Detailed Nb Surface Morphology Evolution During Electropolishing for SRF Cavity Production

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Introduction:

Electropolishing of niobium is currently an important part of attaining the best performance of SRF cavities. We endeavour to develop sufficient understanding of the process dynamics to gain predictive power over specific topographies subjected to controlled electropolishing conditions. This work examines the evolution of highly reproducible Nb surface morphology produced by centrifugal barrel polishing (CBP) of fine-grain and single-crystal material as this material is electropolished under different well-controlled conditions. The morphology evolution of Nb surface has been described using a combined approach of scaling analysis and predictions of the electropolishing theory. A preliminary computational model has been developed that simulates the evolution of specific topography of a niobium surface under parameterized conditions. This work is expected to lead to the direct linking of starting surface morphology specification, specific processing protocol, and consistently attained finished surface condition

Scaling Formalism and Mathematical Theory of Electropolishing

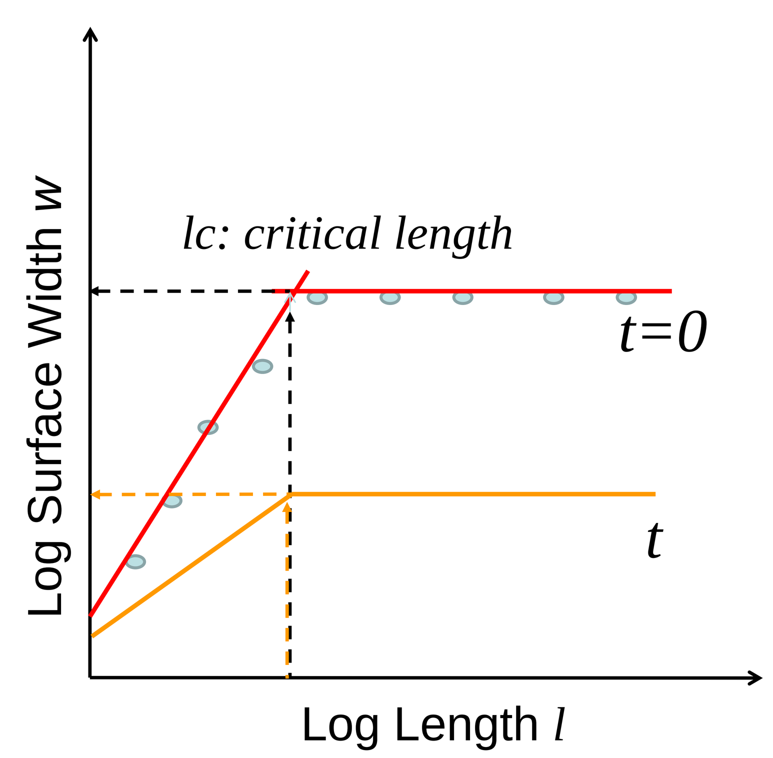
$$w(l,t) \equiv \sqrt{\frac{1}{L}\sum_{i=1}^{L}[h(r,t)-\bar{h}(r,t)]^2}$$

Scaling Analysis

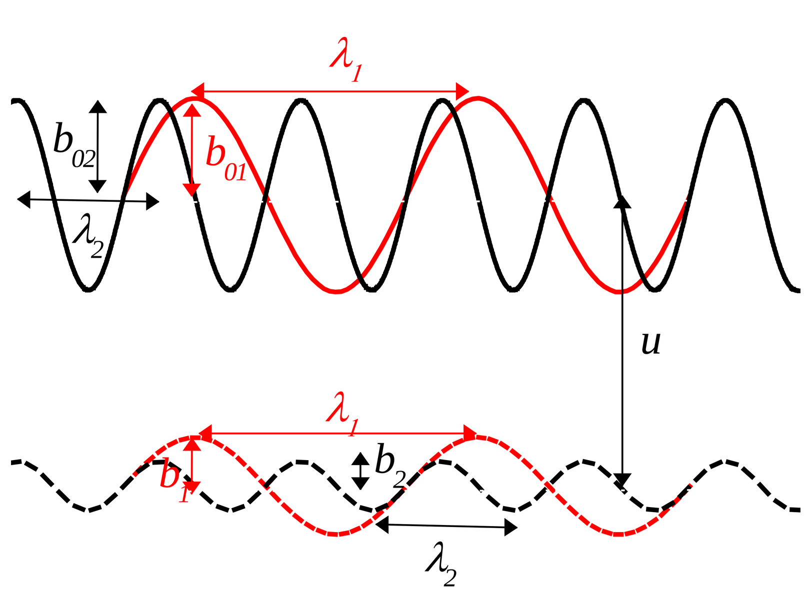
For $l \le l_C$, $w \sim l^{\alpha}$ (α : roughness exponent)

