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# Nanostructure of niobium near-surface in superconducting cavities

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Superconducting radio frequency (SRF) cavities are a state-of-the-art technology implemented in particle acceleration, micro-resonators, cavity QED, and single photon detectors. The benefit of using low-dissipation niobium superconducting cavities comes from maintaining the cavities well below niobium superconducting temperature (Tc=9.25K) during operation. Even milli-Kelvin size Joule heating of the niobium near-surface causes significant dissipations at cryogenic temperatures. Dissipations degrade the quality factors of the cavities (Q) and bring up operational costs to economically prohibitive values. In the absence of well-known degrading factors (ambient magnetic fields, hydrogen Q-disease, etc.), resistive heating is produced by intrinsic features of niobium that are located within the magnetic field penetration depth. Since the niobium near-surface of an SRF cavity is a complicated product of multiple steps of mechanical, chemical and temperature treatments, nano-scale investigations are a key for understanding SRF cavity performance limitations.

For investigations of the mechanisms of common SRF cavities performance limitations, such as high field Q-slope, it's crucially important to characterize the original samples directly cut from the cavities. Our studies are based on a unique combination of advanced thermometry during cavity RF measurements, and TEM structural and compositional characterization of the samples extracted from cavity walls at both room *and cryogenic* temperatures. Comparison of the original cavity cutouts with known heating profiles guarantees the absence of artifacts associated with witness sample preparation. Using TEM temperature dependent structural characterization, we directly discovered the existence of nanoscale hydrides in electropolished cavities limited by high field Q slope, and showed decreased hydride formation after 120C baking. Furthermore, precipitation of nanoscale niobium hydrides was consistently found after buffered chemical polishing and 800C baking, which are commonly known to produce high field Q slope degradation in niobium cavities. TEM EELS characterization of the niobium near-surface, before and after a high field Q slope eliminating 120C bake, shows modification of the surface oxide, which is in line with the previous studies. Overall, detailed temperature-dependent investigations of the first micron of SRF niobium cavities provided a valuable understanding of the commonly-used cavity processing steps.

**Keywords**: