Fermilab

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Simulation of Nb_3Sn layer deposition in Nb cavities

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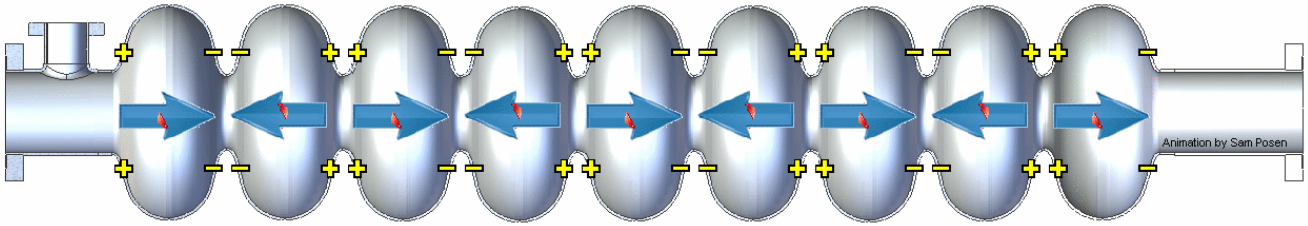
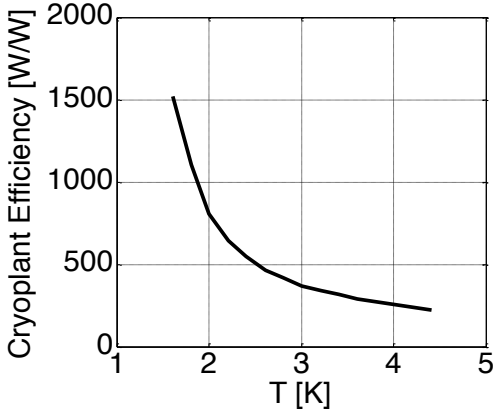
SRF Cavity

Courtesy of Sam Posen



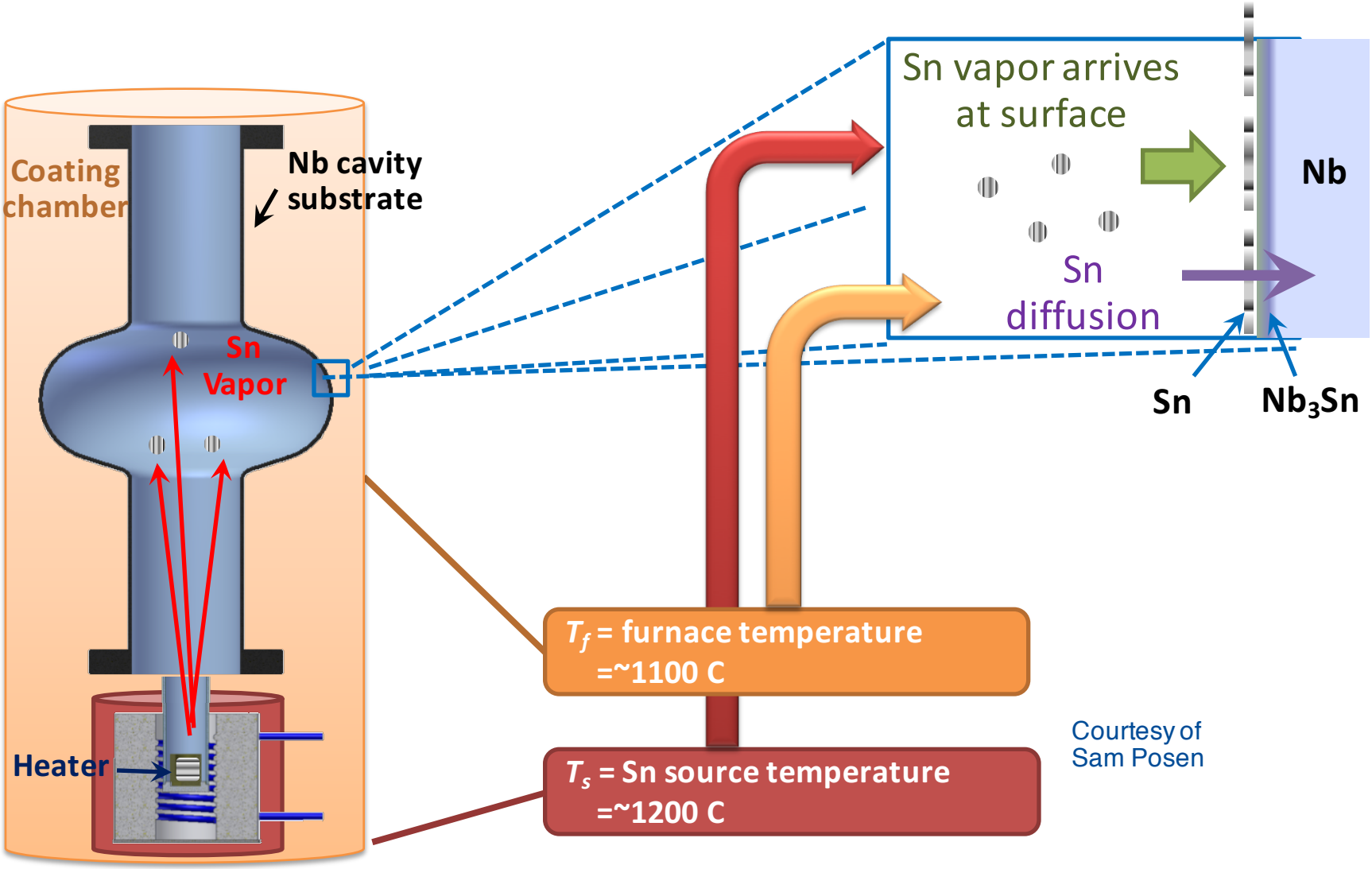
Cryoplants for large installations cost ~$100 million and require MW of power

