Computational Algorithm Predicting Surface Morphology Evolution During Electropolishing

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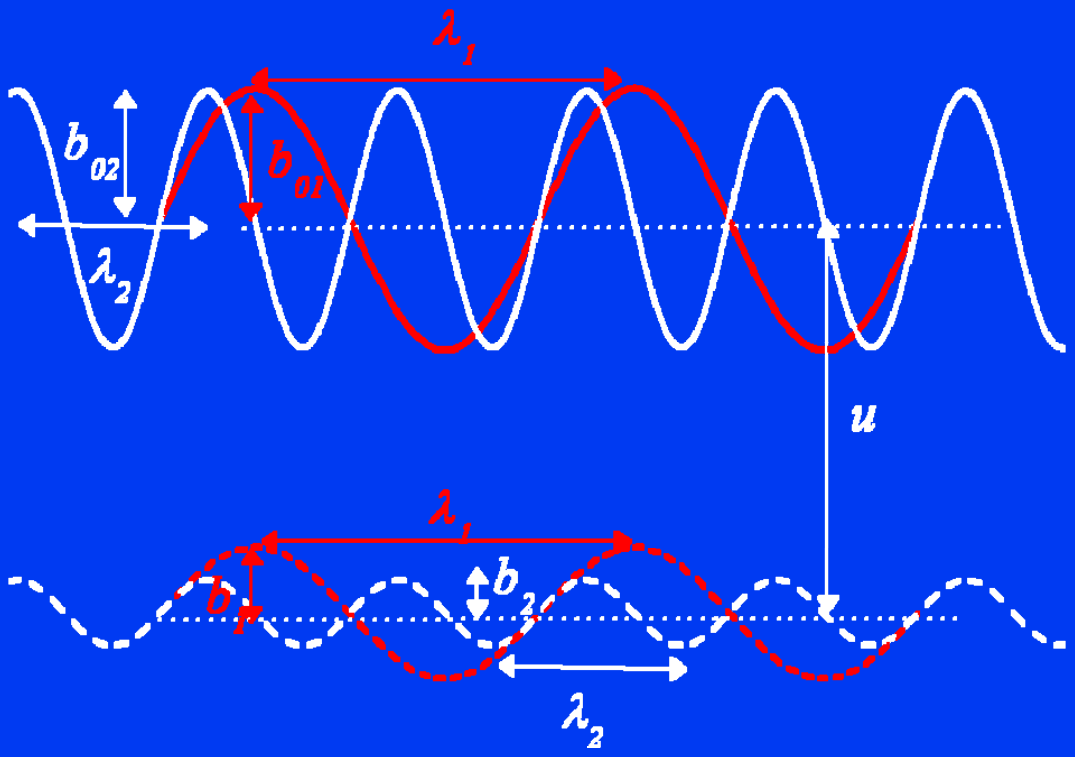
Mathematical Theory of Electropolishing



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

$$\Psi = \frac{2\pi \cdot j \cdot M}{nF \cdot \rho}$$

M

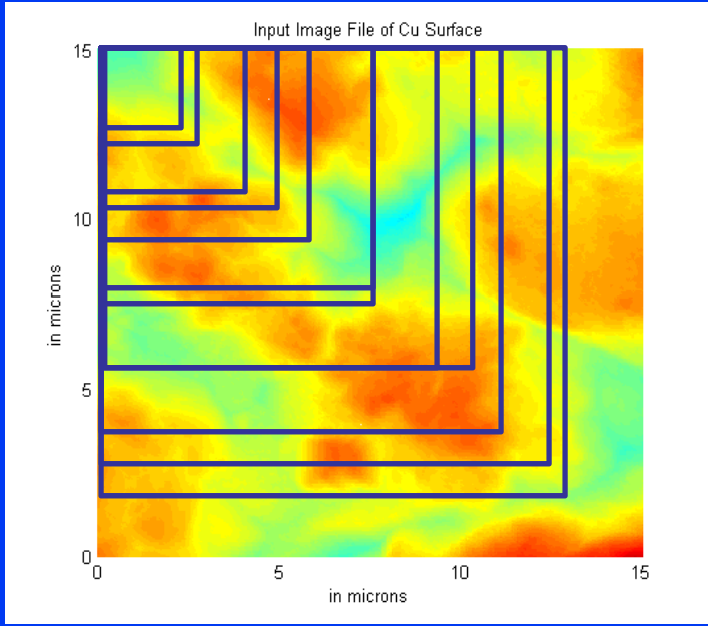
important:

