

Improving Nb₃Sn Cavity Performance Using Mechanical Polishing

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Introduction

Superconducting radiofrequency (SRF) cavities are essential components for providing the electric fields required to accelerate charged particles in particle accelerators. SRF cavities coated with a layer of Nb₃Sn can reach up to 100 MV/m of accelerating field in theory. However, in practice surface roughness and other defects limit Nb₃Sn SRF cavity performance. Centrifugal barrel polishing (CBP) is a proven technique for mechanically polishing Nb SRF cavities to nanometer scale smoothness. Here, we apply this technique to a Nb₃Sn coated, 1.3 GHz, TESLA geometry SRF cavity, and see an improvement in the accelerating gradient. To show the evolution of the surface during CBP, we polish Nb₃Sn samples using a special coupon cavity, which can simulate accurate polishing conditions. The samples show a very low surface roughness after 8 hours of polishing with only a few hundred nanometers of material removal.

Background Information

- Centrifugal Barrel Polishing (CBP) is a technique used to polish niobium cavities without using toxic chemicals such as HF.
- CBP uses a custom built tumbling machine that can fit up to 9-cell size cavities, and can accelerate the polishing media against the cavity surface with up to 6g of force.
- An alumina nanoparticle suspension is used as the abrasive material. Felt cubes are added to push the abrasives against the cavity surface.

