Single-Cell Superconducting RF Cavities from Ultra High Purity Niobium

X.Singer^a, E.Filimonova^b, D.Reschke^a, A.Rostovtsev^b,
W.Singer^a, T.Tokareva^b, V.Zaharov^b

^a *Deutsches Elektronen-Synchrotron (DESY), Hamburg, Germany*

^b *Institute for Theoretical and Experimental Physics (ITEP), Moscow, Russia*

Abstract. The 1.3 GHz single-cell superconducting RF cavities are made from ultra high purity niobium. The cavities meet specification criteria for XFEL and ILC linear accelerators. The results of the cavity measurements are discussed.

Keywords: Superconducting cavity, niobium, linear accelerator, accelerating gradient.

PACS: 29.17.+w; 85.25.-j

Corresponding Author: Dr. Waldemar Singer

Waldemar.singer@desy.de

DESY, Notkestr 85

22607 Hamburg

Germany

Tel: +49 40 8998 2775

Fax: +49 40 8998 1970

A superconducting property of high-purity niobium makes it the preferred material for many accelerator projects using superconducting technology. The future International Linear Collider (ILC) would use over 500 tons of pure niobium to build 20,000 superconducting RF cavities. The cost of high-purity niobium material is a substantial fraction of the total cost of the linear accelerator. Furthermore, the demand for high-purity niobium material is steadily growing. It is therefore important to consider different manufacturers and different fabrication methods of the superconducting cavity material. In addition, the high cavity accelerating gradient (E_{acc}) and quality factor (Q_0) are fundamental parameters as they affect the overall cost of the accelerator in a direct way. The accelerating gradient of the superconducting niobium cavities has been raised remarkably in the past decades with an advance of the cavity fabrication technology. For 1.3 GHz single-cell cavity made from pure (99.95%) niobium the best results are approaching 50 MV/m [1], while reliably reproducible resonators are obtained with E_{acc} close to 30 MV/m. We investigate below whether further increase of the E_{acc} and Q_0 -values could be achieved for cavities made from niobium with significantly higher purity. This paper discusses a fabrication and measurement of RF cavities made from ultra high purity niobium sheets produced by Institute for Experimental and Theoretical Physics (ITEP) in cooperation with State Research and Design Institute of Rare-Metal Industry (GIREDMET) in Moscow.

The ITEP-GIREDMET (IG) niobium metal is consolidated via the electrolysis of niobium oxide followed by the electron beam melting in vacuum. The niobium sheets were fabricated from the obtained niobium ingots by cross rolling. A chemical analysis of the IG niobium sheets has shown that there is a very low level of impurities of refractory metals such as tantalum (2 wt. ppm) and tungsten (6 wt. ppm); other metal impurities are below 1 wt. ppm. The gaseous contamination was found to be well below 10 wt. ppm. The Residual Resistance Ratio (RRR) of the IG niobium sheets was measured to be between 700 and 1000 which is substantially higher than the DESY specification (RRR=300) for the material to fabricate RF cavities [2]. Metallographic analysis of the niobium sheets shows an average grain size of about 50 μm . The niobium sheets have been scanned at DESY using the eddy current technique to localize any foreign inclusions or metallurgical defects down to a scale of 100 μm [3].

Half-cells were deep-drawn at the factory from the niobium sheets and thereafter electron beam welded (EBW) at DESY. Since the cavities will be exposed to high magnetic or electric fields the quality of welds at the equator and iris of cells is very critical. Thorough cleaning by ultrasonic degreasing, chemical etching, ultra pure water rinsing, and clean room drying is mandatory before the welding. Careful preparation and the high vacuum provided by DESY EBW machine (up to 10^{-8} mbar) [4] allowed the ultra high purity of the material in the welding area to be maintained. This was confirmed by the measurements on the EB welded samples from high RRR IG material (see Fig. 1).

Fig. 1. Nitrogen, hydrogen contamination (wt. ppm) and RRR of IG niobium sample across the EB-welding region.

Three single-cell 1.3 GHz cavities of TESLA shape have been fabricated from IG niobium. After electropolishing of RF surface, 800° C annealing for 2 hours, high pressure water rinsing and baking at 130° C for about 48 hours, the cavities have shown a high performance in both the Q_0 -value and the maximal accelerating gradient E_{acc} . One of the best results for single cell cavities is shown in Fig 2.

Fig. 2. Q_0 vs E_{acc} curve of a single-cell cavity from IG high RRR niobium at 2K before (squares) and after baking (circles).

As is seen from Fig 2, the maximum accelerating gradient is equal 34 MV/m at a Q_0 -value of about 10^{10} . The maximum quality factor value achieved is above $2 \cdot 10^{10}$. The observed Q_0 behavior as a function of E_{acc} is very similar to that found earlier for cavities fabricated from the lower purity RRR=300 niobium.

In summary, the single-cell 1.3 GHz cavities of TESLA shape fabricated from IG high purity niobium met both the XFEL ($E_{acc} = 23.6$ MV/m, $Q_0=1 \cdot 10^{10}$) and ILC ($E_{acc} = 31.5$ MV/m, $Q_0=1 \cdot 10^{10}$) specifications for an operating gradient. In order to complete the qualification of IG niobium, the nine-cell cavity from high RRR niobium has to be built and tested. The purity of the material plays an important role in the RF cavity fabrication. Nevertheless, at the present state of cavity fabrication technology and RF surface treatment a radical improvement of niobium purity doesn't allow a significant improvement of the RF resonator parameters. However, provided a significantly higher accelerating gradients are reached in the future, the higher purity materials might start to play a key role in a construction of superconducting accelerators.

References

- [1] R.L. Geng, H. Padamsee, A. Seaman, V.D. Shemelin, World Record of Accelerating Gradient Achieved in a Superconducting RF Cavity, in proceedings of Particle Accelerator Conference, Knoxville (2005), 653.
- [2] W.Singer, Metallurgical and Technological Request for High Purity Niobium, in proceedings of Second International Symposium on Hydrogen in Matter, AIP Conference Proceedings 837 (2006) 51.
- [3] W.Singer, A.Brinkmann, D.Proch, X.Singer, Quality Requirements and Control of High Purity Niobium for Superconducting RF Cavities, Physica C 386 (2003) 379.
- [4] W.Singer, X.Singer, J.Tiessen, H.M.Wen, F.Schölz, RRR Degradation and Gas Absorption in the Electron Beam Area of High Purity Niobium, in proceedings of First International Workshop on Hydrogen in Materials & Vacuum Systems, AIP Conference Proceedings 671 (2003) 162.