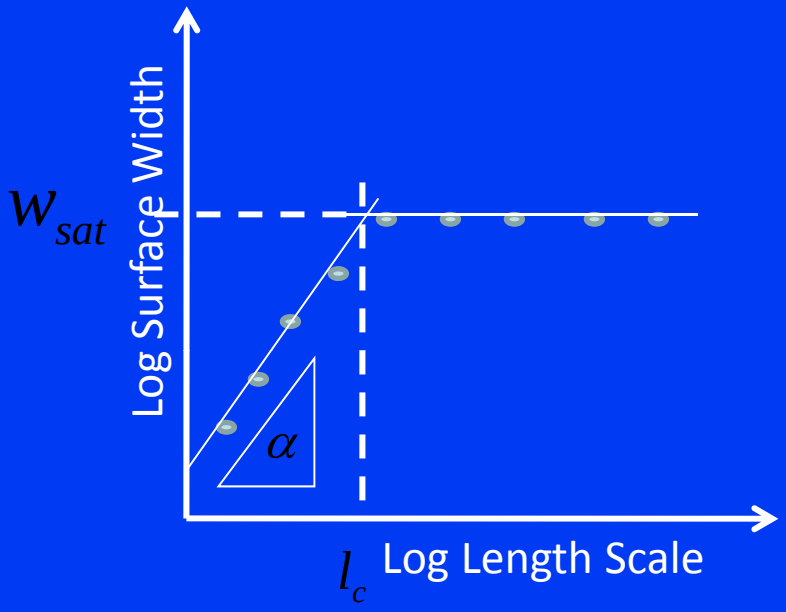
$b(t)\downarrow \quad for \quad \lambda\downarrow$

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

Scaling Analysis of AFM Data

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





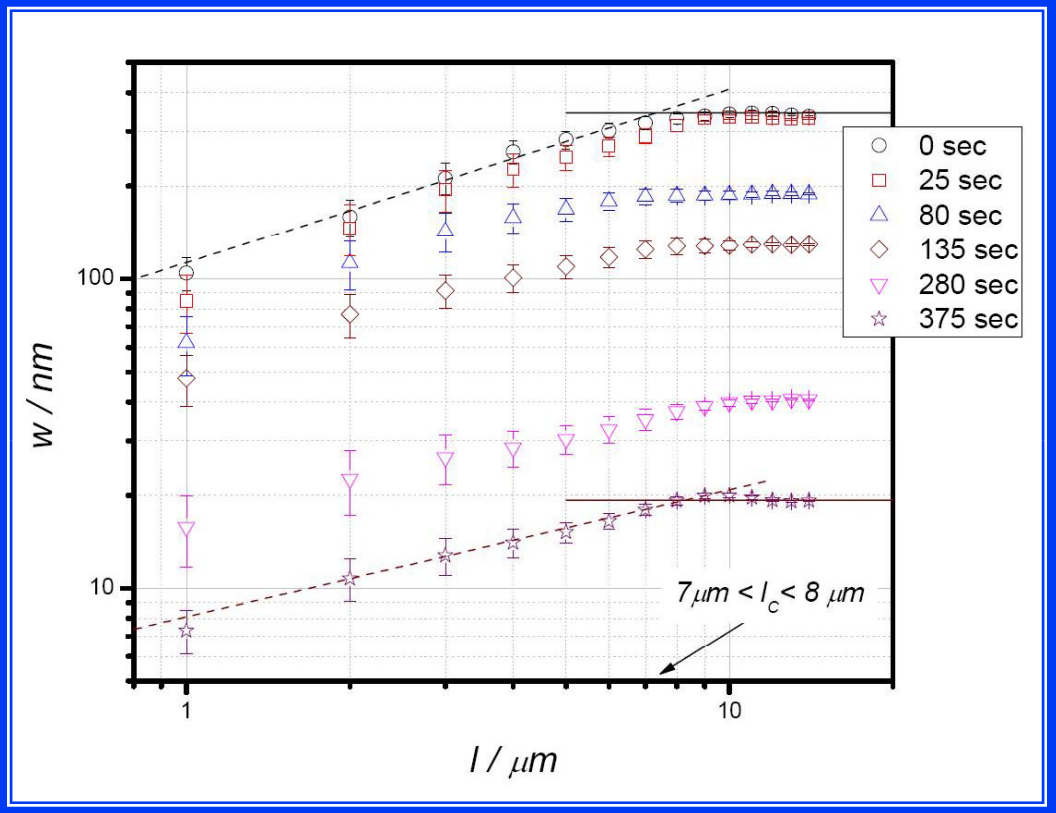
SCALING ANALYSIS :

