Measurements of the Amplitude-dependent Microwave Surface Resistance of a Proximity-coupled Au/Nb Bilayer

Thomas Oseroff, Zeming Sun, Matthias Liepe

Cornell Laboratory for Accelerator-based Sciences and Education (CLASSE)

The Center for BRIGHT BEAMS
A National Science Foundation Science & Technology Center

SRF 2023 GRAND RAPIDS

Outline

Motivation

Sample preparation

RF excitation & measurement

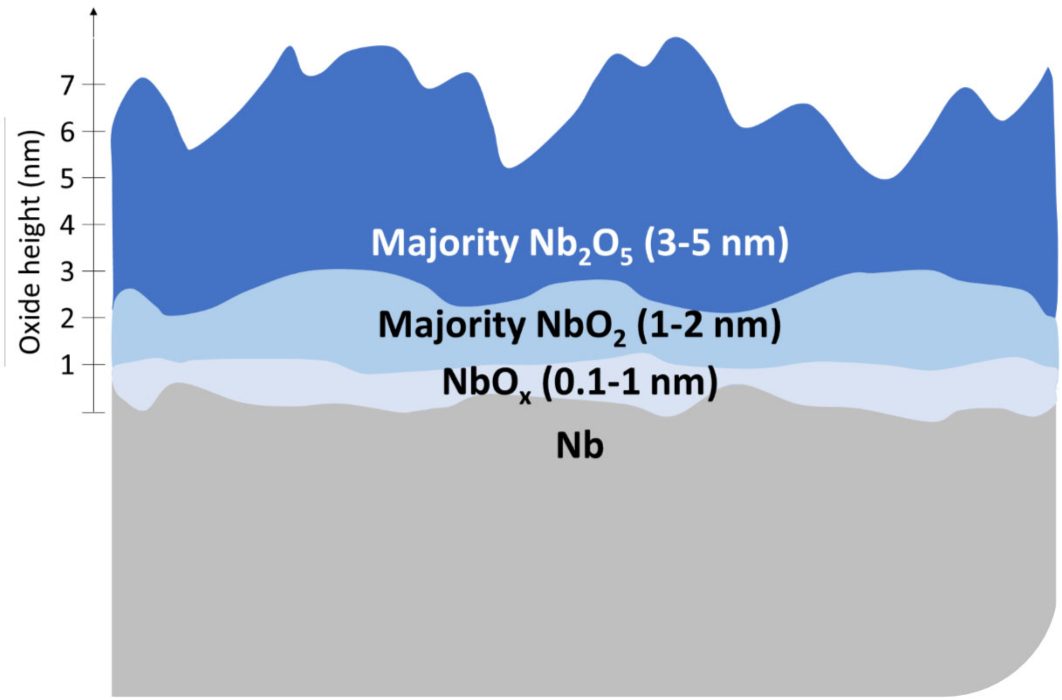
Results

Niobium oxide

Metallic NbO

- **normal conductor** (for accelerators)
- Practically immune to heat treatments
- Present on most/all cavity measurements
- What is its effect on surface resistance?

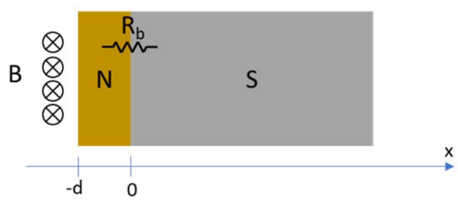
Cartoon (following a 5 hr 800° C UHV bake)



Proximity-coupling

Parameters

- R_b: contact resistance
- d: normal layer thickness
- σ: electrical conductivity

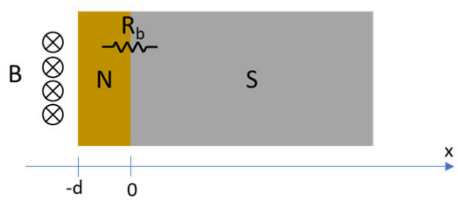


Alex Gurevich and Takayuki Kubo
Phys. Rev. B 96, 184515
Takayuki Kubo and Alex Gurevich
Phys. Rev. B 100, 064522

Proximity-coupling

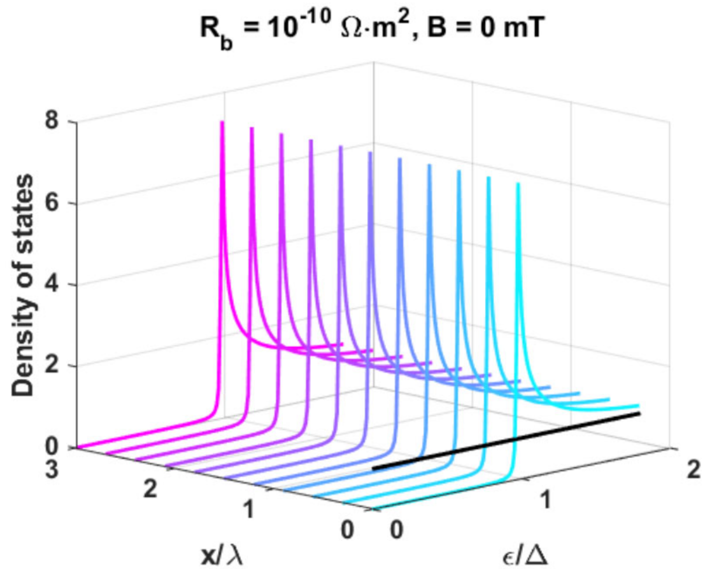
Parameters

- R_b: contact resistance
- d: normal layer thickness
- σ: electrical conductivity

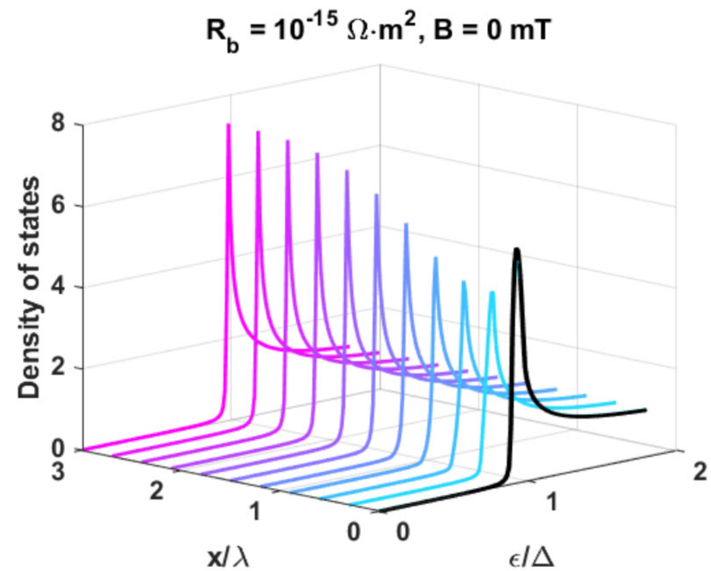


Alex Gurevich and Takayuki Kubo
Phys. Rev. B 96, 184515
Takayuki Kubo and Alex Gurevich
Phys. Rev. B 100, 064522

Weakly coupled (R_b high)



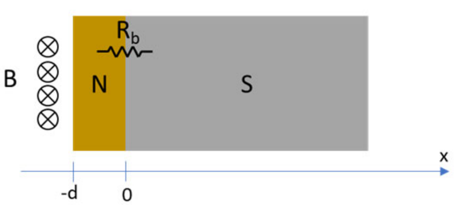
Strongly coupled (R_b low)



Proximity-coupling

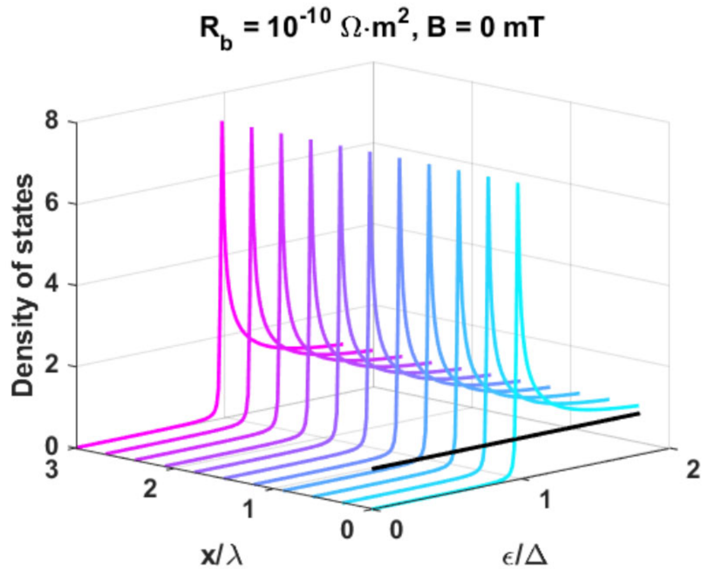
Parameters

- R_b: contact resistance
- d: normal layer thickness
- σ: electrical conductivity

