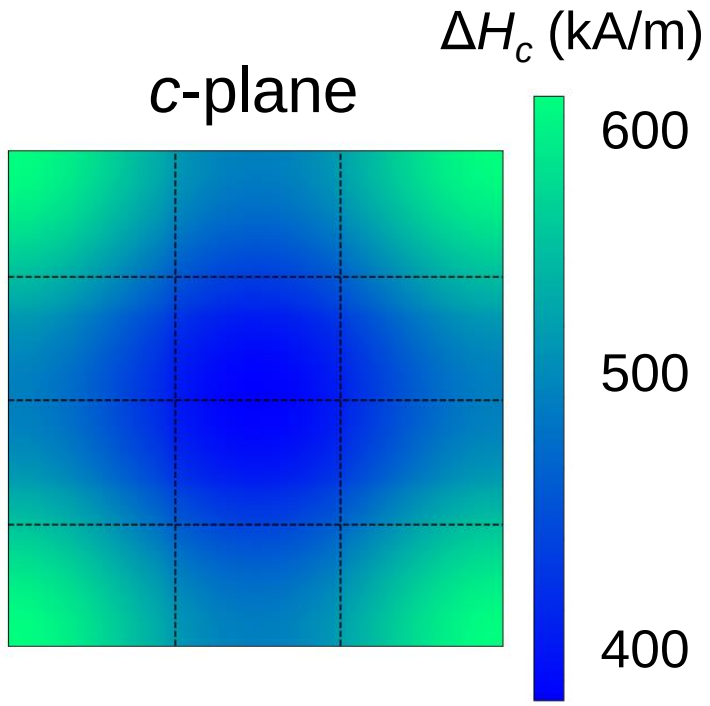
Local coercivity mapping by measuring *M(H)* each for each individual segment