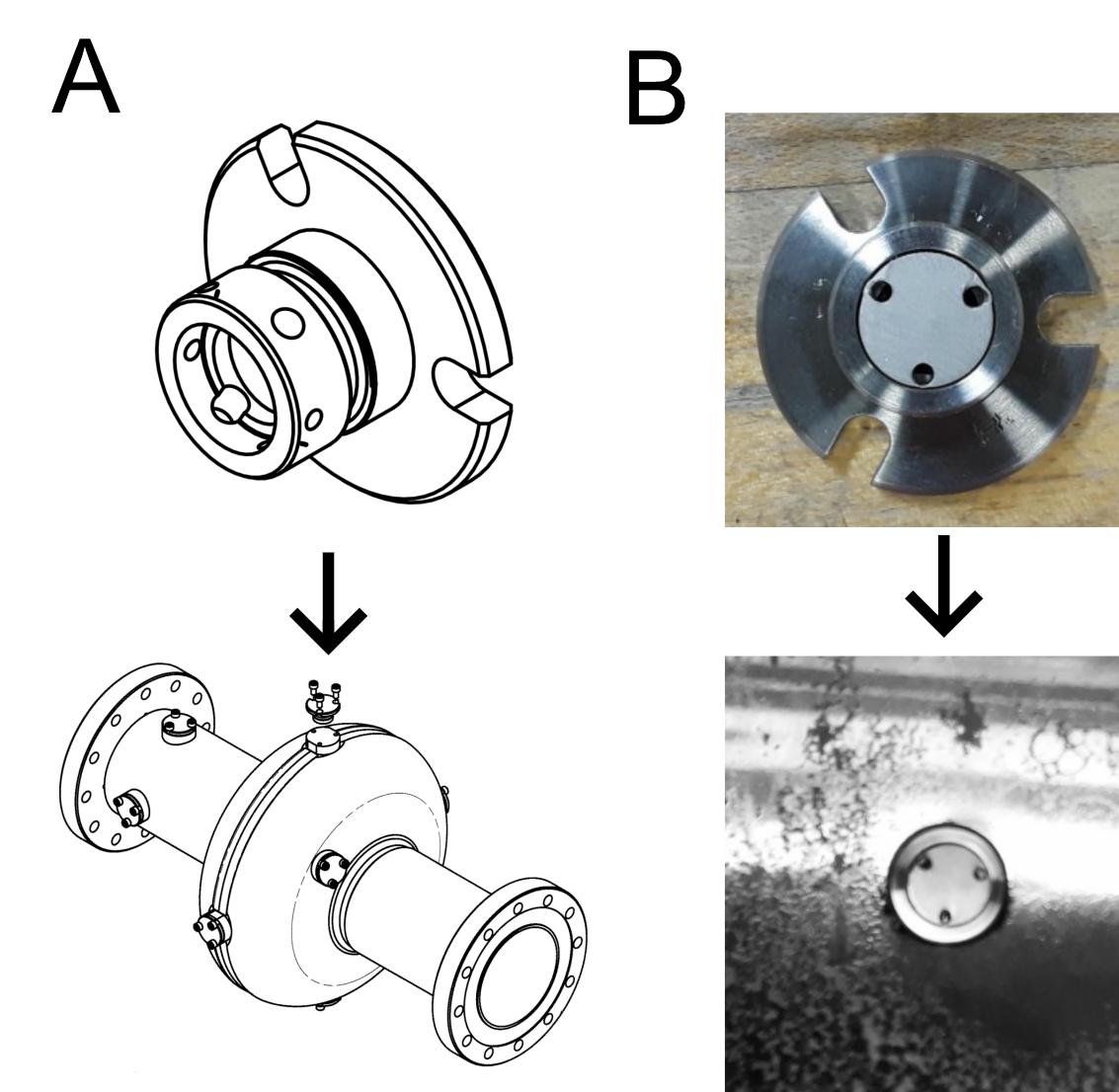


Figure 1. (A) A schematic of the coupon cavity and the sample holder used to polish the Nb₃Sn coated samples. The sample holder can hold 1 cm diameter disks by clamping the sides of the sample with set screws. (B) Pictures of the sample holder sitting outside the coupon cavity and with a sample mounted as seen from the inside of the coupon cavity.

Surface Analysis of Nb₃Sn Polished with CBP

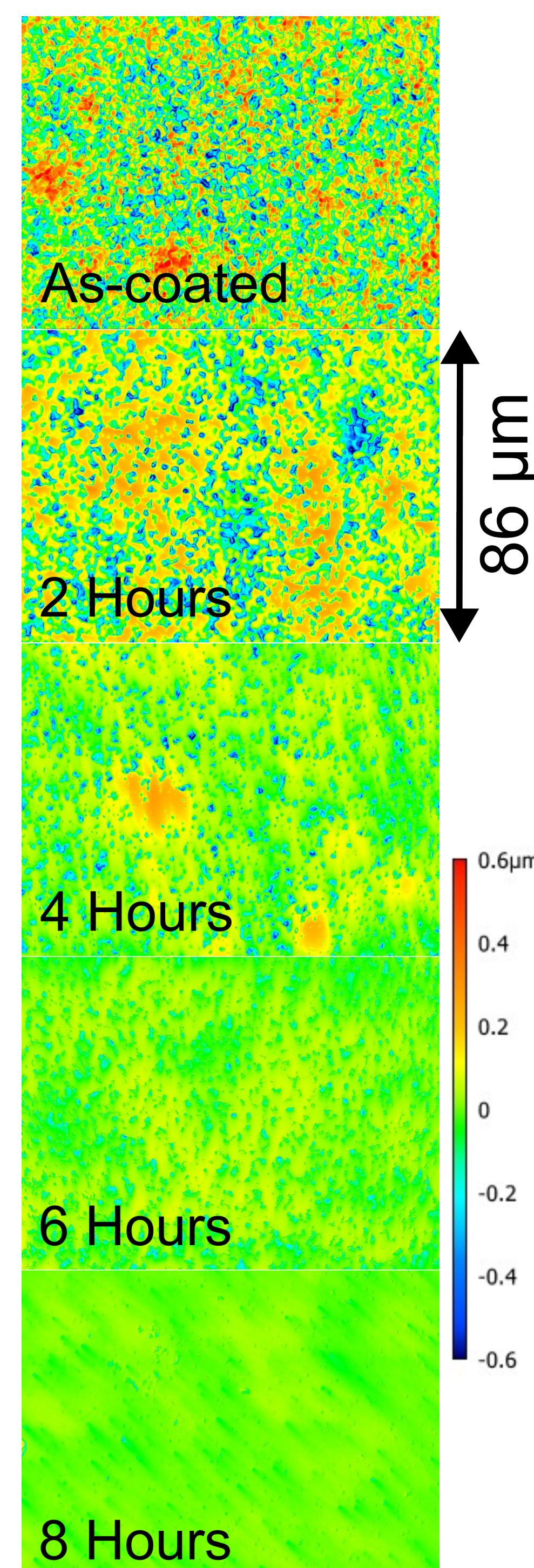


Figure 2. Surface height maps of Nb₃Sn polished between 0 to 8 hours.

To evaluate the performance of CBP, the surface roughness of the polished samples is measured using con-focal laser microscopy and the surface is analyzed using scanning and transmission electron microscopy (SEM and TEM). The material removal rate is measured using focused ion-beam tomography.

- Material is preferentially removed from the highest point on the surface.
- The material removal rate is measured to be 170 nm per hour.
- After 6 hours of polishing, the surface roughness is comparable to the surface roughness of the well-performing, thinly coated Nb₃Sn coatings created at Fermilab[1].
- After 8 hours of polishing, the surface roughness is comparable to a typical niobium surface after EP.