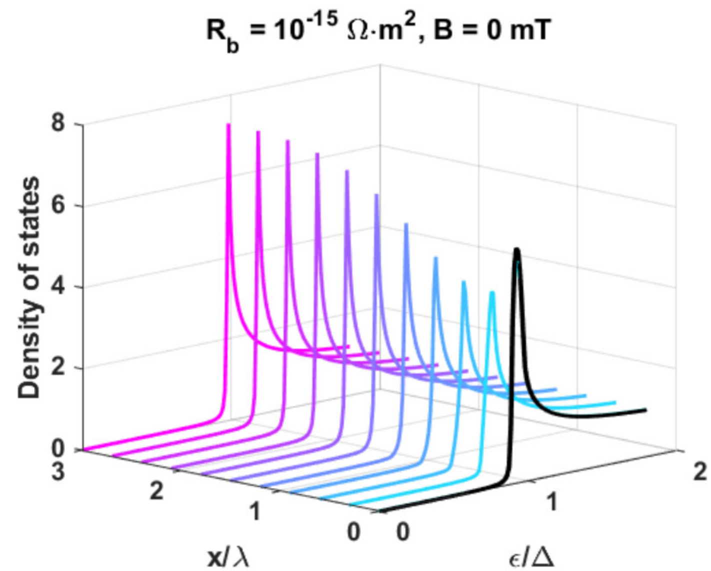


Alex Gurevich and Takayuki Kubo
Phys. Rev. B 96, 184515
Takayuki Kubo and Alex Gurevich
Phys. Rev. B 100, 064522

Weakly coupled (R_b high)



Strongly coupled (R_b low)

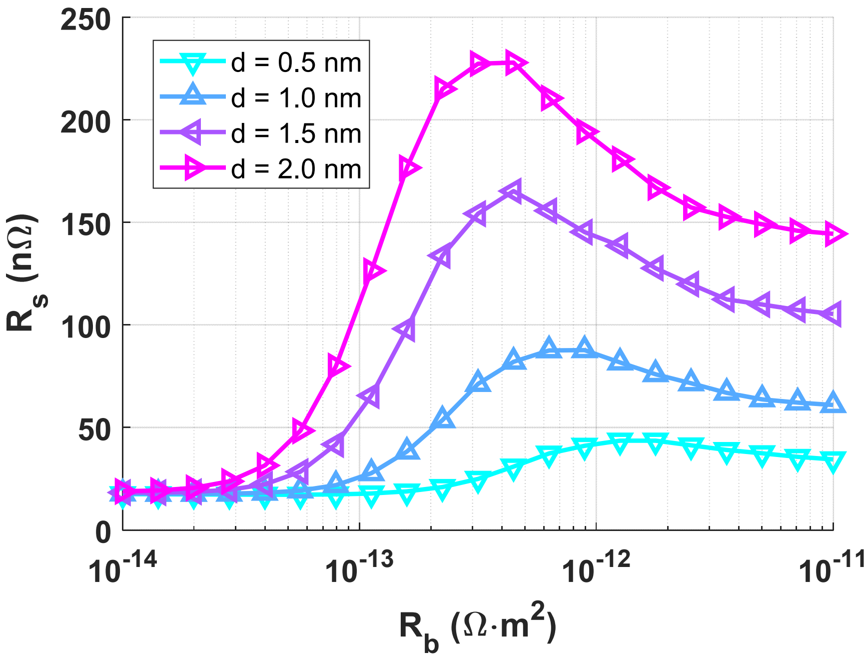


Proximity-coupling

- Normal conducting layer takes on some superconducting behaviors
- Superconducting properties near the interface are altered due to pair-breaking effects

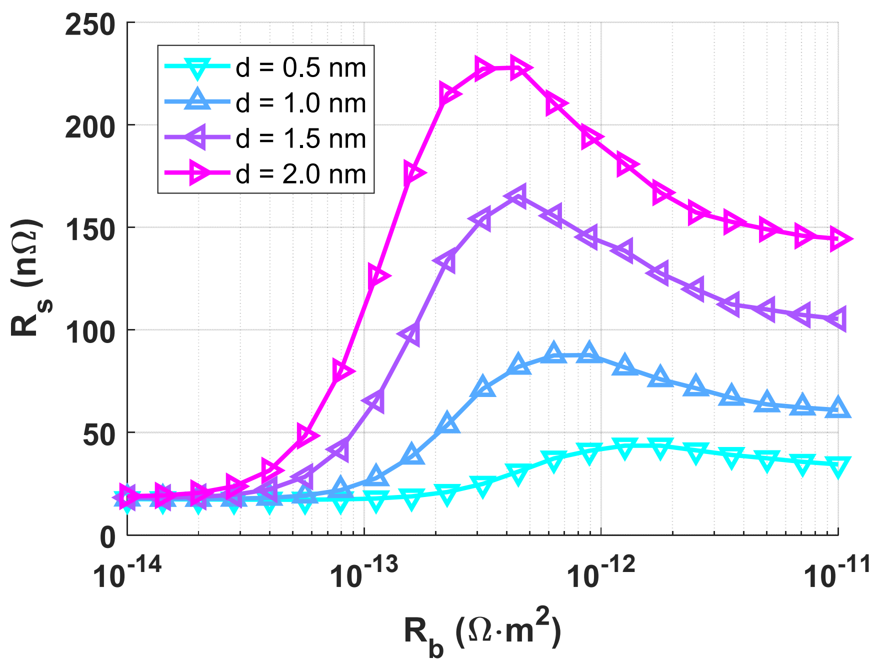
Impact of normal layer on surface resistance

Modeled surface resistance



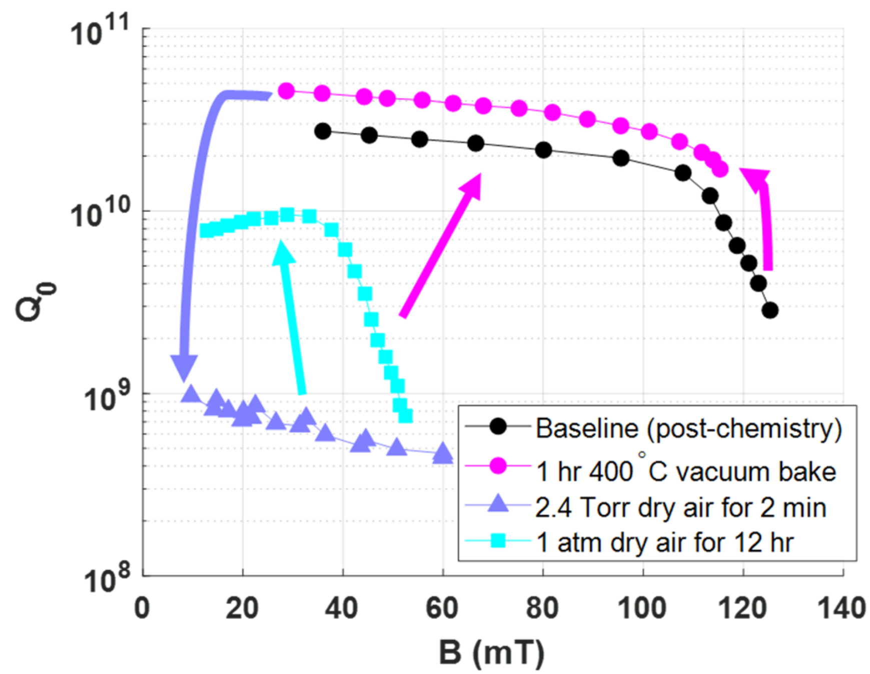
Impact of normal layer on surface resistance

Modeled surface resistance



Experiments on modifying oxide

https://www.classe.cornell.edu/rsrc/Home/Research/SRF/GrigoryEremeev/Grigory_Eremeev_PhD.pdf



How to measure normal layer influence?