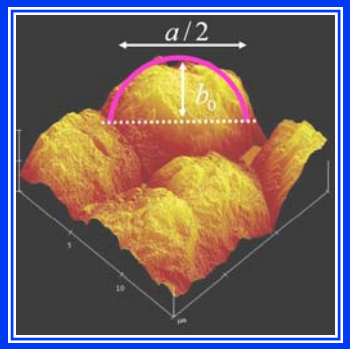
For $l \le l_C$, $w \sim l^{\alpha}$;

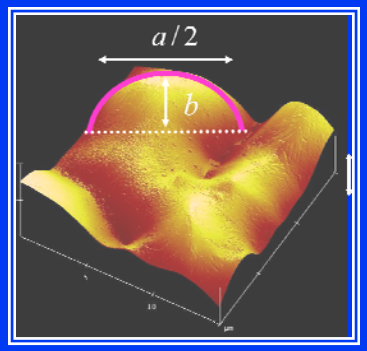
For $l \ge l_C$, $w = w_{sat} = const.$

***F. Family, T. Vicsek, J. Phys. A 18, L75 (1985).**

AFM Results and Discussion for Cu Surface







$$l_C(t) \approx const \approx 7.5\mu m$$

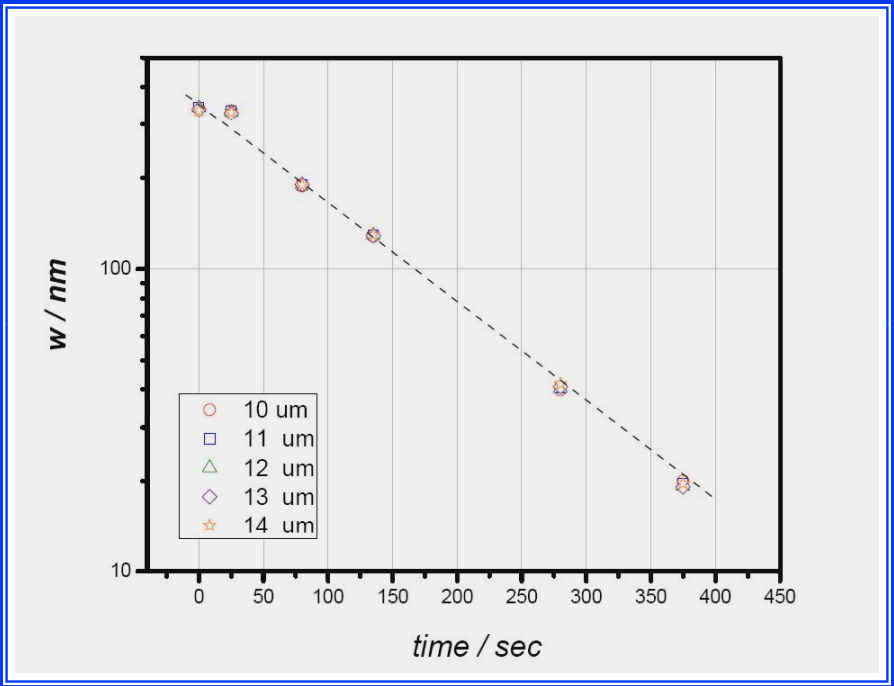
$$\alpha(t) \neq const; \alpha(t) = f(t)$$