For $l \ge l_C$, $w = w_{sat} = const.$

Ref : F. Family and T. Vicsek, J. Phys. A, 18, L75 (1985).



The surface is treated as self affined fractal geometry . The morphology evolution of niobium surface during the electropolishing could be described using a combined approach of scaling analysis and predictions of the electropolishing theory.



Ref : C. Wagner, J. Electrochem. Soc. 101 225 (1954).

$$b(t) = b_0 \cdot \exp\left(-\ u \cdot \frac{t}{\lambda}\right)$$

$$u = \frac{2\pi \cdot j \cdot M}{nF \cdot \rho_M}$$

$$u = 2\pi \cdot removal\quad rate\,[\mu m \cdot s^{-1}]$$

The surface corrugations are presented with periodic sine wave function with an amplitude $\sqrt{\omega}$, wavelength λ, and the average displacement of the surface *u*.

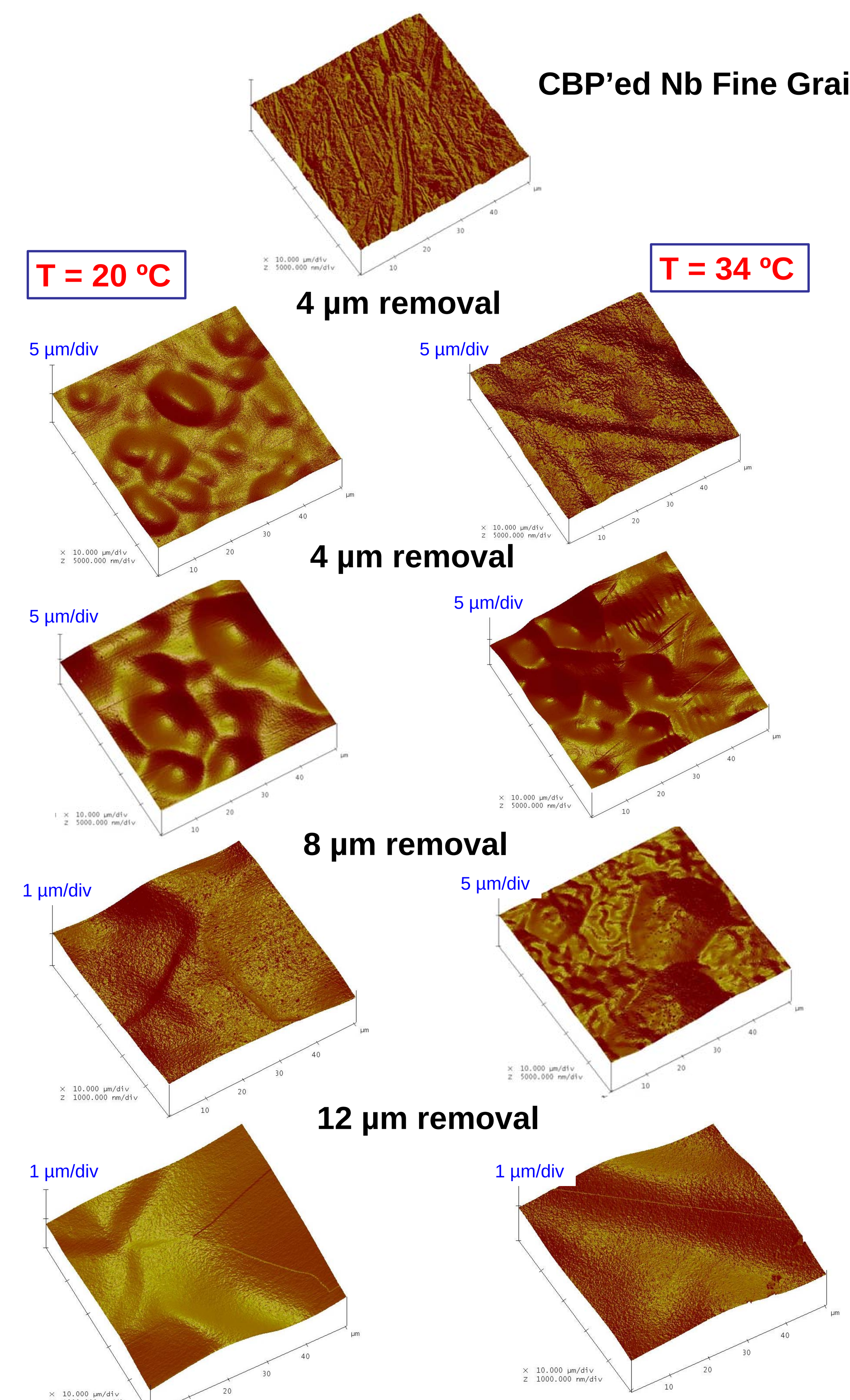
$$\frac{w_{sat}(l_C,0)}{w_{sat}(l_C,t)} = \exp\left(-u\frac{t}{2l_C}\right),$$