Local coercivity mapping



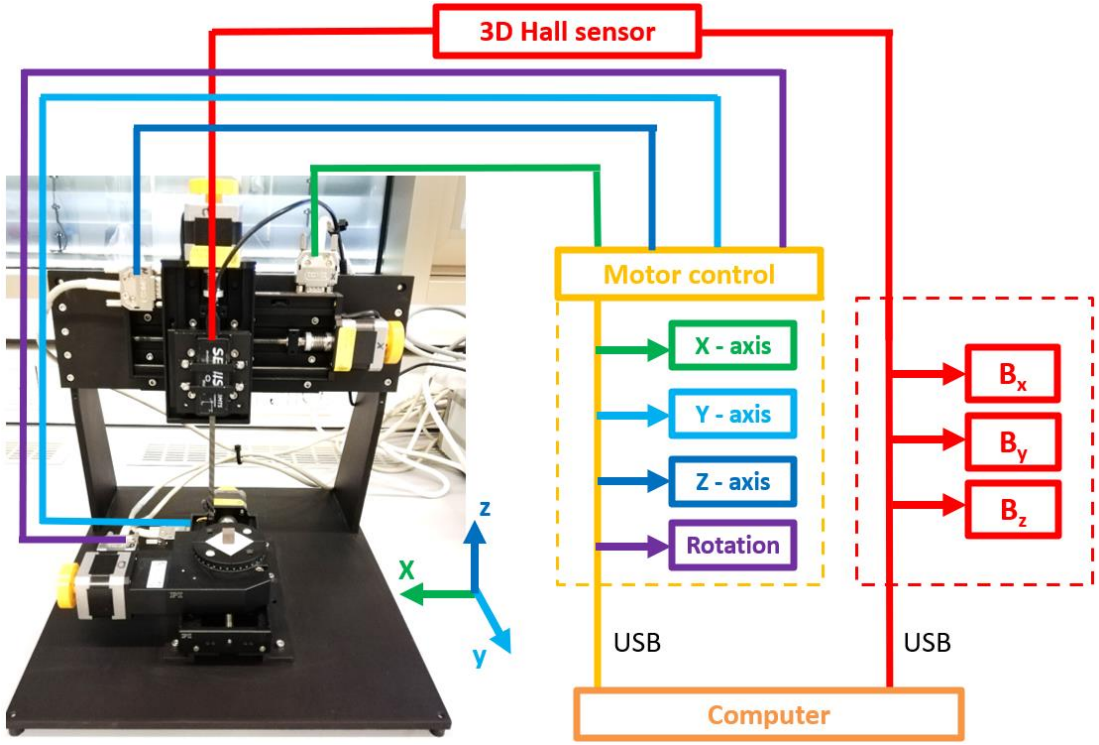
3D view

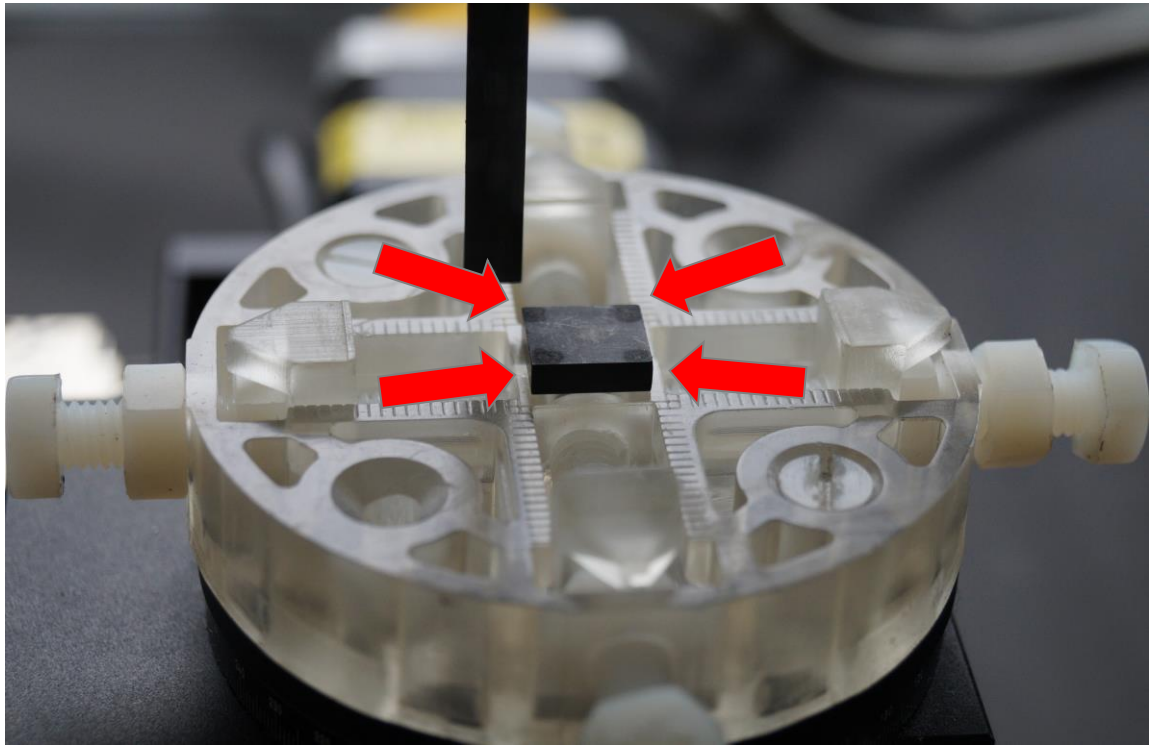




