Structural Investigations of Nitrogen-Doped Niobium for Superconducting RF Cavities

Márton Major1, Lambert Alff1, Michaela Arnold2, Jens Conrad2, Stefan Flege1, Ruben Grewe2, and Norbert Pietarra2
1Technische Universität Darmstadt, Institut für Materialwissenschaft, Darmstadt, Germany
2Technische Universität Darmstadt, Institut für Kernphysik, Darmstadt, Germany

Introduction
Superconducting Radio Frequency (SRF) accelerating cavities are the de facto standard for high energy particle acceleration. The very high achievable quality factor (Q), low losses, robustness and reliability are all in favour of SRF cavities compared to traditional copper cavities. SRF technology could be even more attractive with reduced cooling costs. The possible increase in operating temperature from 2 K to 5 K by the implementation of higher-Tc materials would reduce the size and running cost of cooling plants.

SRF cavities are made of niobium, which has a critical temperature Tc = 9.2 K, the highest amongst the elements. Nb based materials, like Ni3N (Tc = 17.3 K) or Nb3Sn (Tc = 18 K) are potential candidates for high-Q cavities to be operated at higher temperatures. Costs reduction could also be achieved by using copper cavities coated by superconducting films (Nb or Nb3Sn), a direction followed by CERN.

N-doping of Nb samples (@ ADOMBE)

As a reference to later work, virgin Nb samples were baked out in the ADOMBE chamber [2] @ ATTF. The first reference sample was annealed at 850 °C for 4 h, maximal chamber pressure: 6.8·10⁻⁹ mbar. The second sample was annealed at 1027 °C for 4 h, maximal chamber pressure 5.0·10⁻¹ mbar. The N-doped reference sample was annealed at 965 °C for 30 min in 2.10⁻⁷ mbar nitrogen atmosphere, with an atomic nitrogen RF-source pointing at the sample surface.

The SIMS measurements (Fig. 1) showed less hydrogen and carbon in the annealed samples, compared to the virgin one. The level of nitrogen also increased in the N-doped reference sample.

N-doping of Nb samples (@ Wuppertal-oven)

The virgin Nb samples were baked out in the high-temperature UHV oven (Wuppertal oven: @ IKP) [1]. Samples were annealed in vacuum and in nitrogen atmosphere up to 100 mbar, 1550 °C, 10 min (Fig 2). The nitrogen pressure was kept constant by adjusting the entrance valve of the hot-pot (the niobium inner walls of the sample chamber adsorbed nitrogen at high temperatures).

Results

N-doped samples were annealed and N-doped in high-temperature UHV ovens (ADOMBE and Wuppertal) with the updated doping protocol N-diffusion was observed (Fig. 2). The SIMS measurements also showed less hydrogen and carbon doping in the annealed samples (Fig. 1). The annealed Nb samples showed changes in the microstructure (Figs. 5-6). According to the pole figures the grains of the initially already textured Nb surfaces have grown into a few larger ones, changing drastically the pole figure. Simple polishing also changed the texture.

Different N-doped Nb samples showed different textures, a hint on different crystallite size. The change in microstructure could have effect on the cavities physical performance.

Acknowledgement

This work is supported by the BMBF through the projects 05H15HBBBA (part of “Superconducting Radio-Frequency Cavity Development for Future Accelerators”) and 05H16HBBEE (part of “Key technology for SRF accelerators”) and the Accelerate Research Training Group (GRK 2128).

References


Figure 1. Secondary Ion Mass Spectrometry elemental depth profiles.

Figure 2. SIMS depth profiles of Nb normalized to Nb measured on the Nb samples with D² ions.

Figure 3. X-ray diffraction (XRD) pattern of the reference Nb sample before (left) and after N-doping (inserted) in the ADOMBE chamber. The curves are shifted vertically for clarity.

Figure 4. X-ray diffraction pattern of nitrogen doped Nb samples. The irradiation took place in the Wuppertal oven @ 1027 °C. The Bragg peaks of different crystal phases are noted by coloured tick marks.

Figure 5. Pole figure of the Nb-200 reflection (2θ = 55.7°) of a Nb sample before (left) and after nitrogen doping (middle) at 1200 °C @ ADOMBE. On the right the pole figure of a polished sample is shown. The intensity is represented on square root scale (colour bar).

Figure 6. Pole figure of the different phases of a nitrogen doped sample. The sample was annealed in the Wuppertal oven @ 1027 °C at 1550 °C in 100 mbar N₂ atmosphere for 10 minutes [4]. Bragg peaks related to different phases were selected: α-Nb (left), β-Nb₅N (middle) and β-NbN (right). The intensity is plotted on a logarithmic scale (colour bar).

Figure 7. SIMS Cameca (ims5) results.