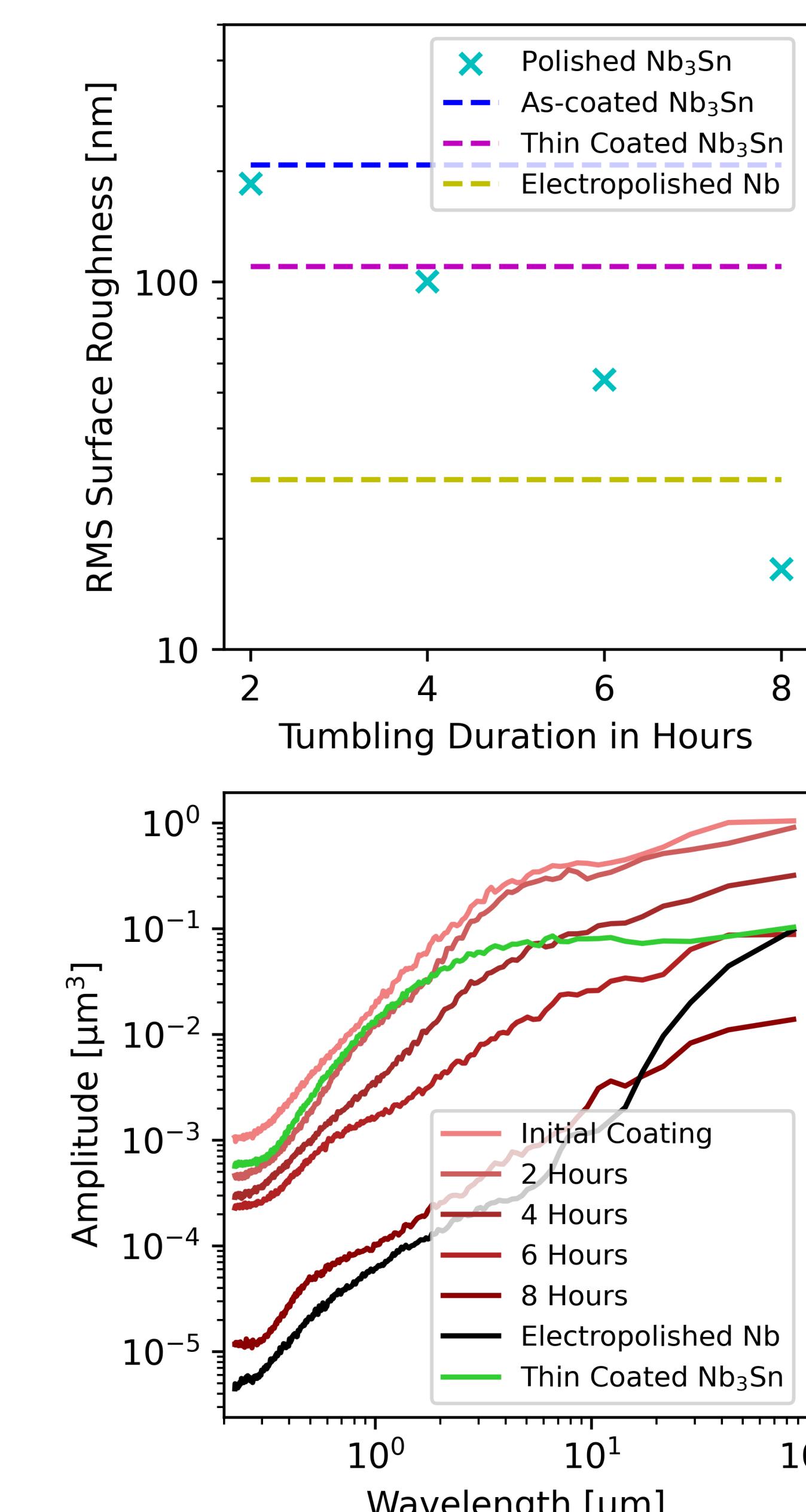


Figure 3. Surface roughness of Nb₃Sn over time (top). The power spectral density (PSD) of the surface profiles, electropolished Nb, and thinly coated Nb₃Sn[1].

RF Performance Improvement from Polishing

A Nb₃Sn-coated single-cell 1.3 GHz cavity was polished for 4 hours followed by high-pressure water rinsing and ultrasonic cleaning for 30 minutes to remove any residual abrasive material. A conservative polishing time was used to minimize the possibility of removing the Nb₃Sn film while still providing a considerable improvement in surface roughness.