Local coercivity mapping by measuring *M(H)* each for each individual segment

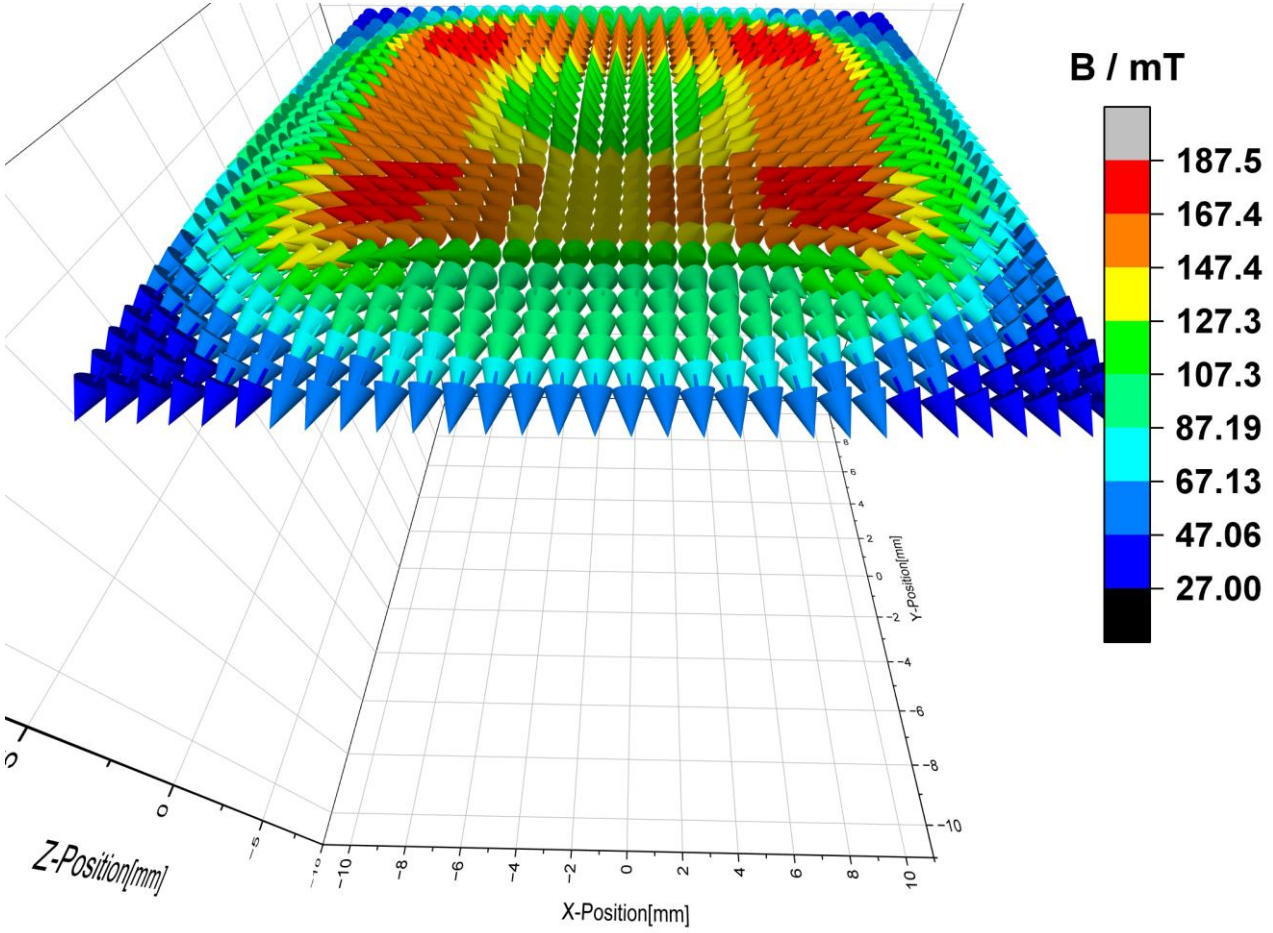
Strayfield mapping using a 3D hall scanner

