A.5: Processing of a field emission free nitrogen-doped high-β single-cell 650 MHz superconducting RF cavity

High-β (HB) superconducting radio frequency (SRF) cavities processed with nitrogen (N) doping technique are known to demonstrate better performance than non-doped cavities. As a result, HB cavity deliverables to Fermilab, under IIFC collaboration, mandates N-doping to be included in the processing recipe. Moreover, successful adoption of such technique in the processing cycle at RRCAT, holds significance for future accelerator programs of DAE. In this technique, the cavity is subjected to standard degassing at 800 °C for 3 hrs. in high vacuum furnace followed by a "2/6 recipe" (2 min. at ~25 mtorr N_2 partial pressure followed by 6 min. soak under high vacuum at 800 °C) and thereafter cool down.

To augment its benefits, efforts at RRCAT were initiated, which included setting up of a nitrogen (N_2) gas bleeding attachment to the furnace; N-doping studies on Niobium (Nb) samples followed by trial on HB cavities and its testing. The performances were however, limited by the maximum accelerating gradient (E_{max}) at ~ 14.5 MV/m, quality factor (Q_o) < 1 x 10^{10} at E_{max} along with high field emission (FE) (x-rays > 500 µSv/h).

As a result, modifications to nitrogen gas bleeding set-up were adopted, followed by detailed evaluation of the gas purity using a residual gas analyzer (RGA) fitted on furnace chamber such that no traces of O_2, Ar, CO_2 and moisture was observed during testing of the line with high purity nitrogen gas. Based on the above upgradations and another round of sample studies, a single-cell cavity (HB92-RRCAT-104) was processed. This cavity had previously underwent four rounds of processing and testing with E_{max} limited to 12.8 MV/m and Q_o < 1 x 10^{10} at E_{max} and high field emission. Hence, the RF surface of this cavity was first reset by 50 µm electropolishing (EP) followed by ultrasonic cleaning (UC) and high pressure rinsing (HPR) to prepare pristine surface for N-doping. The cavity along with niobium samples were then loaded in the furnace as shown in Figure A.5.1 and doped using above mentioned recipe. Secondary electron (SE) imaging of the representative niobium samples revealed star shaped niobium-nitride precipitates on surface, which are a characteristic of proper doping procedure (see Fig. A.5.2). Compositional depth profiling also revealed contamination free nitrogen-diffusion at majority of locations. The cavity was then light electropolished for ~7 µm, under cold conditions, followed by ultrasonic cleaning and 3+5 pass high pressure rinsing with ultra-pure water, drying and assembly in an ISO Class-4 cleanroom. Stringent quality control during assembly was followed along with few procedural modifications.

Fig. A.5.1: Single-cell cavity loaded in furnace.

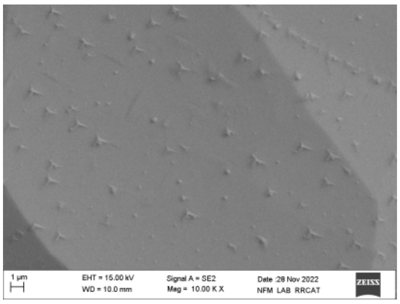

Fig. A.5.2: Secondary electron image of Nb-nitride precipitates.

Subsequently, the cavity was evacuated with upgraded slow pumping set up followed by high vacuum pumping, leak testing and sealing at vacuum < 1.0 x 10^{-6} mbar. Low power RF testing of this cavity at 2K revealed excellent field emission free (x-rays < 0.2 µSv/h) gradient up to 24.7 MV/m with an improved Q_o of 3 x 10^{10} at 18.8 MV/m (see Fig. A.5.3).

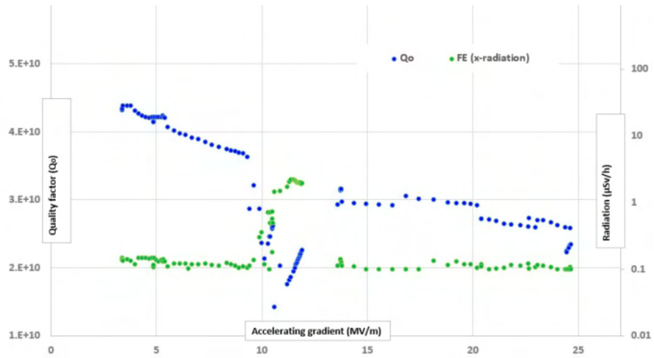

Fig. A.5.3: RF performance of N-doped HB92-RRCAT-104 single cell cavity at 2K.

The results show improvement in cleanroom operational procedures and understanding of N-doping treatment, resulting in the first field emission free and high gradient cavity to be processed successfully at RRCAT. This expertise shall be immensely beneficial for future accelerator programs of DAE.

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