$l_C \approx$ *lateral size of the grains*

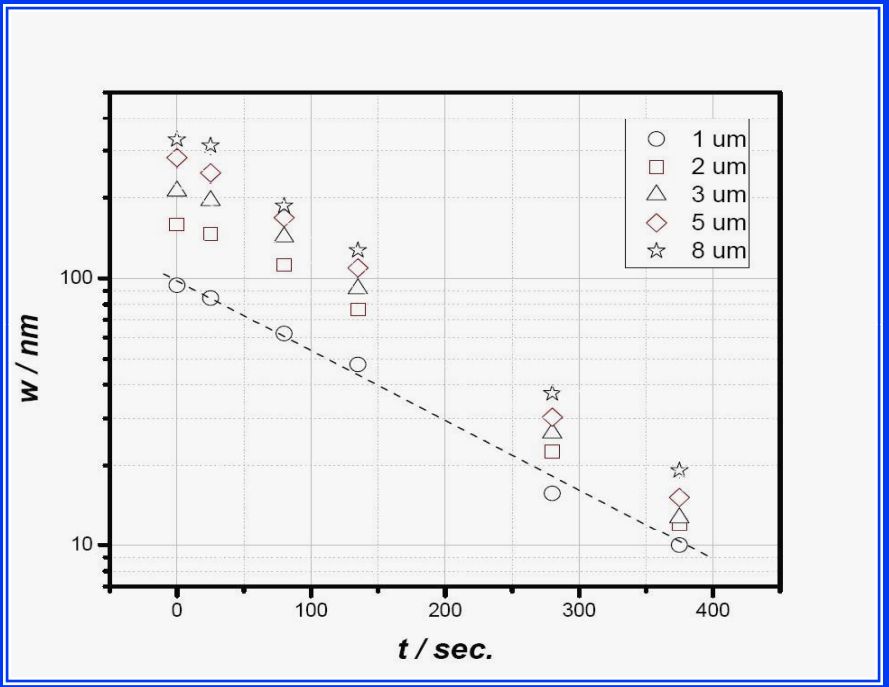
S. Shivareddy, S.-E. Bae and S. R. Brankovic, *Electrochem. Solid State Lett., 11, 1 (2008).*

AFM Results and Discussion for Cu Surface

For $l \geq l_C$ case :



For $l \leq l_C$ case :



$$\lambda \approx const \approx 2l_C \approx 15.5\mu m$$

$$l \leq l_C,\ \lambda \neq const, \lambda \uparrow,\ l \downarrow$$

$$w(t) = w_0 \cdot \exp\left(-\Psi \cdot \frac{t}{\lambda}\right)$$

Synergy Between Scaling Formalism and Mathematical Theory of Electropolishing

$$\Rightarrow \alpha(t) = \alpha_0 - Bt$$

$$\Rightarrow \lambda \approx \frac{1}{\frac{1}{2l_C} - \frac{B}{\psi}\ln(l_C / l)}$$

Scaling Functions (Electropolishing)

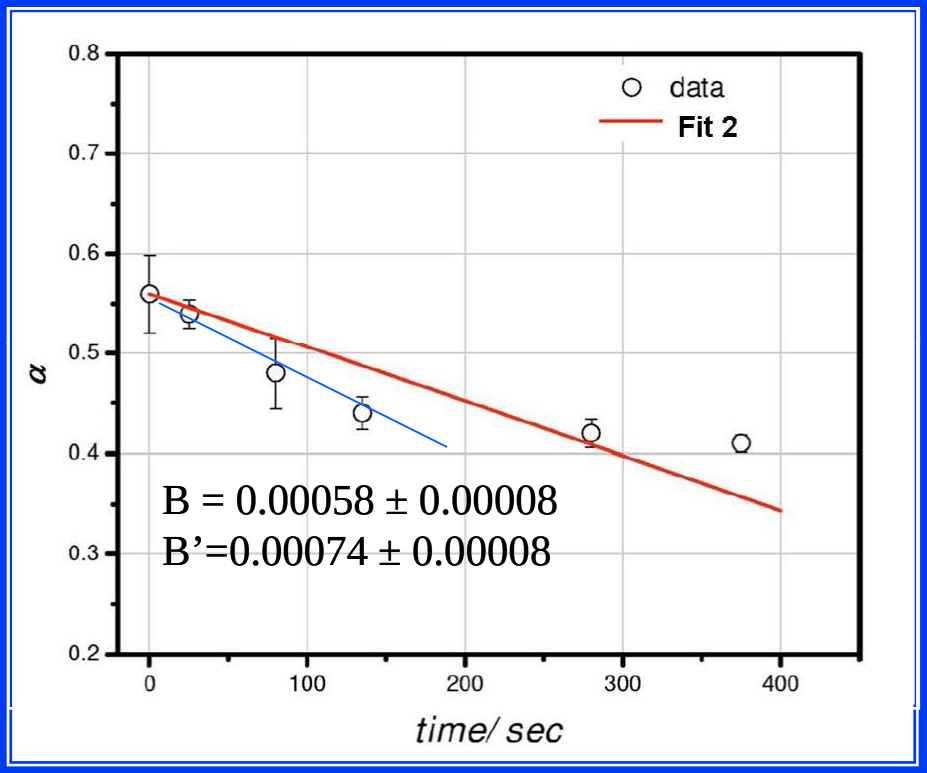
$$w(l \le l_C, t) \approx w(l \le l_C, 0)\exp\left(-\psi \frac{t}{\lambda}\right)$$