Directly with niobium oxide

- One explanation for variation in measurements with varying oxide structure
- Difficult to characterize properties
- Difficult to control for systematic study

Replace with Gold

- Adheres well to niobium
- Noble metal → minimal oxidation
- Expect better control of relevant properties

Outline

Motivation

Sample preparation

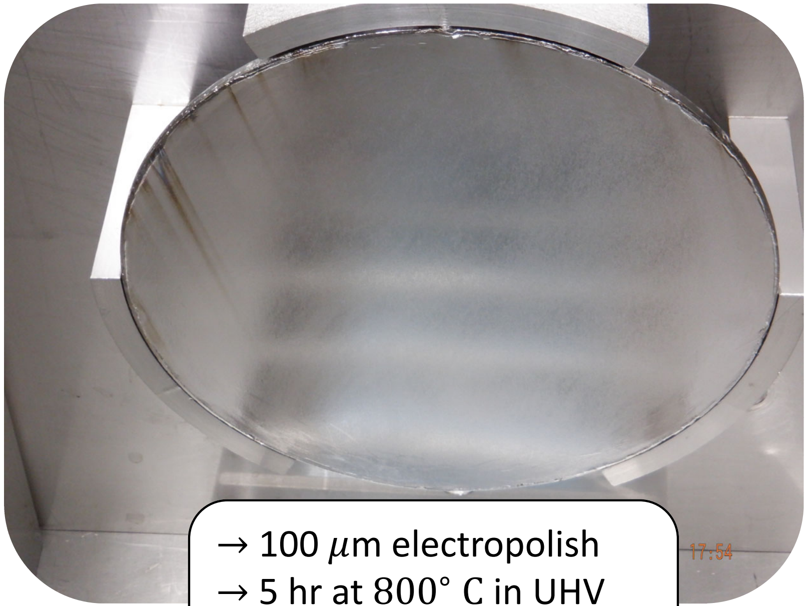
RF excitation & measurement

Results

Sample preparation

Procedure

- Standard preparation of niobium



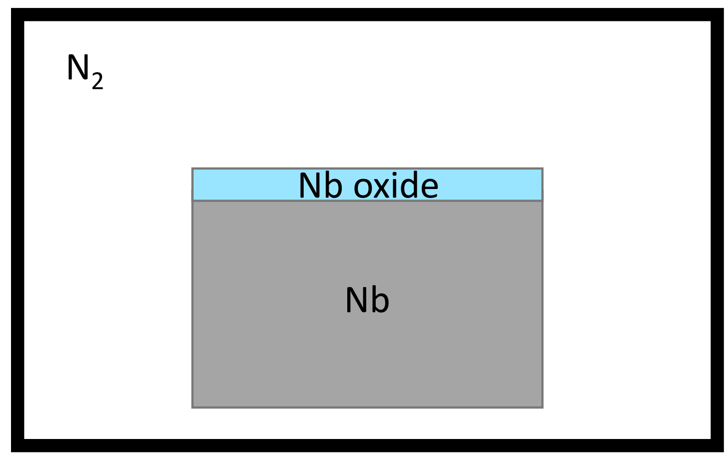
→ 100 μm electropolish
→ 5 hr at 800° C in UHV
→ 4 μm electropolish
→ High pressure rinse in DI

Sample preparation

Procedure

- Standard preparation of niobium
- **Remove oxide** in N_2 atmosphere
  - Dilute HF soak in glove box
  - Seal in plastic bag

Glovebox

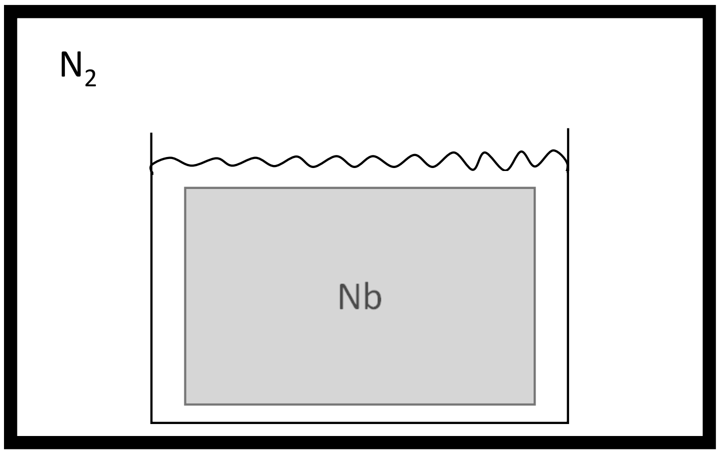


Sample preparation

Procedure

- Standard preparation of niobium
- **Remove oxide** in N_2 atmosphere
  - Dilute HF soak in glove box
  - Seal in plastic bag

Glovebox

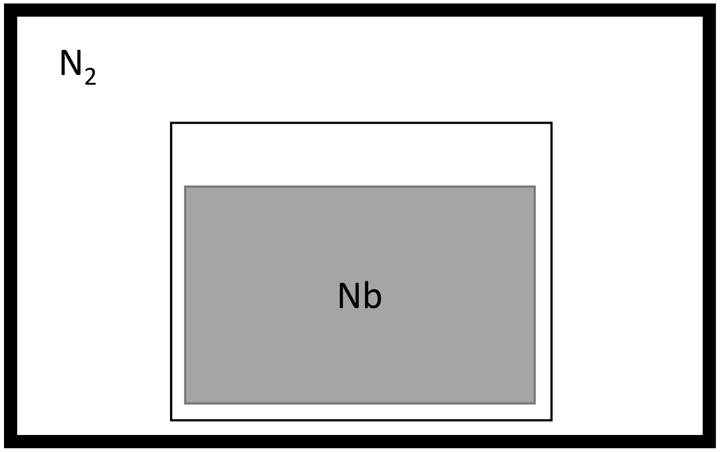


Sample preparation

Procedure

- Standard preparation of niobium
- **Remove oxide** in N_2 atmosphere
  - Dilute HF soak in glove box
  - Seal in plastic bag

Glovebox

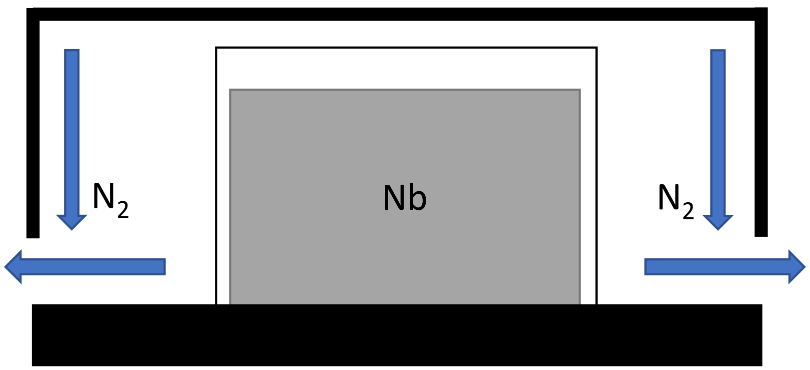


Sample preparation

Procedure

- Standard preparation of niobium
- **Remove oxide** in N_2 atmosphere
  - Dilute HF soak in glove box
  - Seal in plastic bag
- **Thermal evaporation of gold**
  - Open bag with N_2 purge active
  - Pump chamber
  - Deposit gold

Thermal evaporation chamber

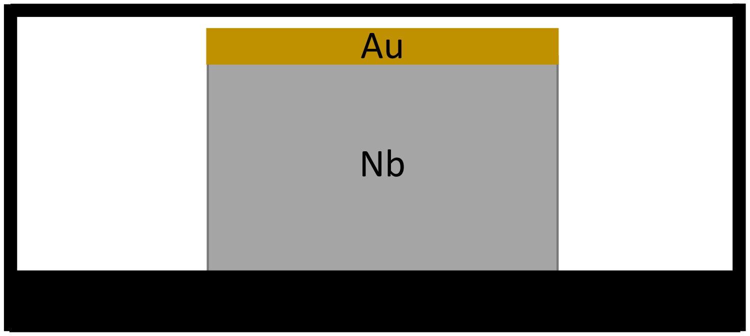


Sample preparation

Procedure

- Standard preparation of niobium
- **Remove oxide** in N_2 atmosphere
  - Dilute HF soak in glove box
  - Seal in plastic bag
- **Thermal evaporation of gold**
  - Open bag with N_2 purge active
  - Pump chamber
  - Deposit gold

Thermal evaporation chamber



Sample preparation

Procedure

- Standard preparation of niobium
- **Remove oxide** in N_2 atmosphere
  - Dilute HF soak in glove box
  - Seal in plastic bag
- **Thermal evaporation of gold**
  - Open bag with N_2 purge active
  - Pump chamber
  - Deposit gold
- **Measure contact resistance**