- SC materials works at cryogenic temperatures => High cost and huge power requirements
- Possible solution: replacing standard Nb cavities with ones coated with a low-dissipation superconductor Nb3Sn
- One of main criteria: ability to fabricate the layer with a high degree of uniformity.



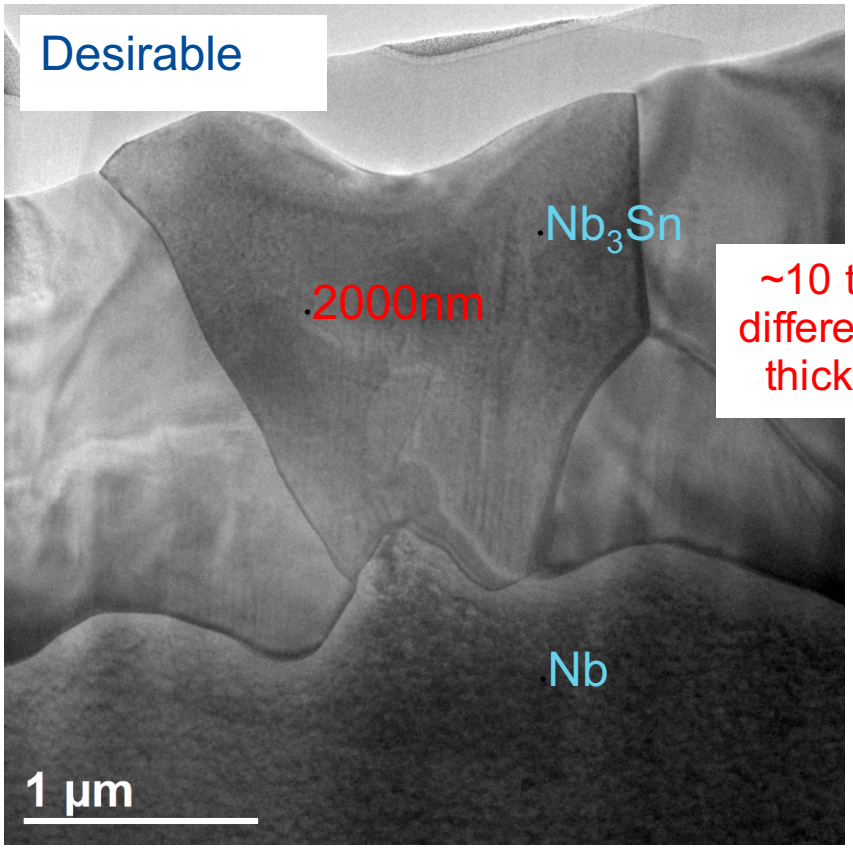
Motivation: Simulate deposition process in order to get higher uniformity