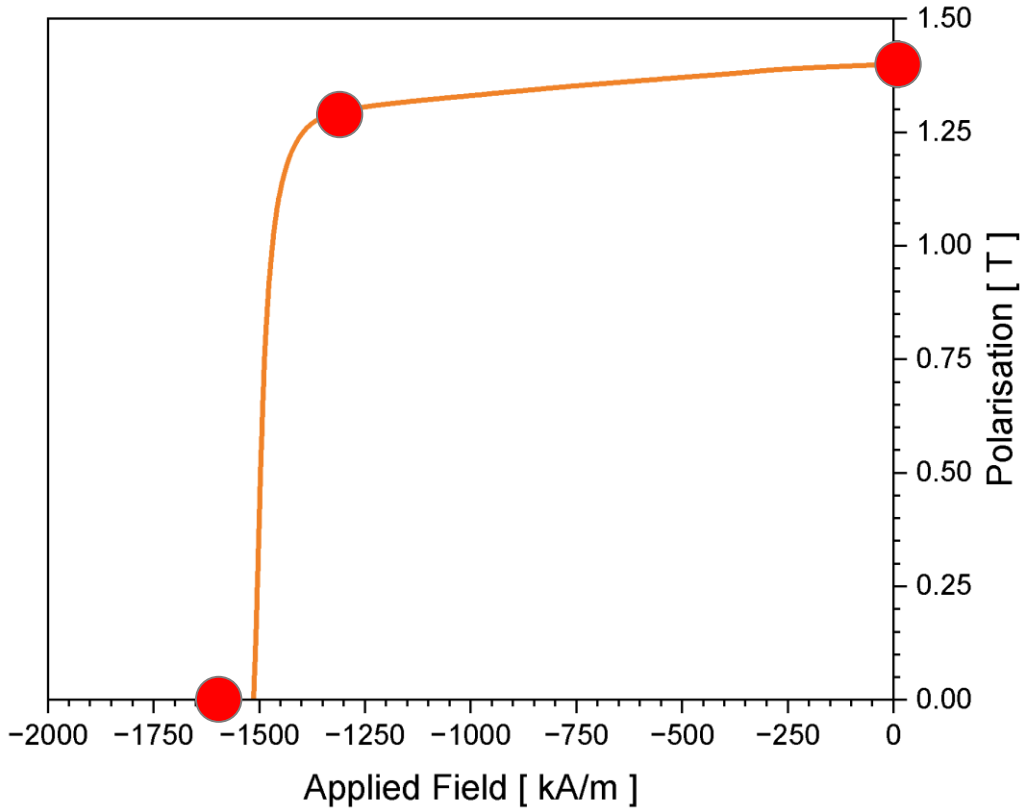




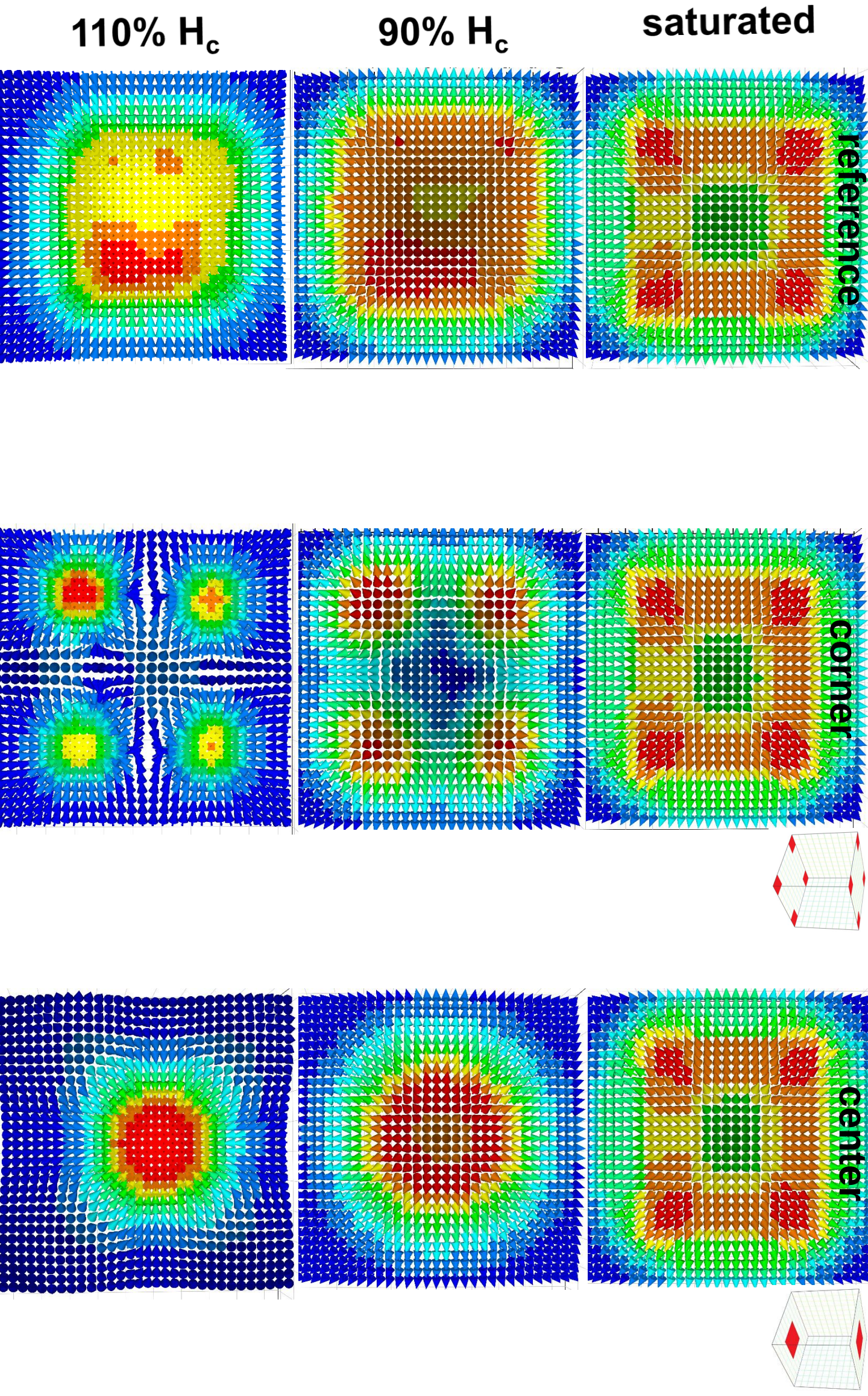
Local mapping of B_x, B_y, B_z above magnet surface across the hysteresis loop

Strayfield mapping using a 3D hall scanner

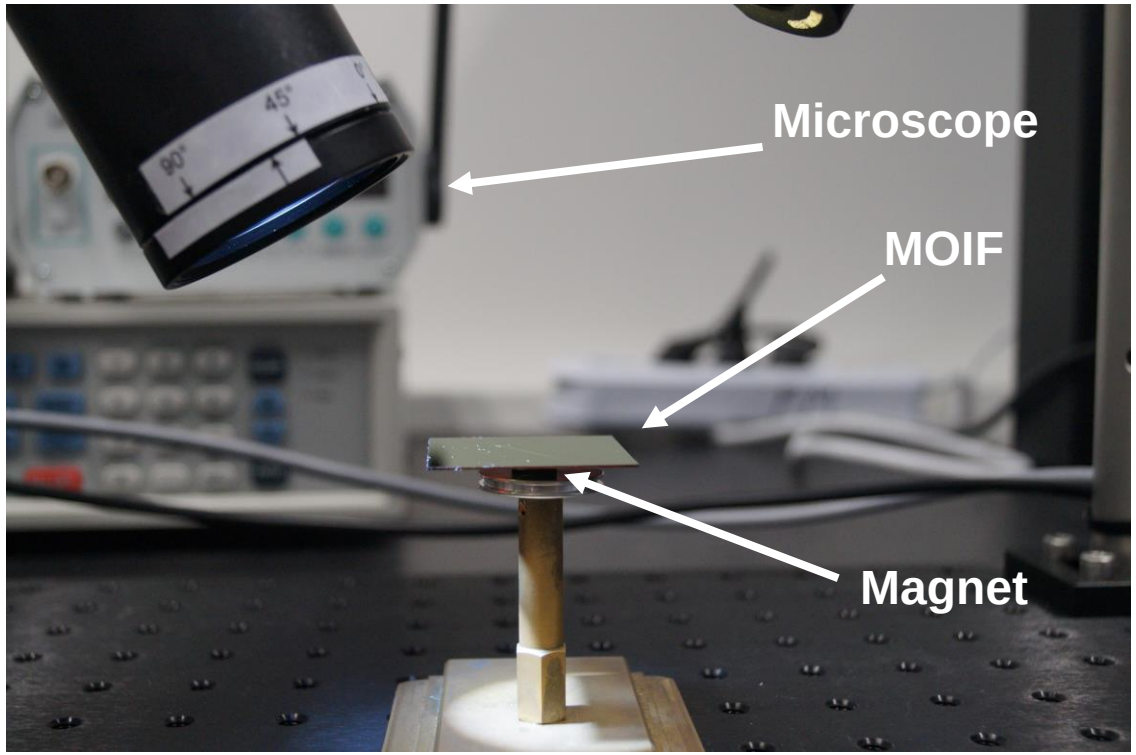


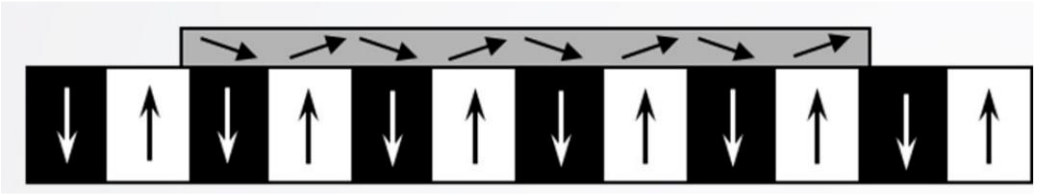


Local mapping of B_z above magnet