Measure contact resistance on sample

- With native oxide: $R_B = 5.0 \times 10^{-12}\ \Omega \cdot m^2$
- With glovebox: $R_B \approx 5.6 \times 10^{-13}\ \Omega \cdot m^2$

Outline

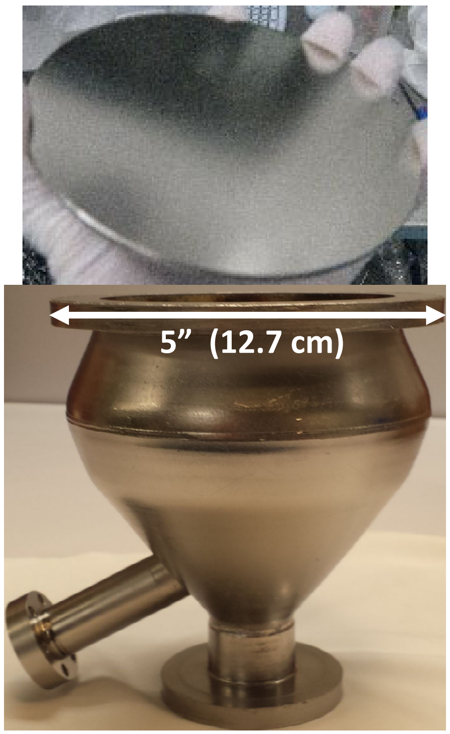
Motivation

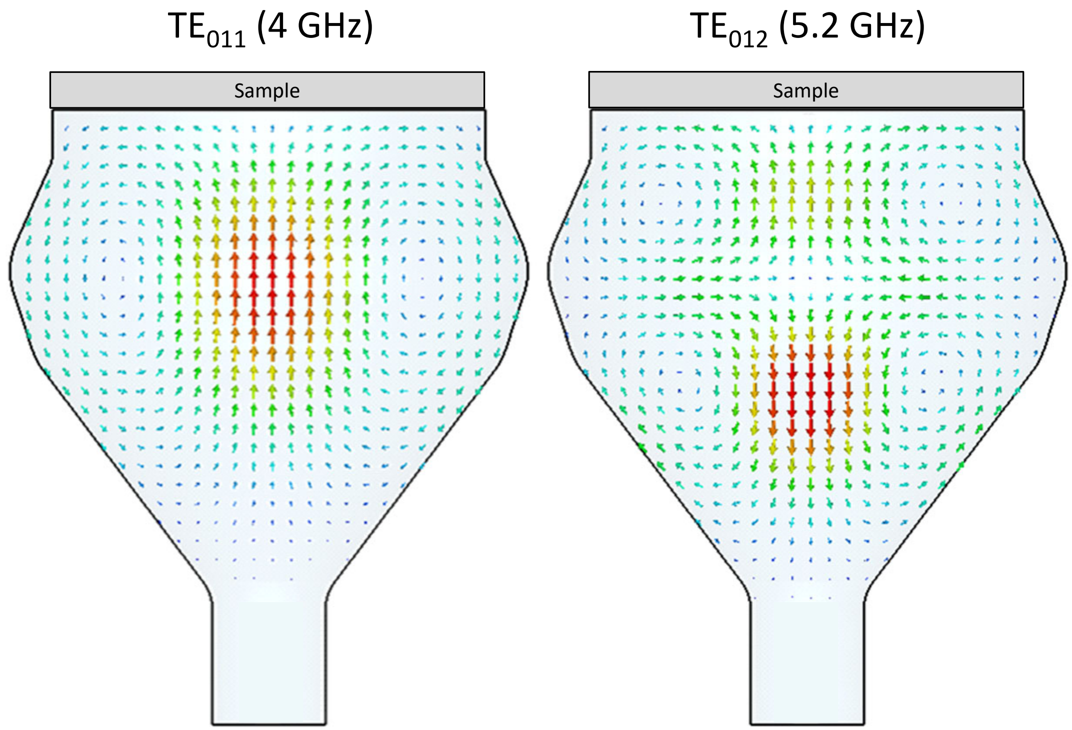
Sample preparation

RF excitation & measurement

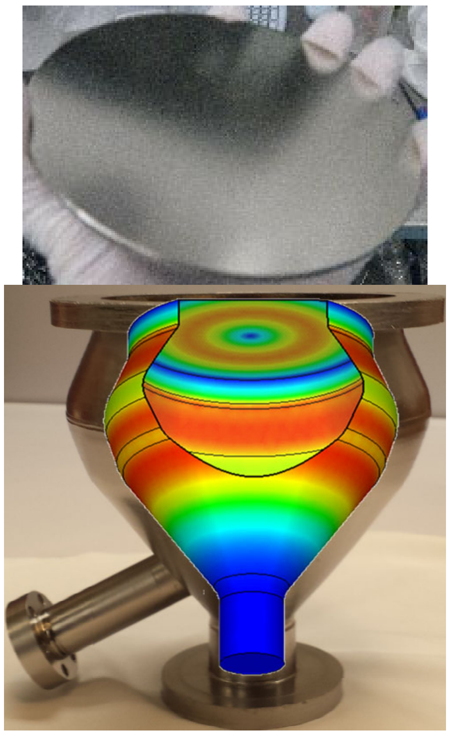
Results

Sample host cavity

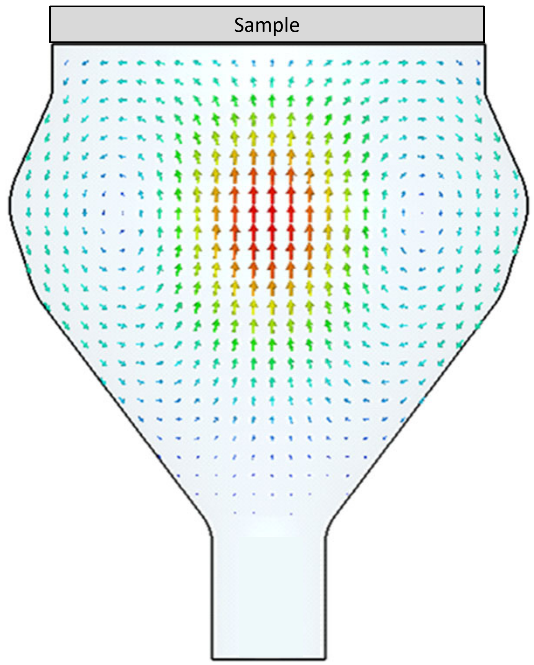




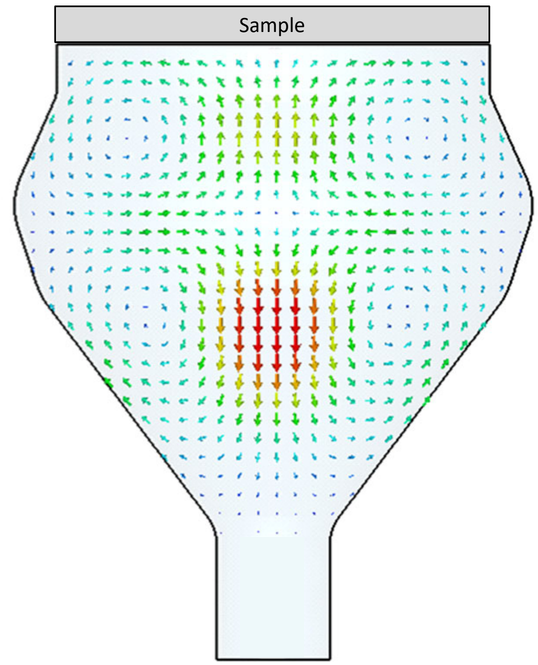
Sample host cavity



TE$_{011}$ (4 GHz)



TE$_{012}$ (5.2 GHz)



Calibration measurement (niobium sample)