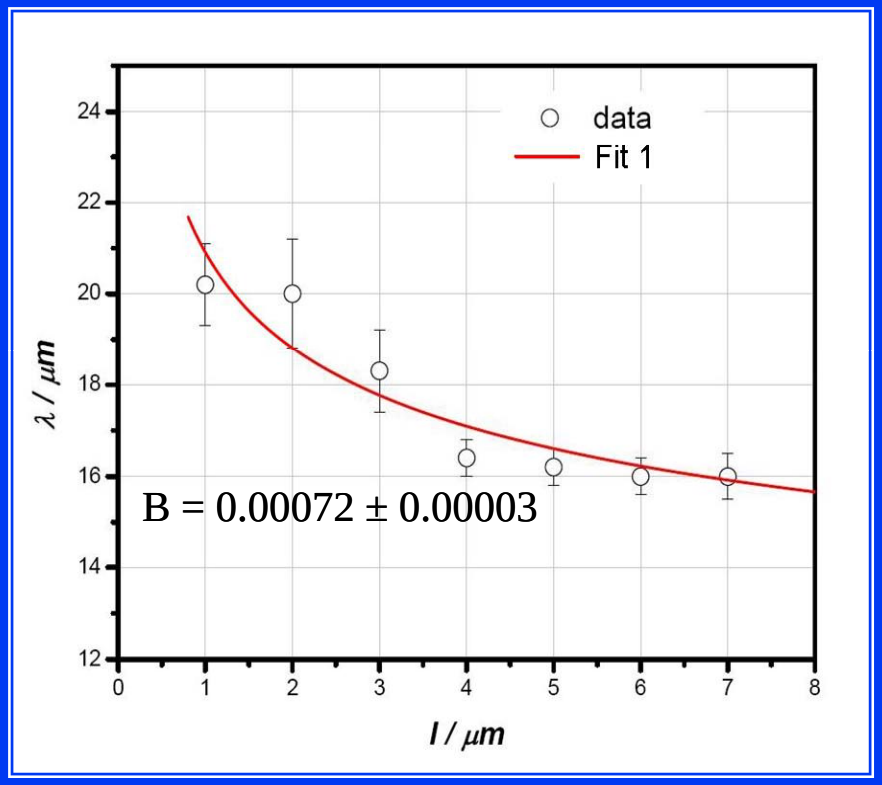
$$w(l \ge l_C, t) \approx w(l \ge l_C, 0)\exp\left(-\psi \frac{t}{2l_C}\right)$$

$$\Rightarrow \lambda \to \infty \Rightarrow \frac{1}{2l_C} - \frac{B}{\psi}\ln(l_C / a) = 0$$

$$B = 0.00073 s^{-1}$$

Results Analysis: λ vs. l for $l \leq l_C$ and $\alpha = f(t)$





$$\alpha(t) = \alpha_0 - Bt$$

$$\lambda \approx \frac{1}{\frac{1}{2l_C} - \frac{B}{\psi}\ln(l_C / l)}$$

Theoretical Estimate: B = 0.00073s^{-1}

Simulation Algorithm for Cu Electropolishing

Image (t=0)

Image 2D FFT

Algorithm (l_C, B, Ψ)