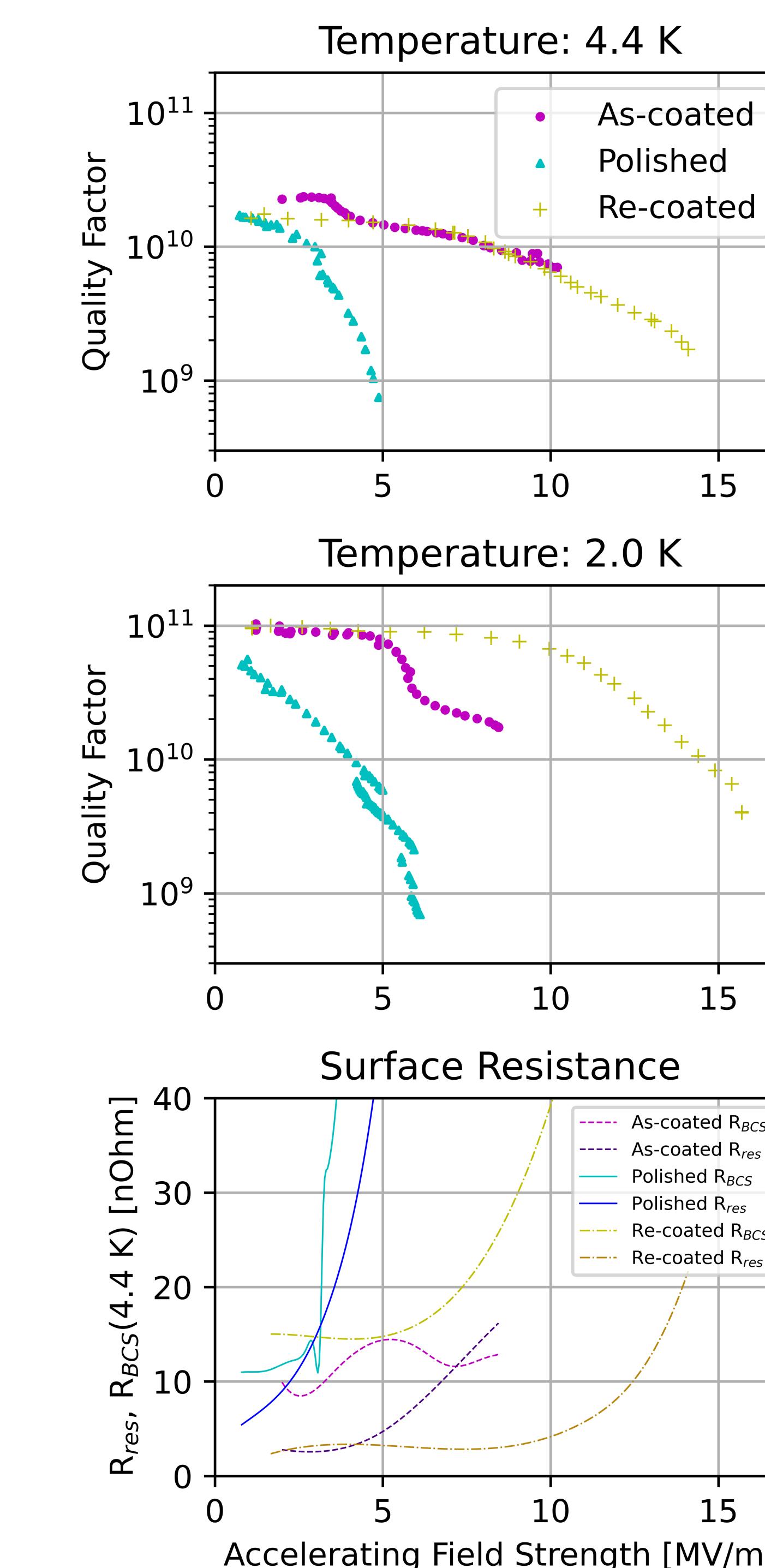


Figure 4. The RF performance of the Nb₃Sn-coated SRF cavity before and after mechanically polished and after a re-coating treatment.

- The resulting cavity surface had a mirror-like appearance.
- The as-coated performance was poor, with a maximum gradient of around 10 MV/m and Q of 10¹⁰ at 4.4 K.
- After polishing, the cavity exhibited Q-slope and the maximum gradient was only 5 MV/m.
- A re-coating procedure was applied to repair surface damage and subsurface defects at 1,000 °C, using one third of the normal amount of tin and no SnCl₂.
- After the re-coating procedure, the Q-slope was ameliorated, and the maximum accelerating gradient increased to 15 MV/m.
- The quality factor of the cavity was also improved over the as-coated state at 2.0 K, but not at 4.4 K.

Bibliography

- [1] Sam Posen, Jaeyel Lee, David N Seidman, Alexander Romanenko, Brad Tennis, OS Melnychuk, and DA Sergatskov. Advances in nb3sn superconducting radiofrequency cavities towards first practical accelerator applications. *Superconductor Science and Technology*, 34(2):025007, 2021.