Microstructural TEM Investigation of Nb_3Sn Superconductors for FCC

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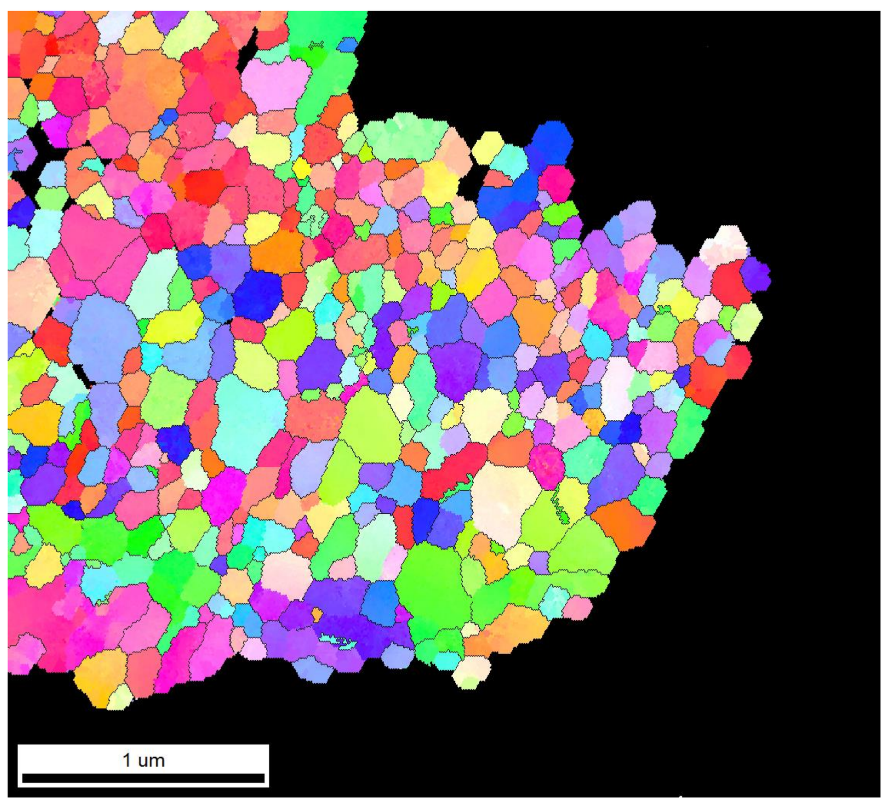
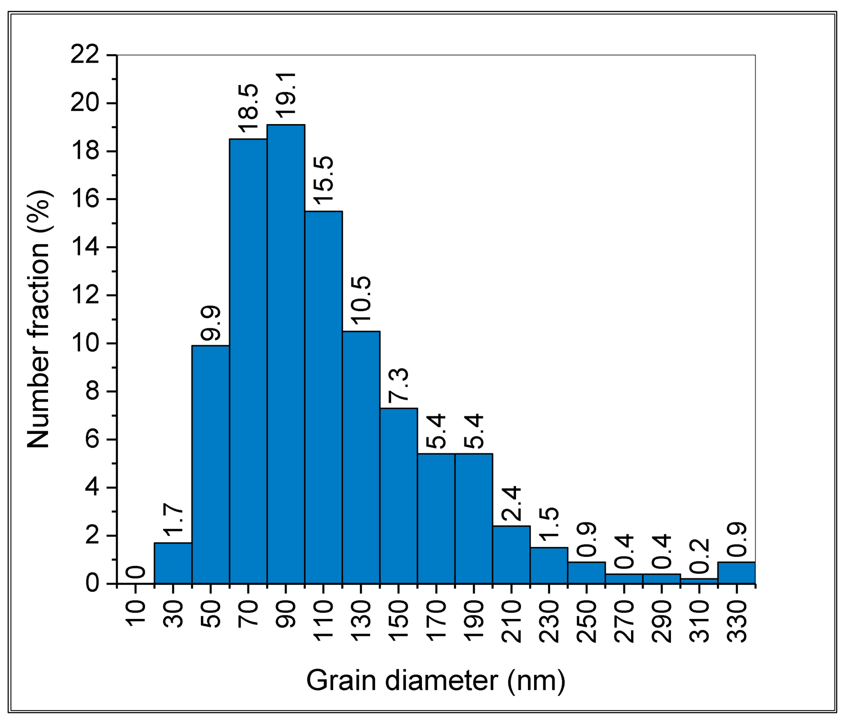
Introduction