Agrees with theory

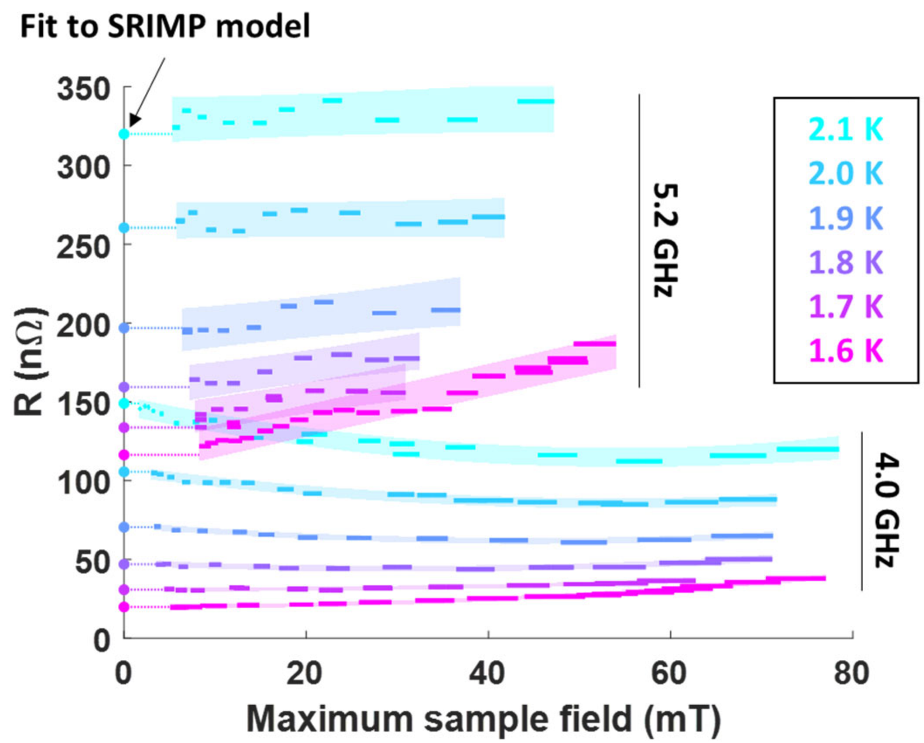
Low-field R(T) fits to SRIMP model using parameters expected for 5 hr 800° C UHV Nb

Agrees with experiment

Comparable resistance to Fermilab 3.9 GHz TM_{010} results with similar preparation

Consistent for niobium samples

- Similar surface resistances
- Similar quench fields



Outline

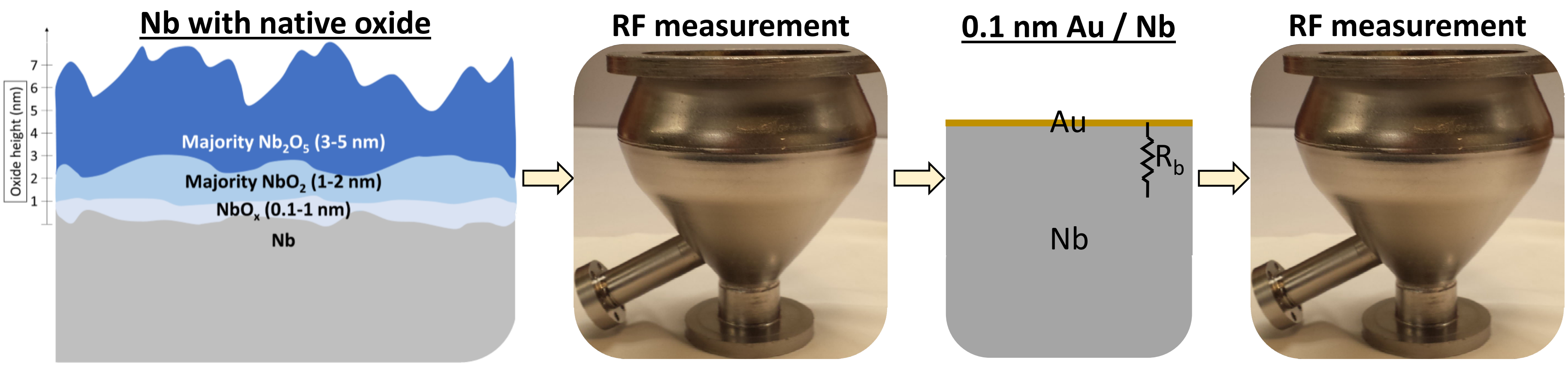
Motivation

Sample preparation

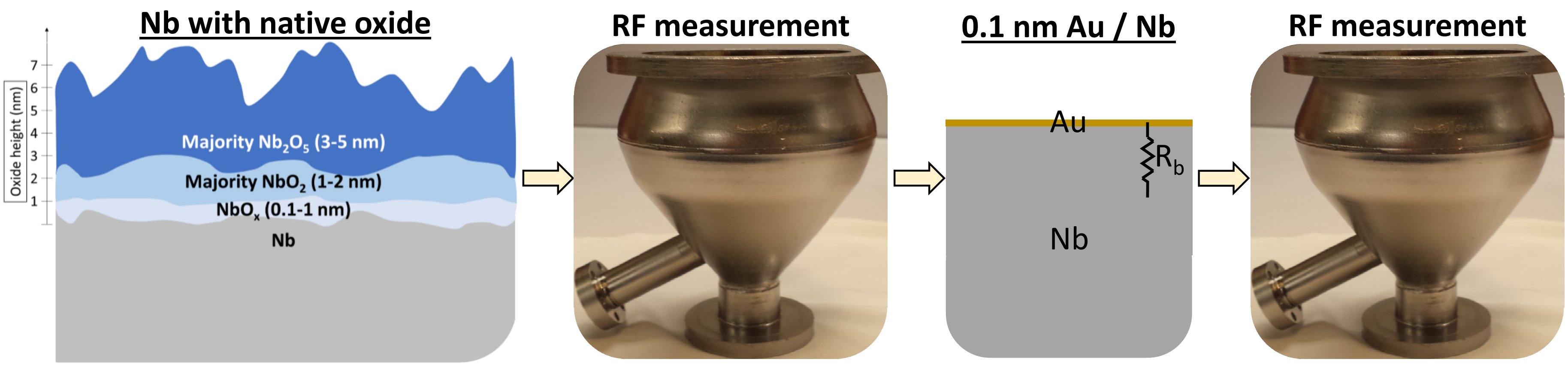
RF excitation & measurement

Results

Attempt to study influence of niobium oxide



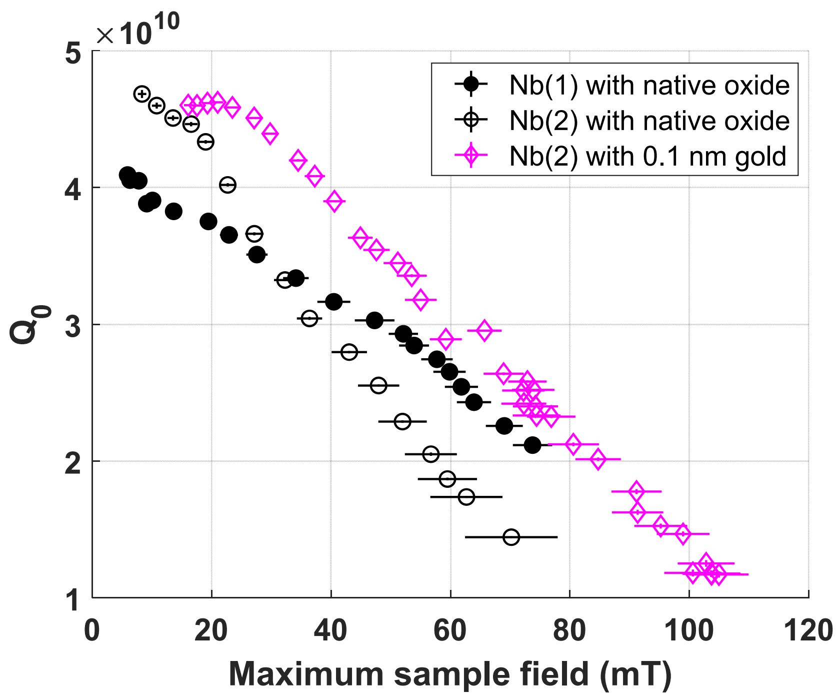
Attempt to study influence of niobium oxide



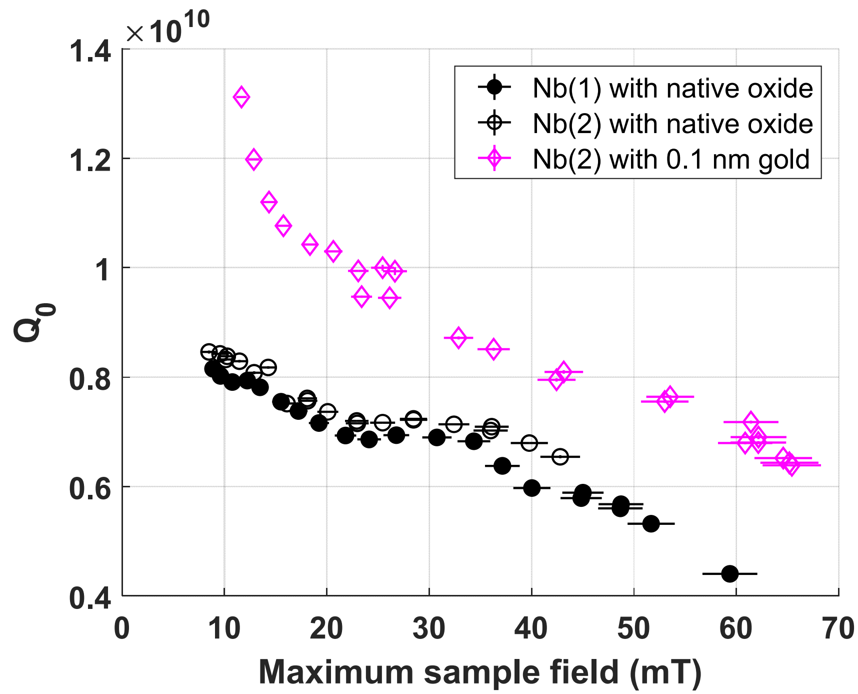
<u>Compare surface resistance with native oxide to that with minimum thickness Au</u>

