Tunneling Study of SRF cavity-grade niobium

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***Abstract*—Niobium, with its very high HC1, has been used in superconducting radio frequency (SRF) cavities for accelerator systems for 40 years with continuous improvement. The quality of cavities (Q) is governed by the surface impedance RBCS, which depends on the quasiparticle gap, delta, and the superfluid density. Both of these parameters are seriously affected by surface imperfections (metallic phases, dissolved oxygen, magnetic impurities). Loss mechanism and Surface treatments of Nb cavities found to improve the Q factor are still unsolved mysteries. We present here an overview of the capabilities of the point contact tunneling spectroscopy method and how it can help understanding SRF cavity performances. Tunneling spectroscopy was performed on Nb pieces from the same processed material used to fabricate SRF cavities. Air exposed, electropolished Nb exhibited a surface superconducting gap delta=1.55 meV, characteristic of clean, bulk Nb, however the tunneling density of states (DOS) was broadened significantly. Nb pieces treated with the same mild baking used to improve the Q-slope in SRF cavities revealed a much sharper DOS. Good fits to the DOS are obtained using Shiba theory suggesting that magnetic scattering of quasiparticles is the origin of the degraded surface superconductivity and the Q-slope problem of Nb SRF cavities.**

***Index Terms*—Tunneling spectroscopy, niobium, RF cavity, magnetism.**

I. INTRODUCTION

FOR over three decades, the SCRF cavities performances have been continuously improved to reach now reproducible quality factor of 10^10 and max accelerating field E of 30 MV/m. However, unresolved mysteries among which High field Q-slope and its mitigation by a mild baking treatment remain and prevent cavities from reaching the intrinsic Niobium limit believed to be around 50-55 MV/m. The interactions between Nb surface superconductivity and the native oxides are complex and not fully understood; a fundamental investigation of the microscopic mechanisms by which oxygen and the complex set of niobium oxides influence cavity performance seems now to be unavoidable. We will present first, a tunneling spectroscopy study of the mild baking effect on cavity-grade electropolished Nb samples that identify magnetic impurities as a heretofore unrecognized contributor to the dissipation mechanism at the surface of Nb. In the second part, we will present preliminary data on the high bias part of the conductance spectrum (>30 mV) that characterize the tunneling barrier itself, here the niobium insulating oxides Nb_2O_5. In the third part, we will present the Atomic Layer Deposition technique and the first attempts to improve the Nb surface superconductivity by getting ride of the oxides: A uniformly 2nm thick Alumina film has been deposited by ALD on Niobium sample and followed by a High temperature heat treatment in Ultra High Vacuum (UHV). In conclusion, the first results obtained on Alumina coated cavities and the future projects associated with ALD will be exposed.

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II. MAGNETIC IMPURITIES AND THE MILD BAKING EFFECT

As we reported previously [1] tunneling measurements on cavity-grade Nb directly probe the surface superconductivity. Our results provide new insights into the Q-slope problem and the baking effect. Air exposed, electropolished poly or single crystals samples reveal a surface gap parameter characteristic of clean, bulk Nb (Δ=1.55 meV) but the tunneling density of states (DOS) is considerably broadened, samples treated using the same mild baking step that reduces the Q-slope (e.g., 120°C for 24h - 48h) show much sharper DOS and reduced zero-bias conductance (Fig.1 Center and right) and this effect prevails whether the sample is baked in air or in vacuum.

Niobium oxides have been widely studied in their bulk, crystalline form: Nb_2O_5 is an insulator with a band gap > 4 eV, NbO_2 is a weak Peierl semiconductor with a gap of 0.1 eV and NbO is metallic and superconducting below 1.4 K. Beyond these three main categories, each of these oxides has the unique property to stabilize a substantial off-stoichiometry, a pristine air-exposed Nb surface develops then a more complex set of oxides with a continuum of gradually increasing oxygen concentration NbO_X from interstitial