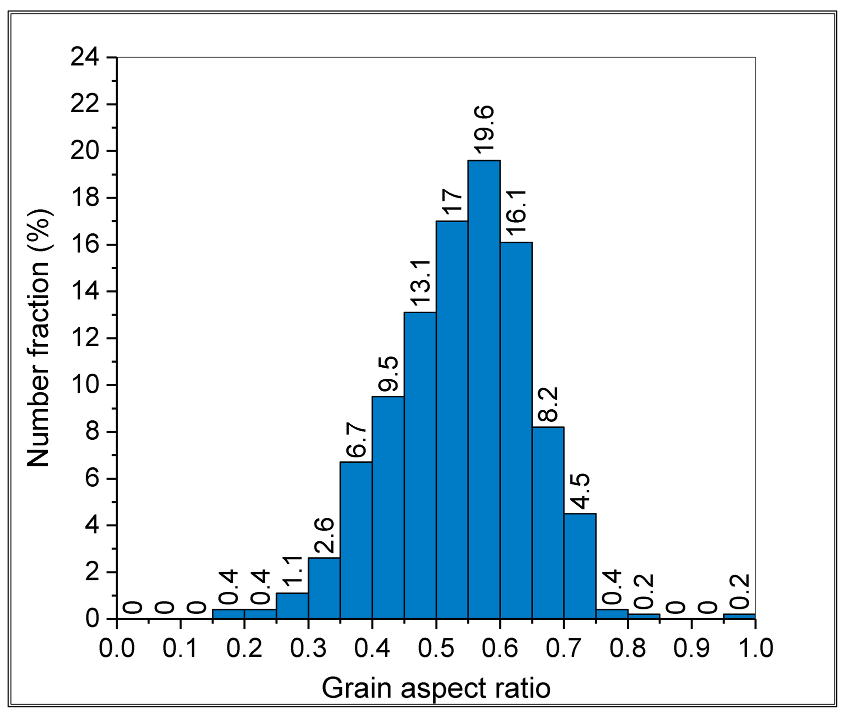
For the design of Future Circular Collider (FCC) superconducting magnets an increase of the high field critical current density in commercial Nb_3Sn wires by about 50 % is required. One possibility of reaching this target is by producing defects in the crystal structure which serve as additional flux pinning centres, as already demonstrated by means of fast neutron irradiation. Another option is grain size refinement by introduction of defects that inhibit grain growth in order to achieve a higher grain boundary density which also increases the pinning force.
In this study, the underlying mechanisms are investigated through combined microstructural and magnetic analysis in order to establish a correlation between microstructure and superconducting performance. This understanding is required for manufacturing such high-performance superconductors in an industrial process.