surface across the hysteresis loop


110% H_c
90% H_c
saturated
reference
corner
center

MOIF - Magneto-Optical Indicator Films

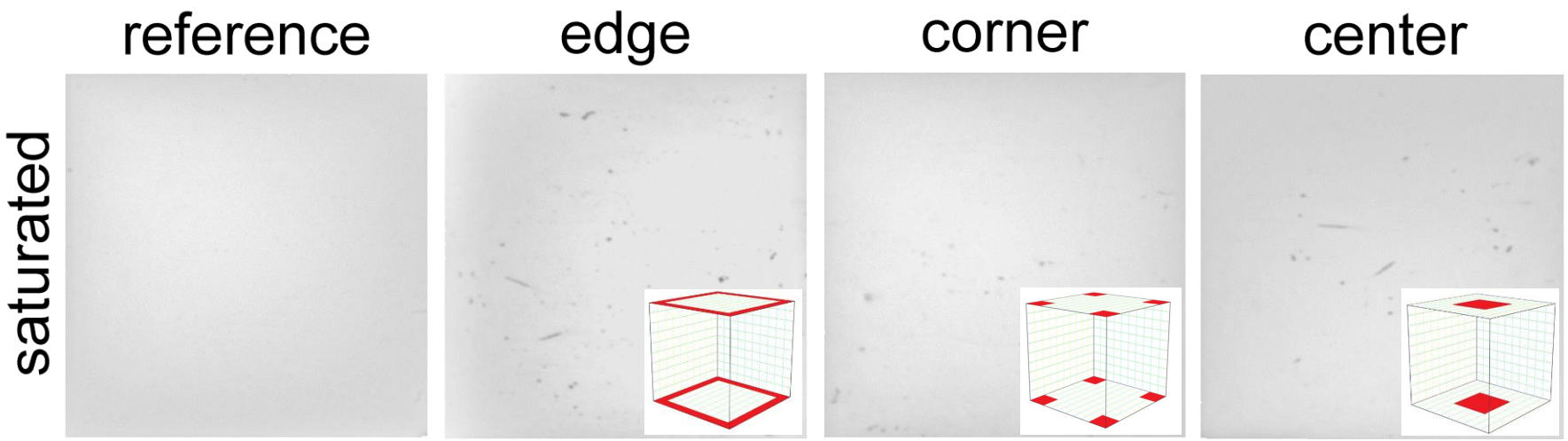