Coating Mechanism: Vapor Diffusion

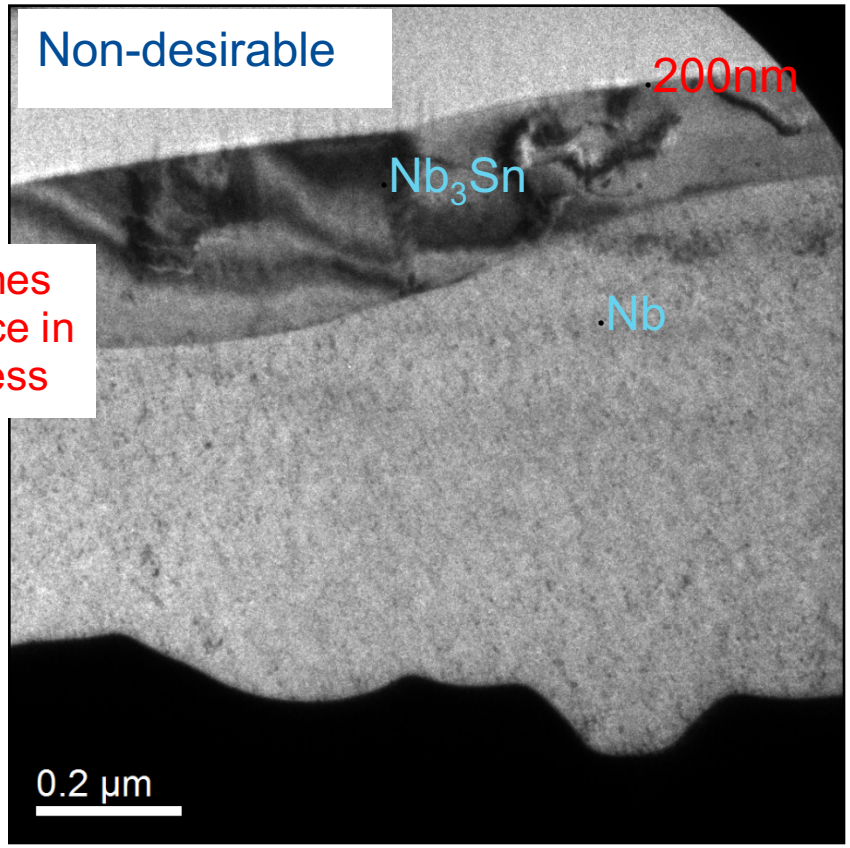


Courtesy of Sam Posen

Results of experiment



~10 times difference in thickness



Courtesy of Yulia Trenikhina | Thin Film Workshop 2016

Model

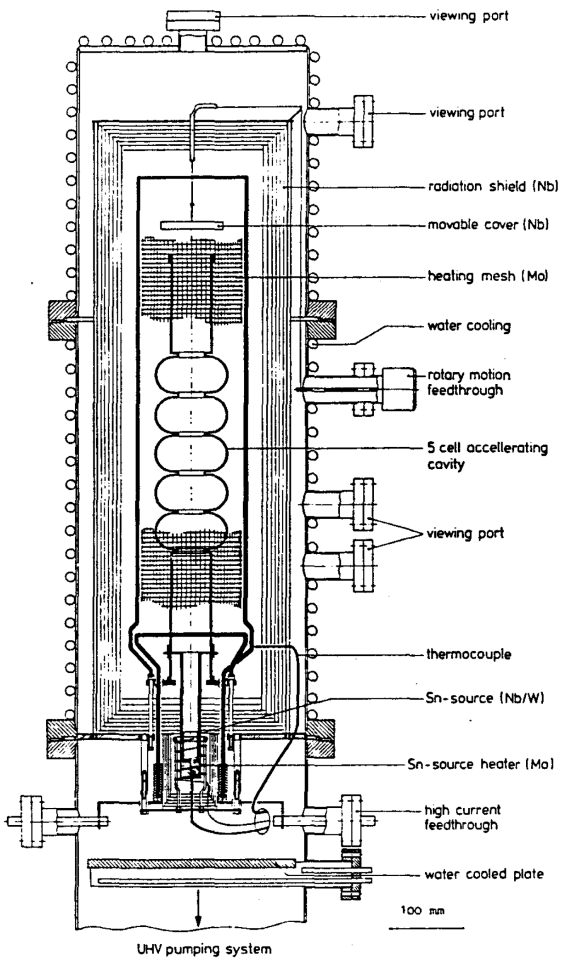