wavelength selection

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

$$b(t) \approx b_0 \cdot \exp\left(-\psi \frac{t}{2l_C}\right)$$

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

$$c(t) \approx c_0 \cdot \exp\left(-\psi \frac{t}{\lambda}\right)$$

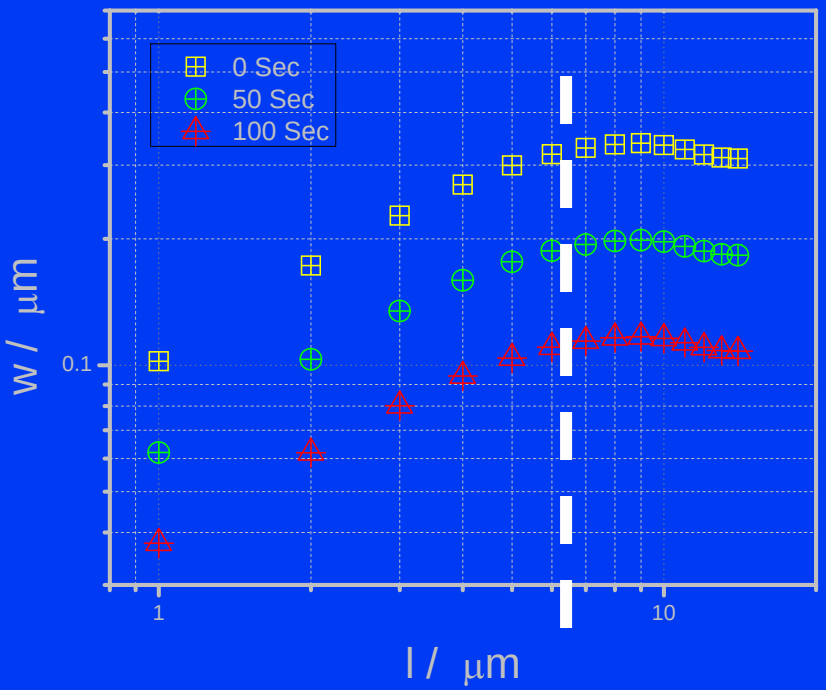
new data matrix after time t

Inverse FFT

Image (t)