Attempt to study influence of niobium oxide

1.6 K & 4.0 GHz

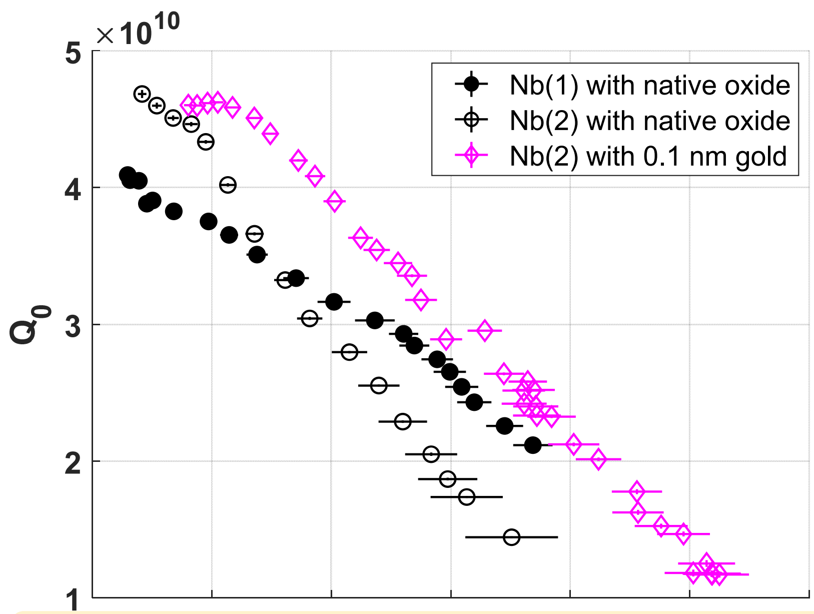


1.6 K & 5.2 GHz

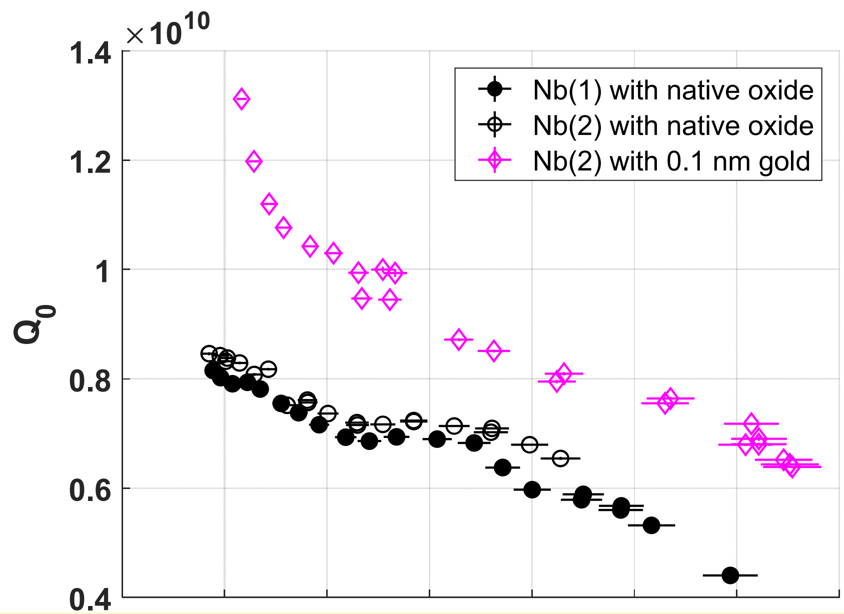


Attempt to study influence of niobium oxide

1.6 K & 4.0 GHz

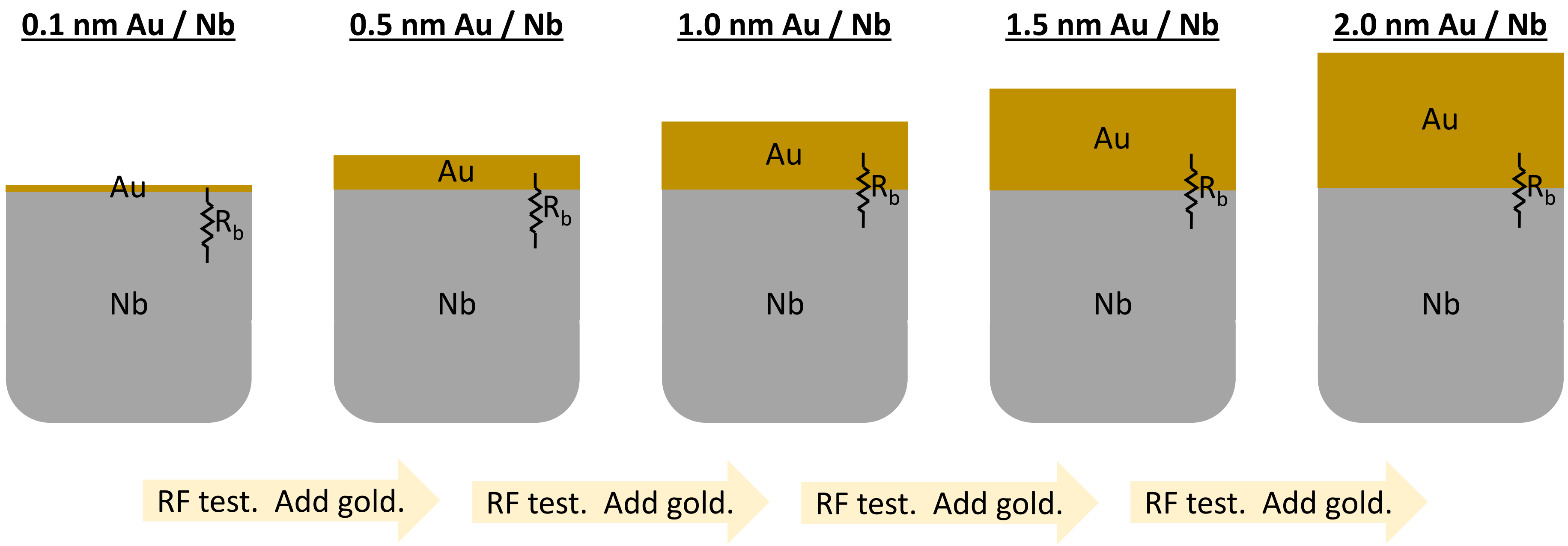


1.6 K & 5.2 GHz

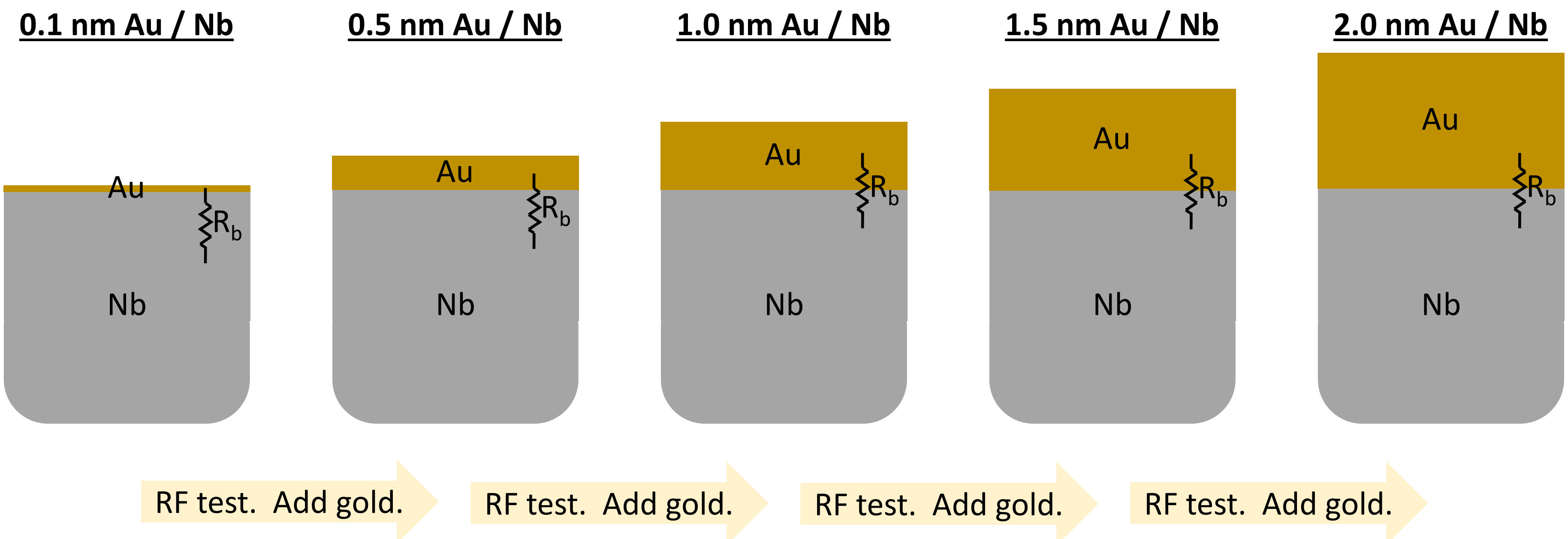


Surface resistance magnitude was reduced following gold-passivation procedure

Effects of gold thickness



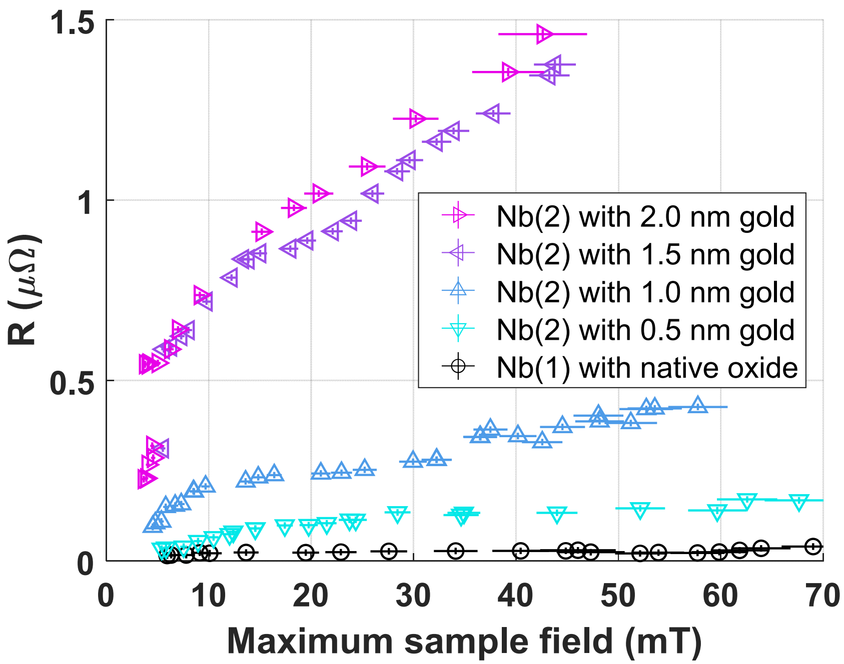
Effects of gold thickness



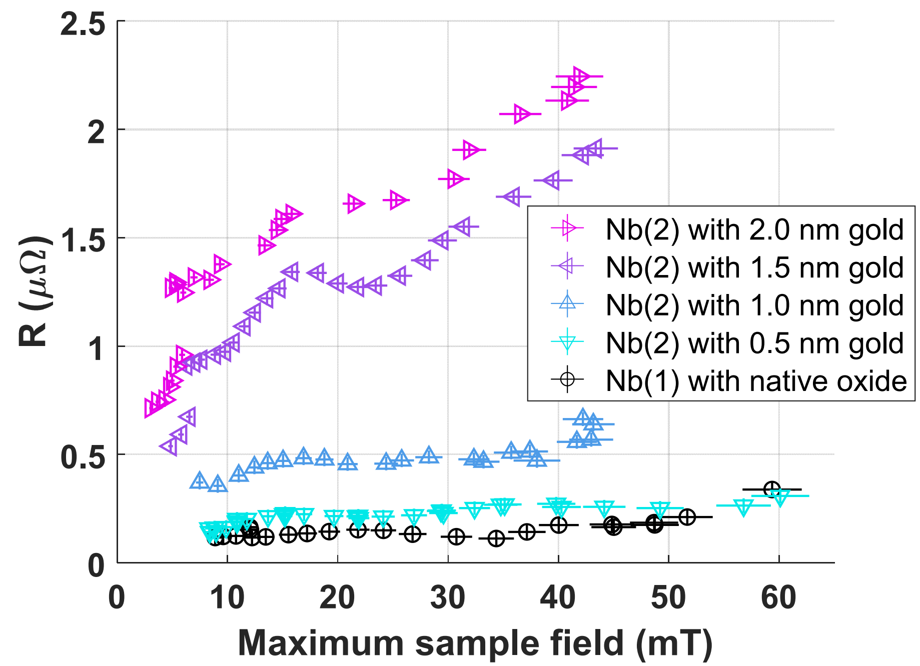
Measure effect of thickness with minimal variation to other relevant parameters