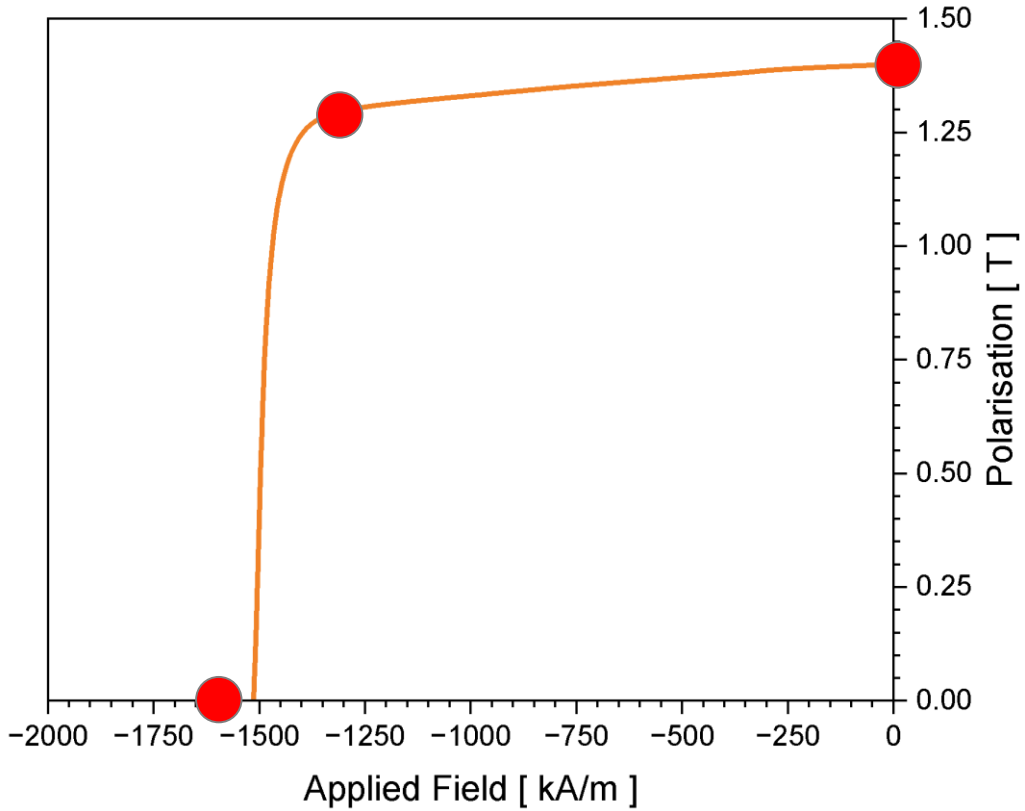


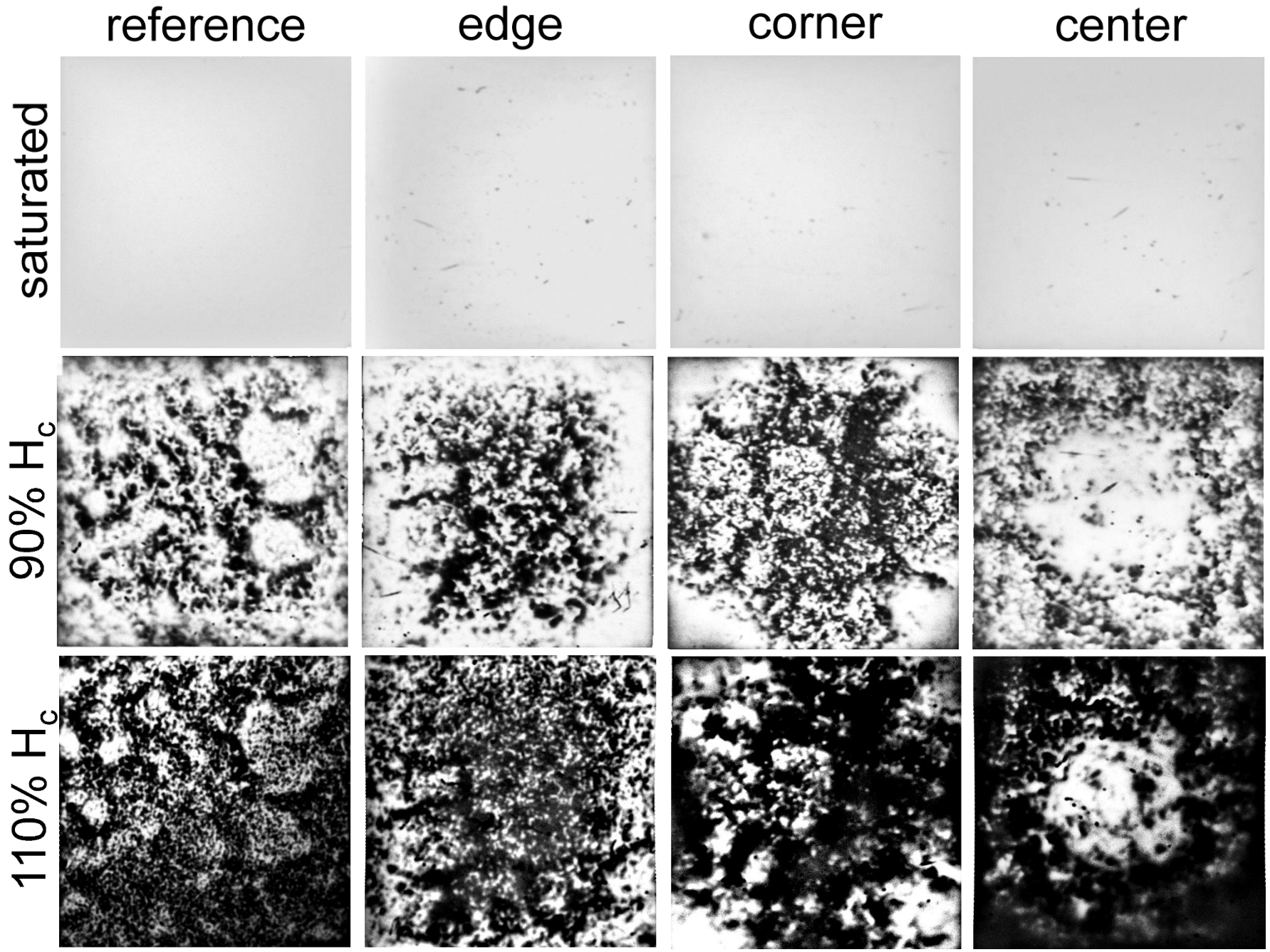
Rotation of magnetization in MOIF under the effect of the sample's stray field