Transmission Kikuchi diffraction

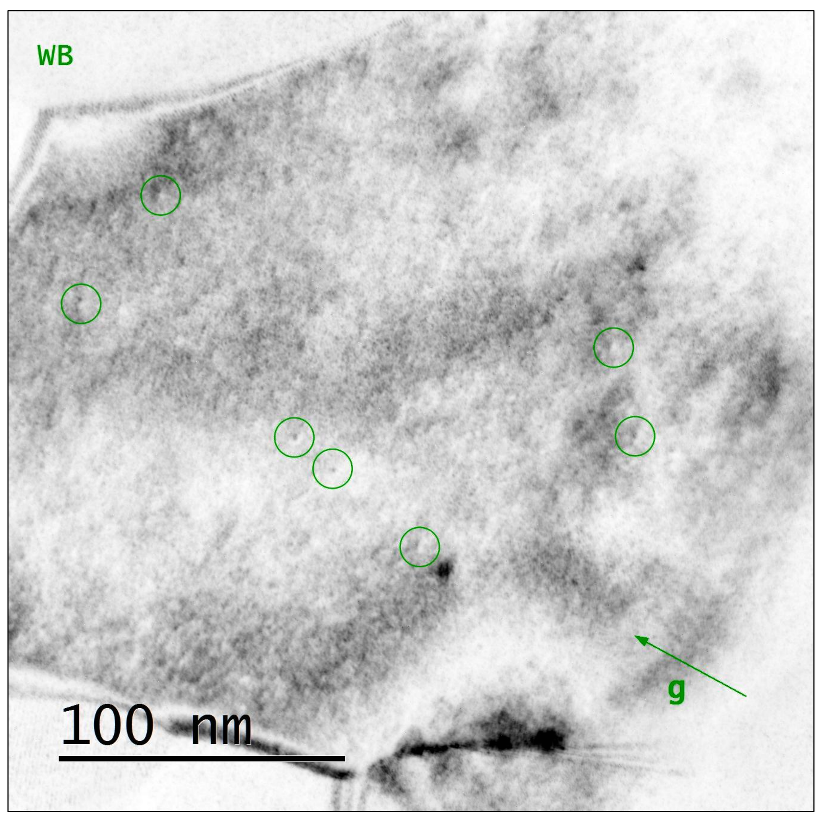
Transmission Kikuchi diffraction (TKD) in the scanning electron microscope (SEM) has the advantage of a higher spatial resolution compared to conventional electron back-scatter diffraction (EBSD) because of a smaller specimen tilt angle. TKD yields information about grain size distribution, orientation and phase distribution.







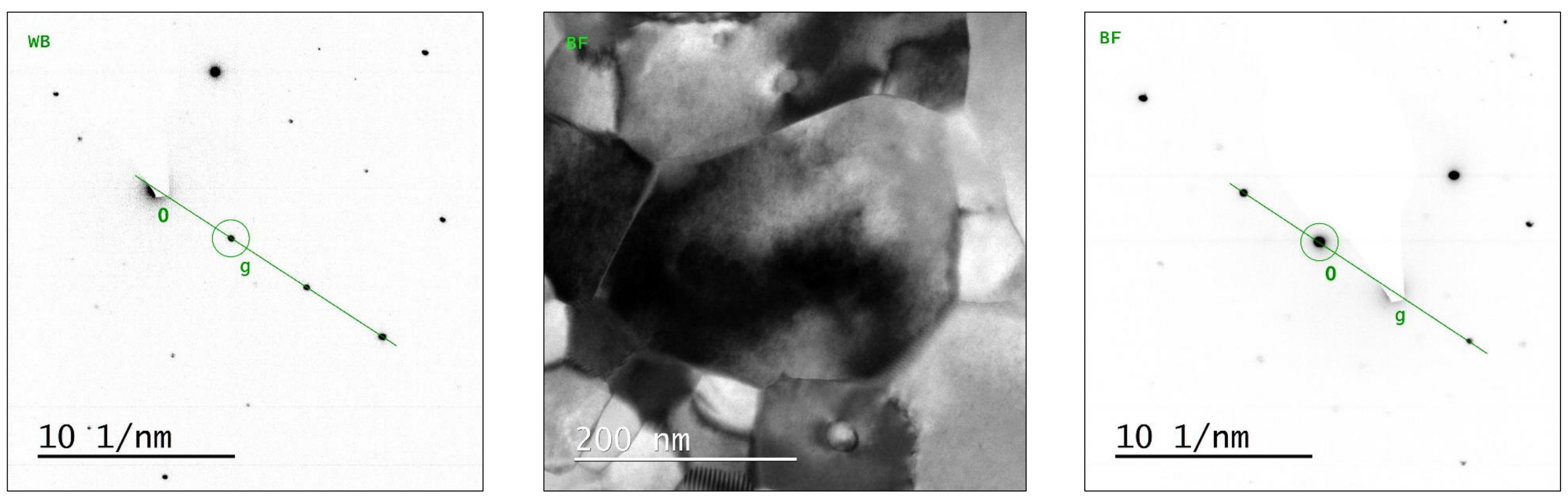
Top: TKD map of 100 nm thin lamella of RRP-Ti wire. **Right:** Corresponding grain size distribution and grain aspect ratio.