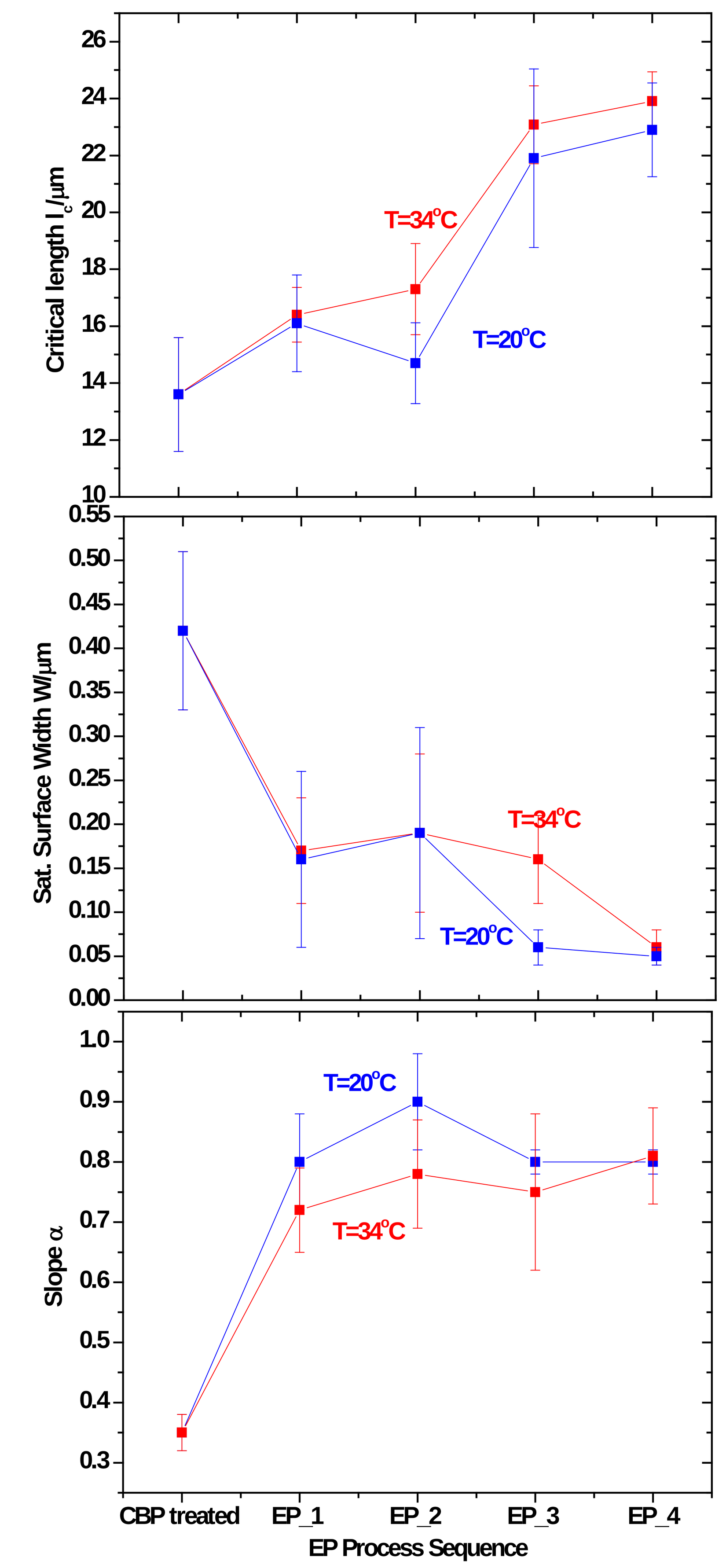
$$\frac{w(l,0)}{w(l,t)} = \exp\left(-u\frac{t}{\lambda}\right)$$

