ABSTRACT
EFFECT OF MICROSCOPIC DEFECTS ON SUPERCONDUCTING PROPERTIES OF HIGH PURITY NIOBIUM USED FOR SRF CAVITIES

By: Mingmin Wang
Advisor: Prof. Thomas R. Bieler

High purity niobium has been used to fabricate superconducting radio-frequency (SRF) cavities for particle accelerator applications for decades due to its high critical temperature (9.3 K) and critical magnetic field. Great progress has been made in achieving high accelerating gradients and quality factors (a measure of efficiency). A high accelerating gradient increases the accelerating performance of Nb cavities, while improved quality factor will make the cavities more energy efficient. However, the performance of Nb cavities still suffers from the variability of the material such that high quality factors and accelerating gradients cannot be consistently produced.

Magnetic flux trapping occurs when the cavity is cooled through its superconducting transition temperature in an earth magnetic field environment. This flux trapping results in suppression of superconductivity where flux is trapped, and this causes energy losses and degrades cavity performance. Microstructural defects including dislocations, grain boundaries, and hydrides are known to cause flux trapping. However, the details of magnetic flux trapping mechanisms and conditions that enable it are still not clear, and research on this topic has been very active in recent years. In order to achieve reproducible high performance of Nb cavities, it is necessary to understand how the material defects affect magnetic flux trapping and early flux entry in the superconducting state.
Both single-crystal and bi-crystal high purity Nb tensile samples were designed with strategically chosen tensile axes and grain boundaries to activate desired slip systems and to achieve different amounts of deformation in the two adjacent grains. Dislocations generated by these slip systems were introduced by a nominal 5% uniaxial tensile deformation. The effect of material defects on flux trapping was investigated using electron channeling contrast imaging (ECCI) and cryogenic magneto-optical (MO) imaging.

Hydrogen plays a key role in grain boundary related flux penetration. The MO imaging results show that grain boundaries contaminated with hydrogen and parallel to the applied magnetic fields are susceptible to preferential flux penetration. Heat treatments before cavity cool down is necessary to remove hydrogen contamination.

Studies of deformed Nb samples show that grains with larger amounts of deformation or higher dislocation densities show more flux trapping. As cold work causes dislocation multiplication and low angle grain boundary development, which is still present after a heat treatment, these defects can lead to flux trapping. Therefore, recrystallization processing should be considered to remove as many dislocations and low angle grain boundaries as possible to achieve higher performance.

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