Top: Weak-beam dark-field TEM image. **Bottom:** Diffraction patterns show the used beam geometry. Several locations of few nm in size with high contrast changes parallel to the g-vector could be identified, as predicted by simulations.

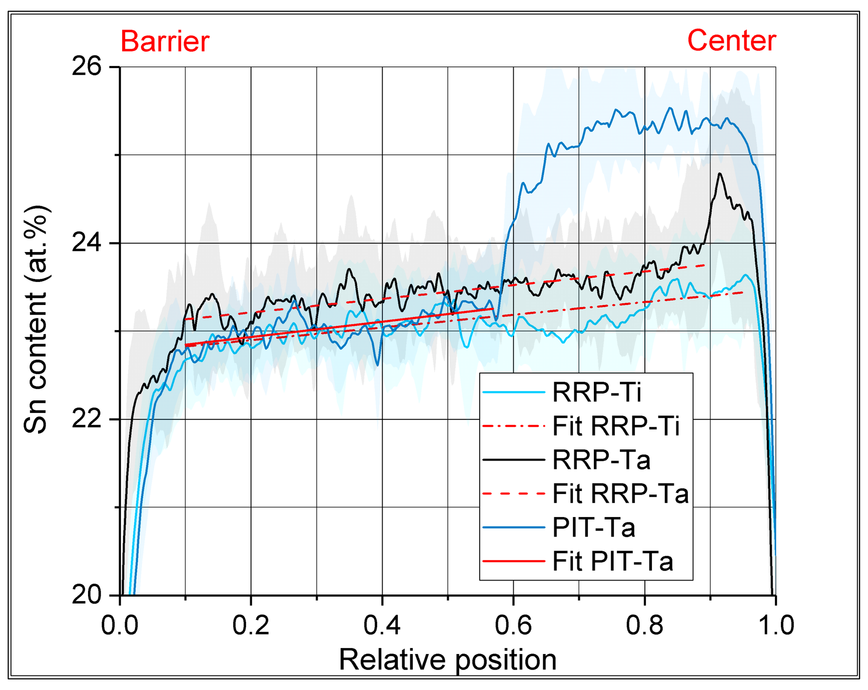
Weak-beam dark-field microscopy

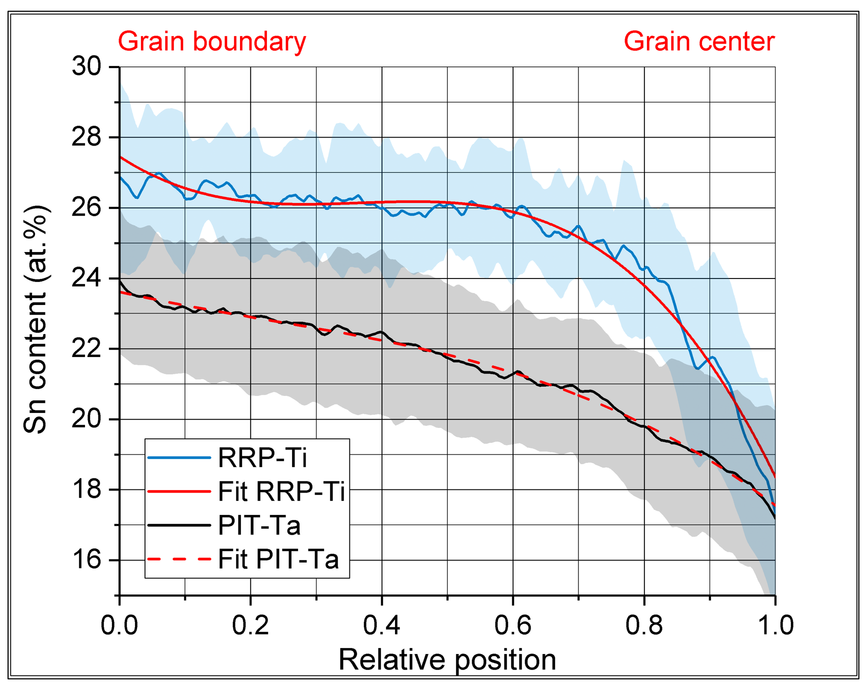
To establish a link between defect density and critical current density, examinations of the defect structure were performed on Nb_3Sn wires before and after neutron irradiation. Using weak-beam dark-field transmission electron microscopy (TEM), neutron impact sites can be made visible. The electron beam is tilted to shift an excited g-reflection (two-beam case) into the optical axis which loses intensity and is used to form the image. Defects in the crystal structure that fulfil the Bragg condition will then show high contrast.