Fig. 1 Nb3Sn coating furnace for 3 GHz accelerating cavities.

From M.Peiniger and et al. "Work on Nb3Sn cavities at Wuppertal" Proc.SRF3, Argonne, pp. 503-532, 1988

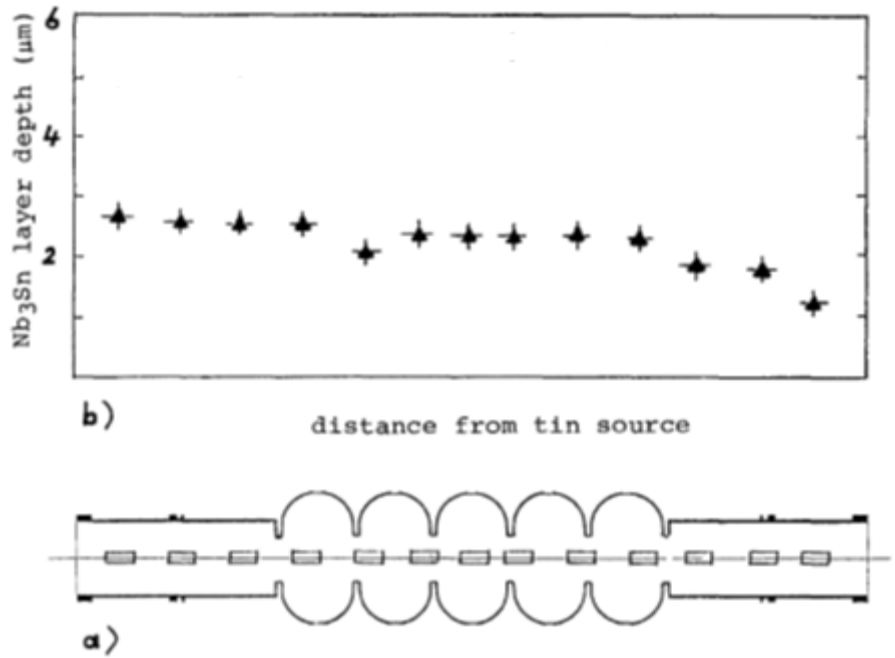
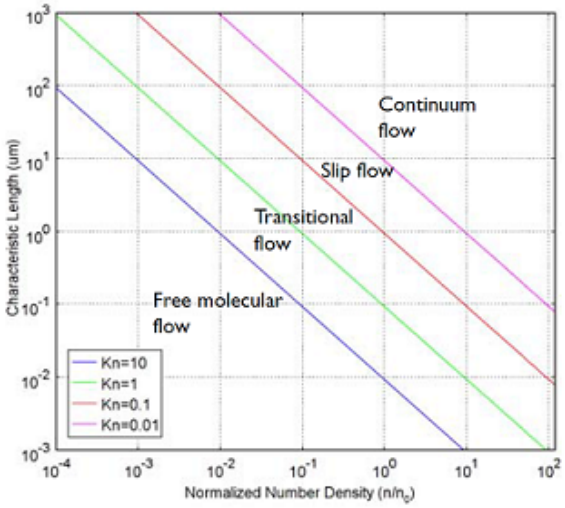