Simulation Algorithm - Results

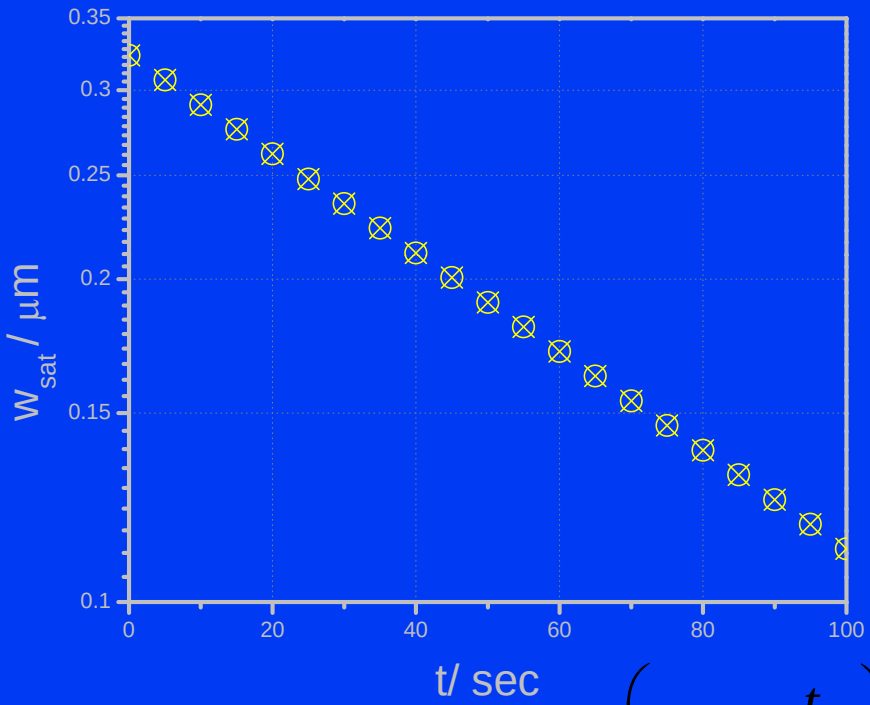
$w = f(l,t)$



l_C

$l_C = 5.3\,\mu m$

$w_{sat} = f(t)$

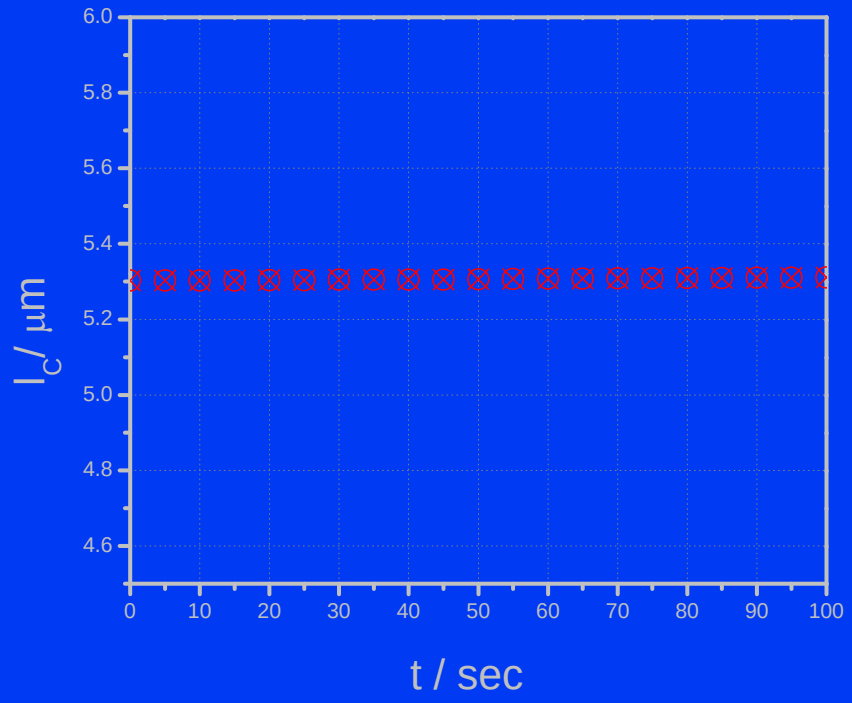


$$w_{sat}(t) = w_{sat}(0) \cdot \exp\left(-\psi \cdot \frac{t}{2l_C}\right)$$

$\psi = 0.115 \mu m s^{-1}$

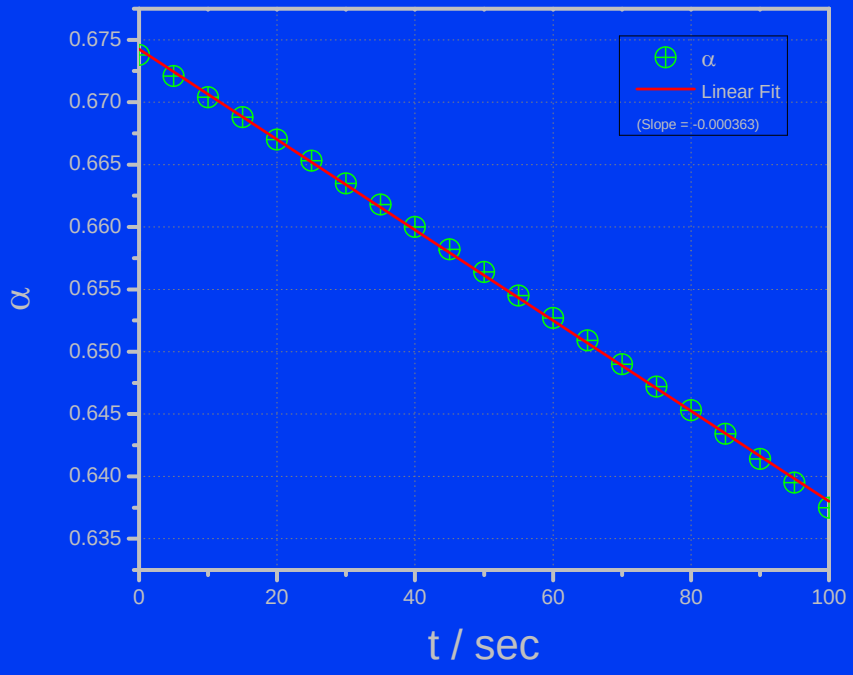
Simulation Algorithm - Results

$$l_C(t) = const$$



$$l_C = 5.3\,\mu m$$

$$\alpha = f(t) = \alpha_0 - Bt$$



$$B = 0.00038\,s^{-1}$$

Real Time Simulations of the Cu Surface Morphology Evolution During Electropolishing

(2+1) D surface

Summary

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- Synergistic combination of scaling analysis and mathematical theory of electropolishing yields the scaling functions that can be conveniently used for development of the simulation algorithm predicting surface morphology evolution during electropolishing.
- The simulation algorithm shod be generally applicable for any electropolishing process including Nb and should help in overall optimization of polishing process (time, current, etc..)
- The quantitative evaluation of the material preparation/processing and resulting polishing results should be possible using this algorithm.
- The quantitative evaluation of current distribution effects (primary and secondary) during electropolishing of Nb SRF cavities should be possible using this algorithm
- Polishing of Cu SRF like shape modules/shells and subsequent coating with Nb layer using electrochemical deposition ?

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