Elemental composition analysis

The elemental content of Sn inside Nb_3Sn sub-elements highly impacts the superconducting performance. EDX linescans performed using SEM and TEM reveal not only a Sn gradient inside sub-elements but also inside single grains.

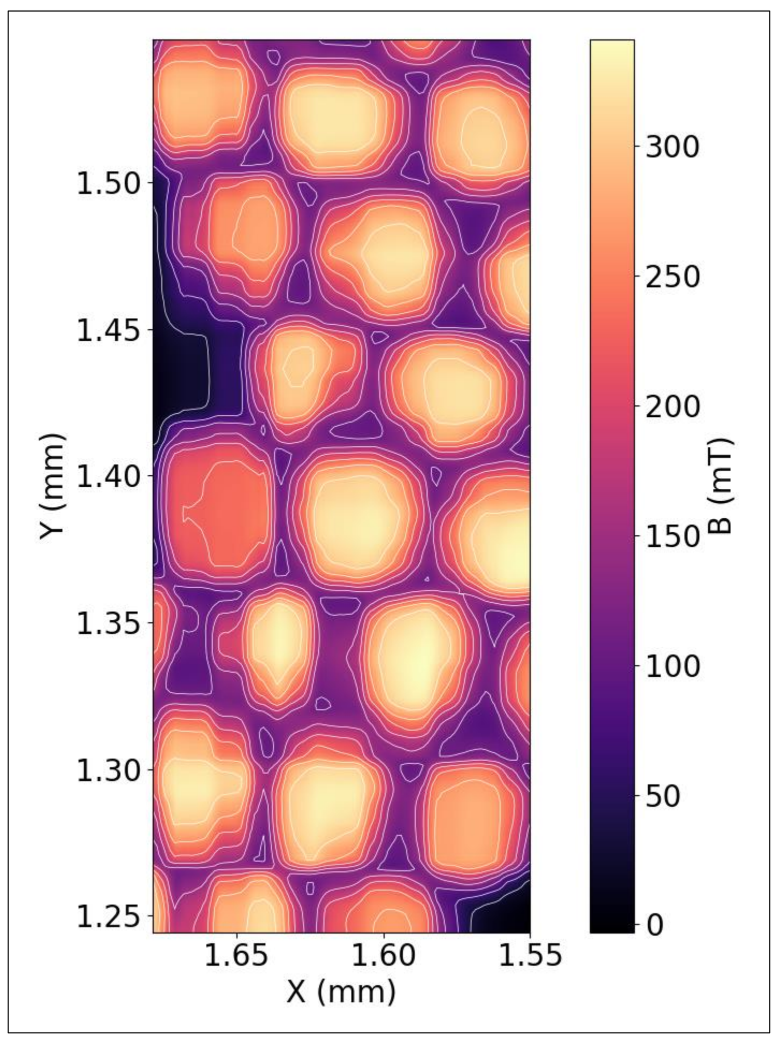




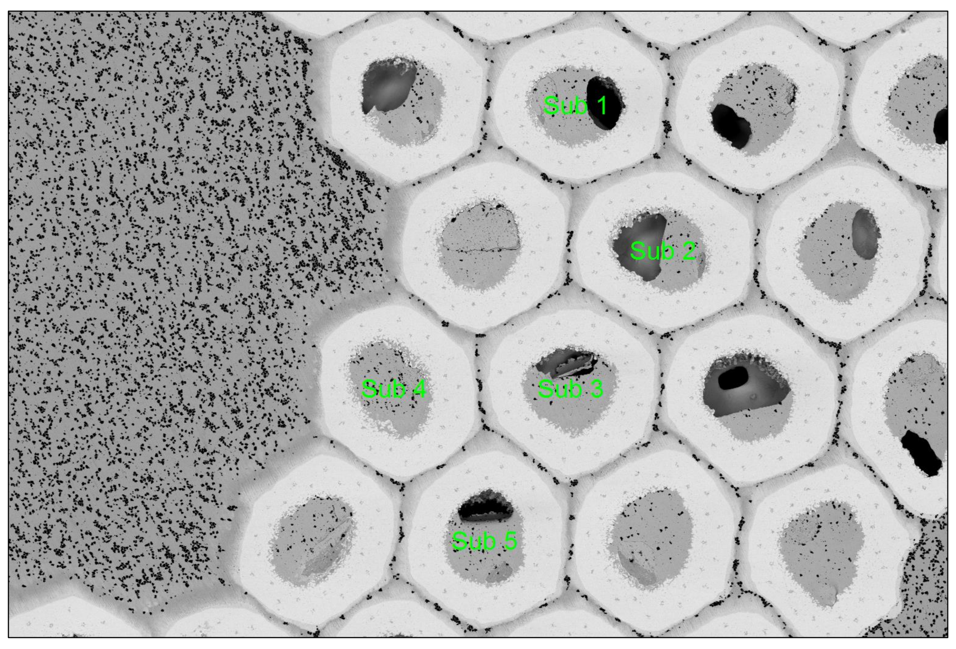
Top left: Statistics of EDX linescans over sub-elements of different wires performed in SEM. **Top right:** Statistics of EDX linescans over grains of different wires from the grain boundary to the center performed in TEM. The highest Sn content can be found at grain boundaries while at the grain center it drops to 18 %.

Scanning Hall probe microscopy

Using a scanning Hall probe microscope, polished cross sections of wires were magnetized before scanning over the surface with a Hall probe. The result is a spatial resolved map of the magnetic flux distribution.