Effects of gold thickness

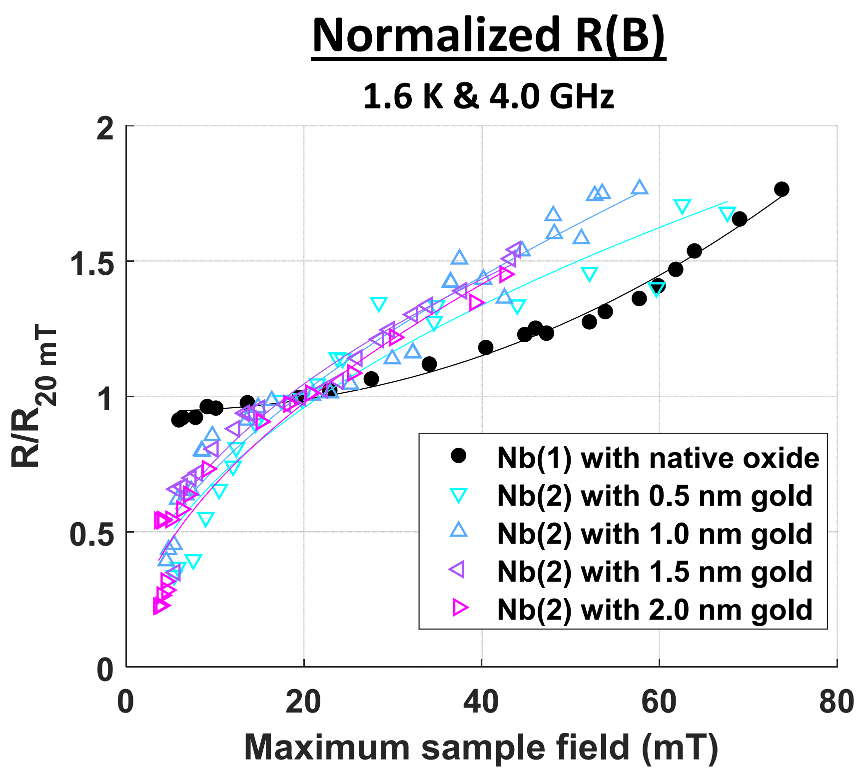
1.6 K & 4.0 GHz



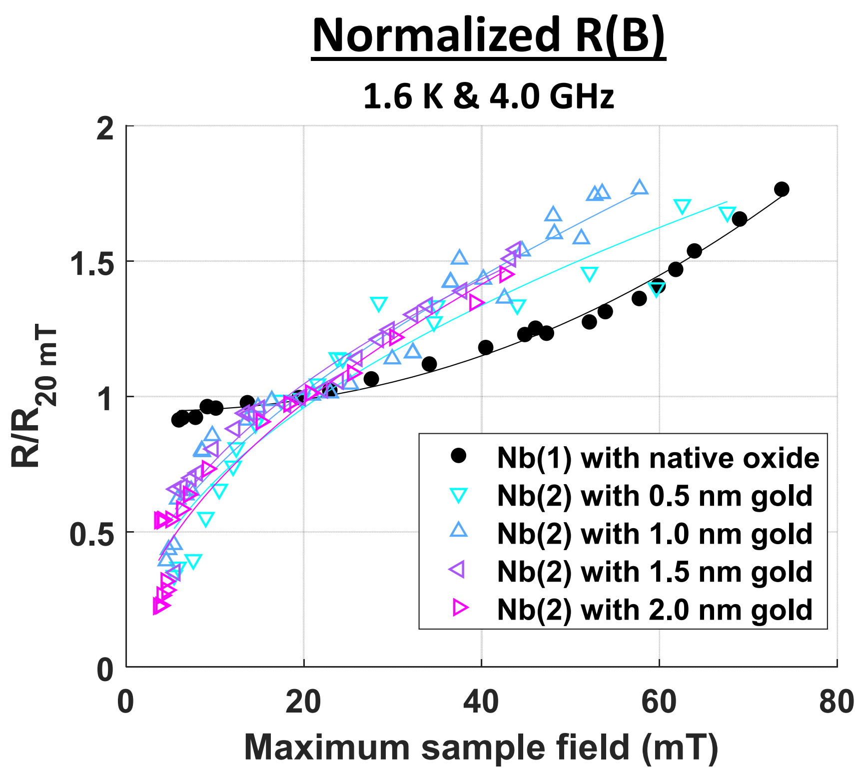
1.6 K & 5.2 GHz

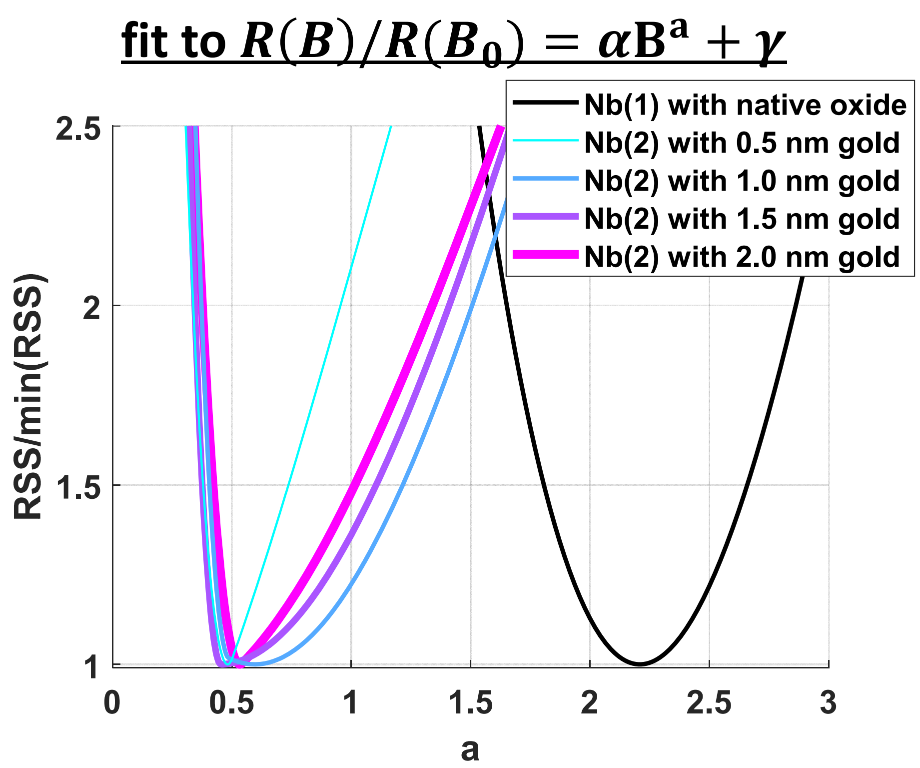


Effects of gold thickness



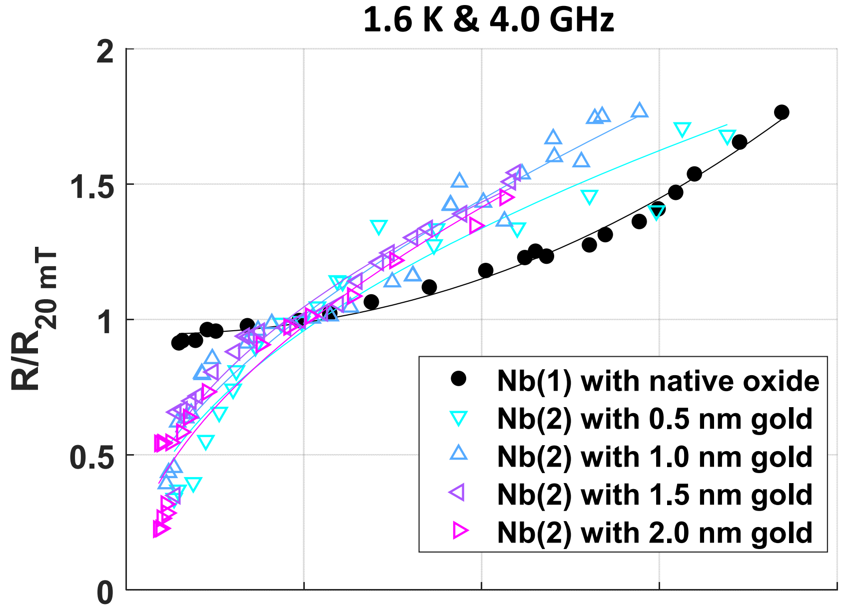
Effects of gold thickness



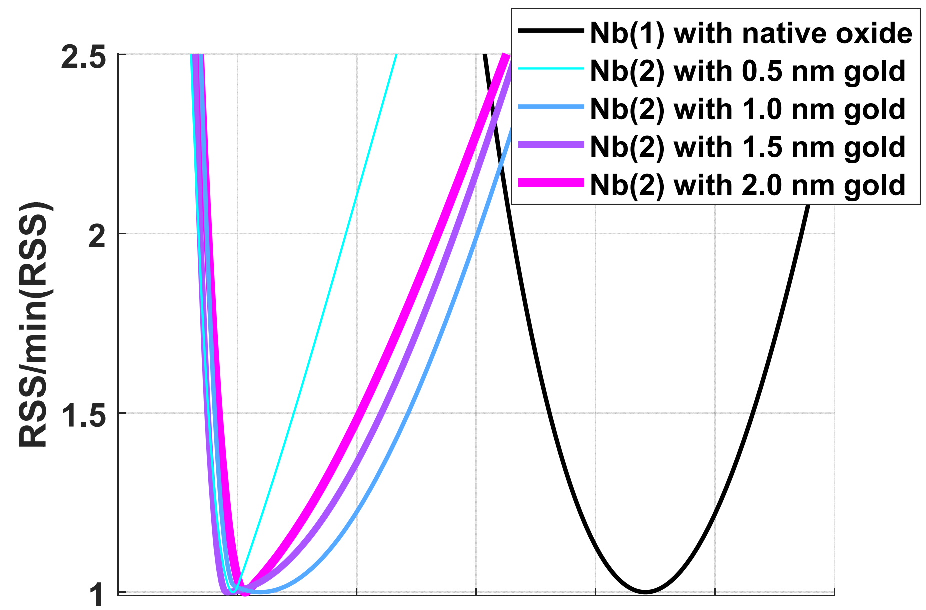


Effects of gold thickness

Normalized R(B)



fit to $R(B)/R(B_0) = \alpha B^a + \gamma$



Surface resistance field-dependence was changed by gold-passivation procedure

Contributions to the community

Further evidence that niobium oxide is relevant to surface resistance

Data on the role of normal conductor thickness in surface resistance

Suggests benefits from gold as a means of surface passivation

Contributions to the community

Further evidence that niobium oxide is relevant to surface resistance

Data on the role of normal conductor thickness in surface resistance

Suggests benefits from gold as a means of surface passivation

More information: https://arxiv.org/pdf/2305.12035.pdf