Magneto-optical contrast arises due to the Faraday effect

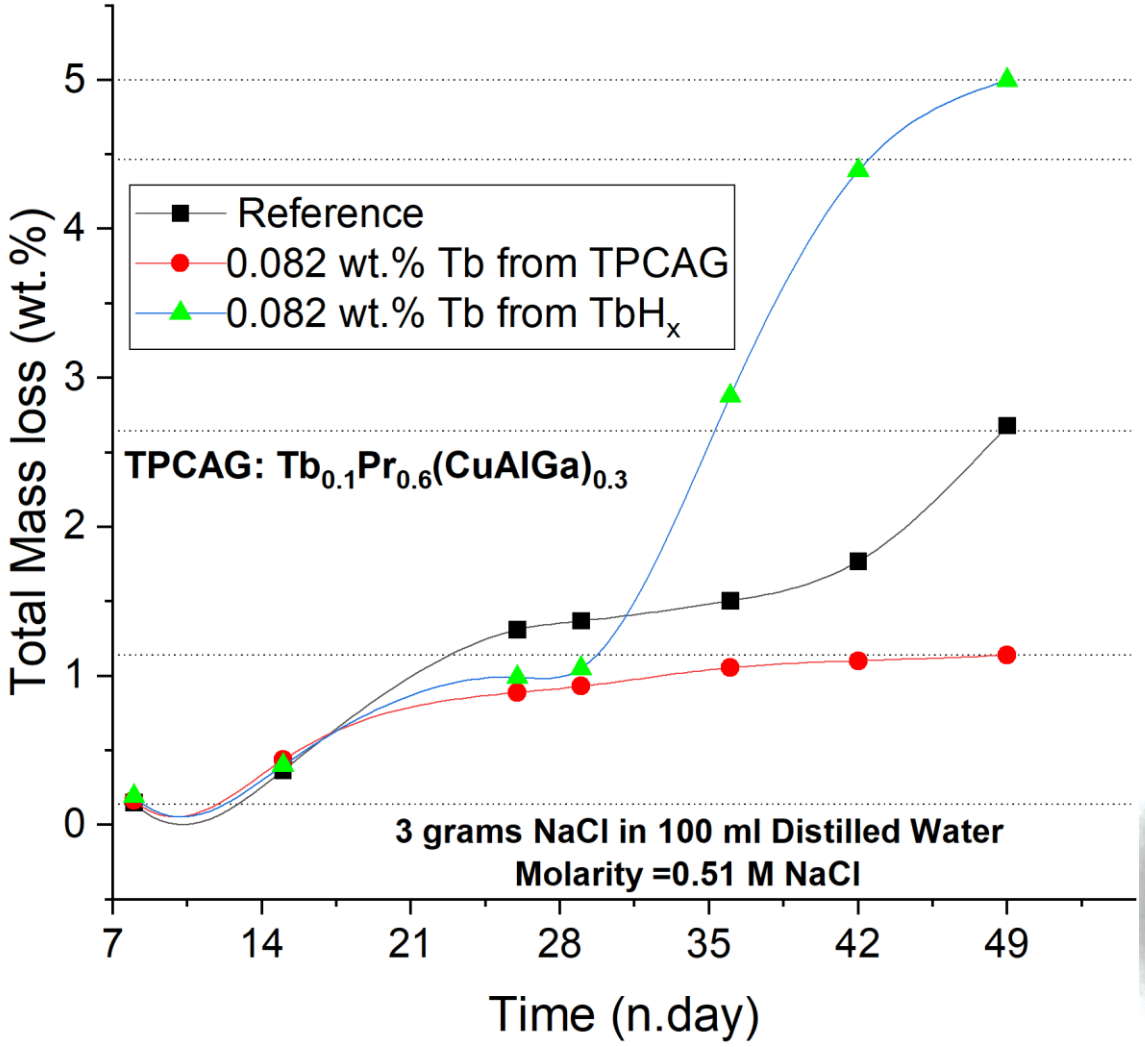
MOIFs as a tool for direct studies of the spatial distribution of magnetic fields and demagnetization processes in permanent magnets. High spatial resolution, large image range.


reference
edge
corner
center
saturated


1.50
1.25
1.00
0.75
0.50
0.25
0.00
Polarisation [T]
−2000
−1750
−1500
−1250
−1000
−750
−500
−250
0
Applied Field [kA/m]


reference
edge
corner
center
saturated
90% H_c
110% H_c

Corrosion: Tb-Pr-Al-Cu-Ga vs TbH_x



- Improved corrosion resistance for the $Tb_{10}Pr_{60}(AlCuGa)_{30}$ GBDP compared to reference magnet and TbH_x GBDP
- Confirmed also after 1 year air exposure

$Tb_{10}Pr_{60}(AlCuGa)_{30}$

After 1 year

TbH_x

Summary

- Low melting Tb-Pr-Al-Cu-Ga alloys are promising for GBDP
- HRE utilization drops significantly with increased GBDP amount
- **0.3 wt.% Tb:** J_r =1.4 T, H_c=1990 kA/m (2.5 T) & H_c= 747 kA/m (0.94 T) @ 150 °C
- Efficient Tb utilization via selected area GBDP
- Simple characterization using MOIF and 3D Hall scanner demonstrated
- Improved **corrosion resistance** compared to TbH_x and base magnet