$$\exp\left(-u\frac{t}{2l_C}\right) = \exp\left(-u\frac{t}{\lambda}\right)\cdot\left(\frac{l_C}{l}\right)^{\alpha(t)-\alpha_0}$$

$$\lambda \approx \frac{1}{\frac{1}{2l_C} - \frac{B}{u}\ln(l_C/l)}, \quad \alpha(t) = \alpha_0 - B\cdot t$$

Fine CBP'ed Nb Surface Morphology Evolution During EP Under Different Temperatures





Electropolishing was done at 20±1˚C and 34±1˚C respectively with 10 volts applied voltage. The removals are kept same for different temperatures under different durations EP: EP_1 ~ 4µm; EP_2 ~ 4µm; EP_3 ~ 8µm; EP_1 ~ 12µm. ** The CBP'ed samples were provided by Kenji Saito and Fumio Furuta in KEK .*

Simulation Algorithm for Nb Electropolishing

image (t=0) → image 2D FFT → wavelength selection

Algorithm l_c, B, ψ ***(experimental measurements)***

$$\sqrt{\lambda_l \cdot \lambda_w} = 2l \ge 2l_C$$

$$\omega(t) \approx \omega_0 \cdot \exp\left(-u\frac{t}{2l_C}\right)$$

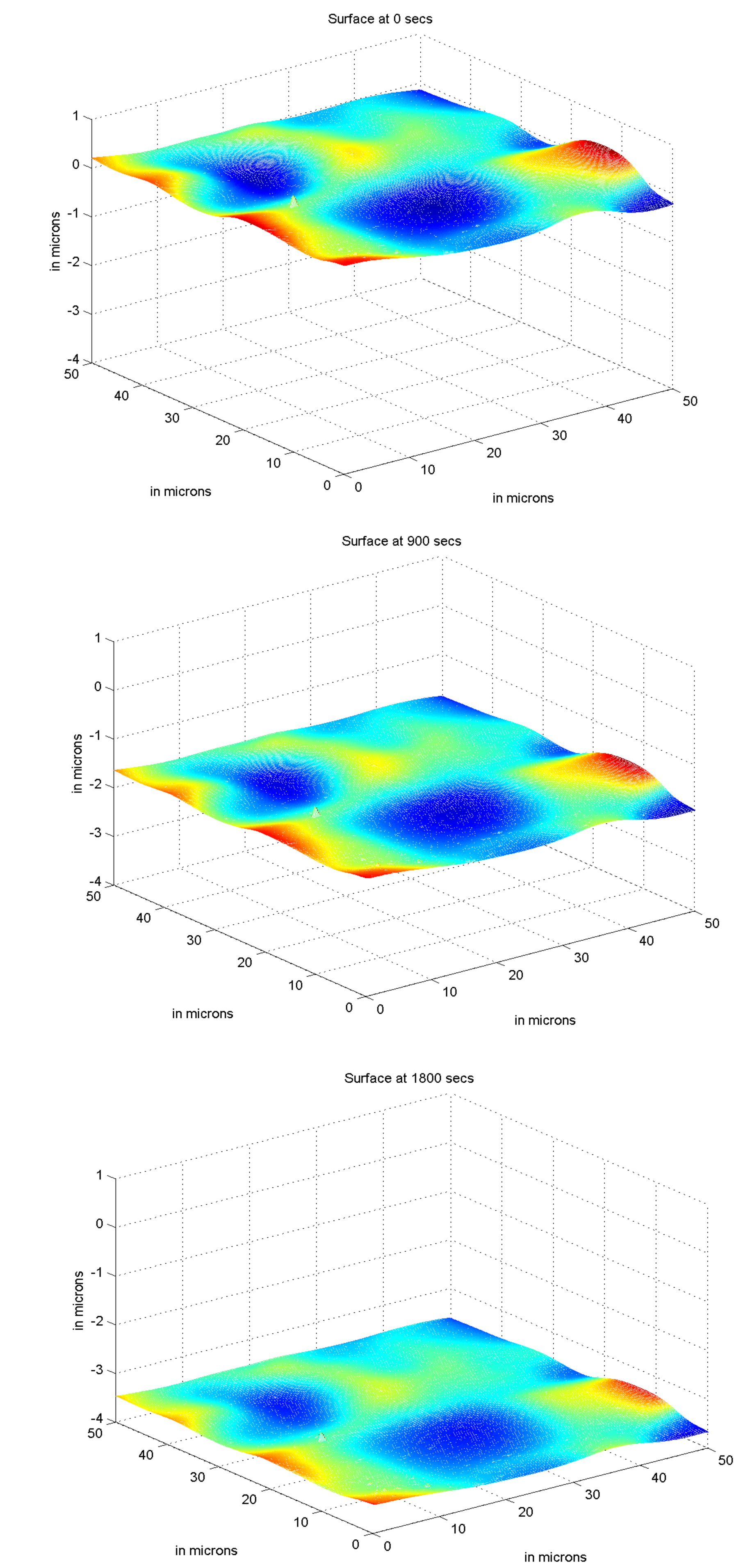
$$\sqrt{\lambda_l \cdot \lambda_w} = 2l \le 2l_C;$$

$$\lambda = \frac{1}{\frac{1}{2l_C} - \frac{B}{u}\ln\left[\frac{2l_C}{\sqrt{\lambda_l \cdot \lambda_w}}\right]}$$

$$\omega(t) \approx \omega_0 \cdot \exp\left(-u\frac{t}{\lambda}\right)$$

new data matrix after time t → Inverse FFT → Image (t)

Simulations of the Nb Surface Morphology Evolution During Electropolishing



For ideal Nb electropolishing

$$\Rightarrow \frac{1}{2l_C} - \frac{B}{\Psi}\ln(l_C/a) = 0$$

$$\Rightarrow B = \frac{\psi}{2l_C}\cdot\frac{1}{\ln(l_C/a)}$$

$$a_{Nb} = 0.34\times10^{-9}m$$

From limited analysis of AFM measurements, we noticed that B is function of temperature B↓ for T↑, further studies will be reported later.

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