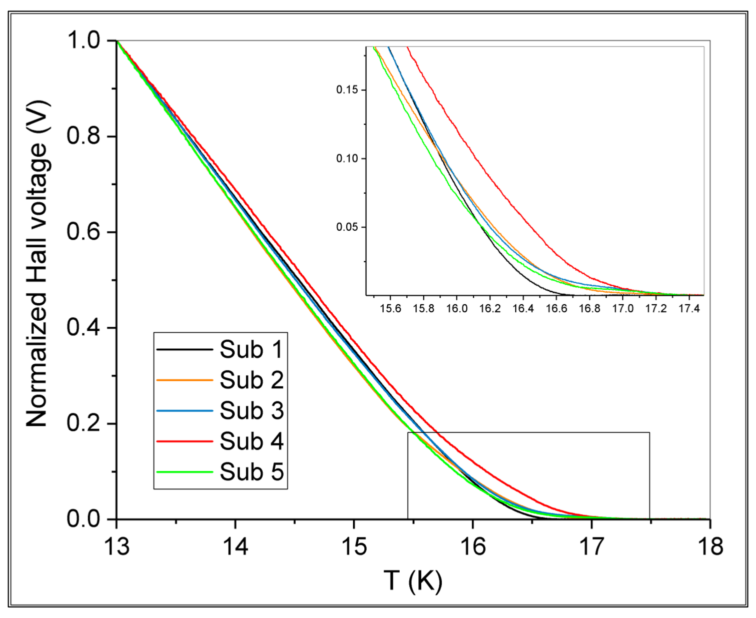


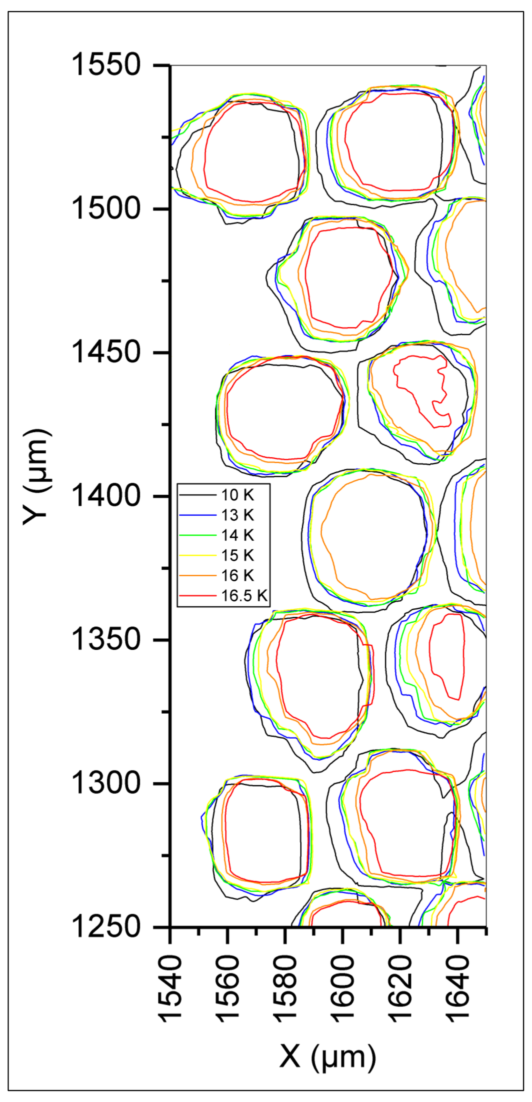
Left: Remanent field scan at 10 K after applying 1 T. Considerable differences between sub-elements could arise due to longitudinal variations of the A15 phase.



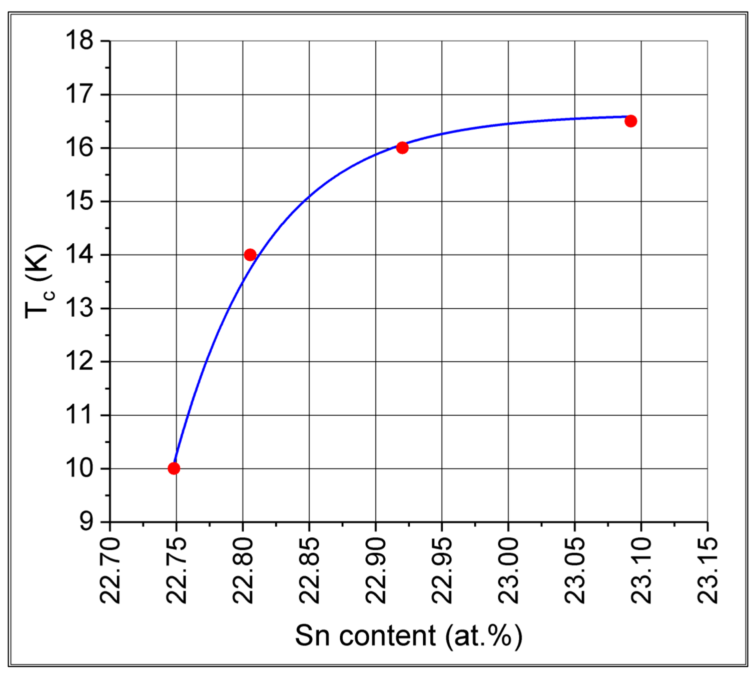
Top: SEM image gives information about geometry of measured sub-elements. **Bottom:** Individual sub-elements also show different behaviour of T_c.

Hall scans in the Meißner state were used to obtain shielding radii which decrease with increasing temperature, revealing a T_c gradient inside the sub-elements stemming from the varying Sn content.





Left: Conture plot shows the paths of shielding currents at 1.84 mT inside subelements of RRP-Ti wire at different temperatures at an applied field of 5 mT.
Right: Correlation of the shielding radii with EDX scans yield the dependency of T_c on the Sn content.



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Acknowledgements

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