Fig.2 Nb3Sn layer thickness of samples coated together with a five cell 3 GHz cavity as a function of distance to the tin source after an evaporation time of 15 hours

Model

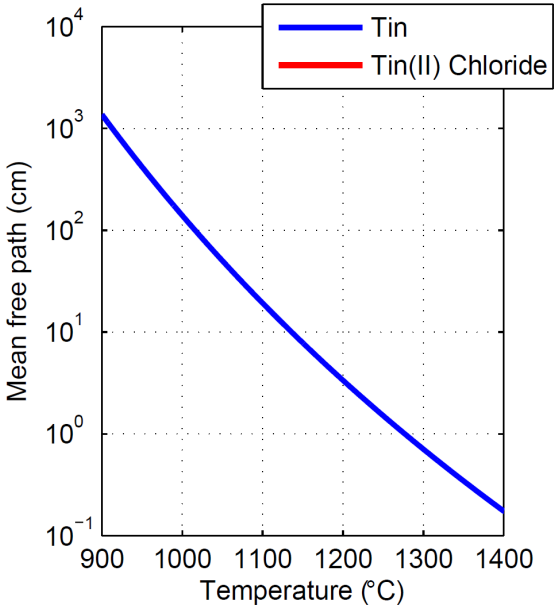


- Continuum flow (Kn<0.01)
- Slip flow (0.01<Kn<0.1)
- Transitional flow (0.1<Kn<10)
- Free molecular flow (Kn>10)

COMSOL Multiphysics

$$\frac{\partial f}{\partial t} + \frac{\boldsymbol{p}}{m} \cdot \frac{\partial f}{\partial \boldsymbol{r}} + \boldsymbol{F} \cdot \frac{\partial f}{\partial \boldsymbol{p}} = -\frac{f - f^{(eq)}}{\tau}$$

Boltzmann equation in BGK approximation

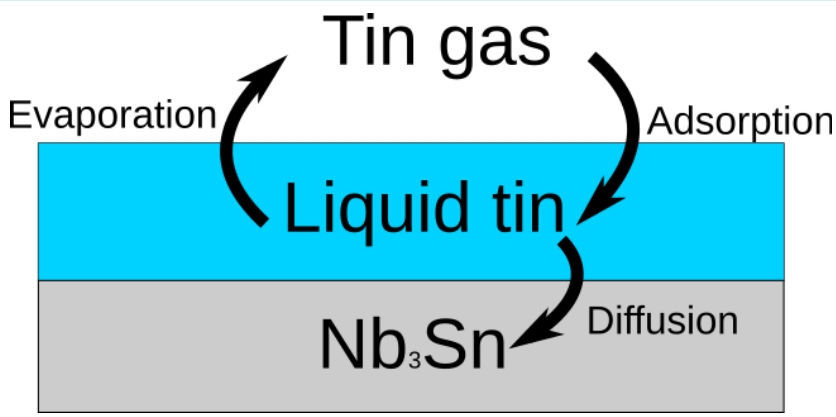


The mean free path of tin as a function of temperature

From S. Posen and D. L. Hall submitted SUST (2016)

Model

From M.Peiniger and et al. "Work on Nb3Sn cavities at Wuppertal" Proc.SRF3, Argonne, pp. 503-532, 1988



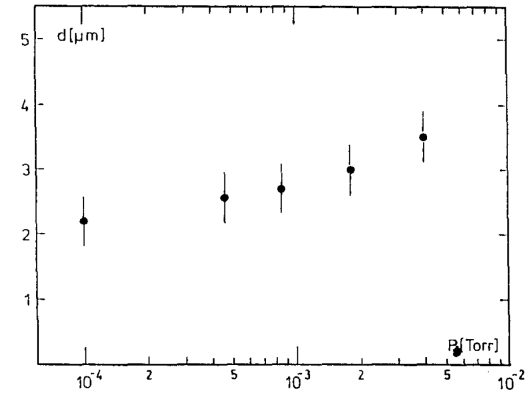


Fig.5 Dependence of the thickness of the Nb3Sn layer on the tin vapor pressure.

Adsorption (evaporation) process rate depends on the gas pressure near the surface (saturated), and the rate is given by:

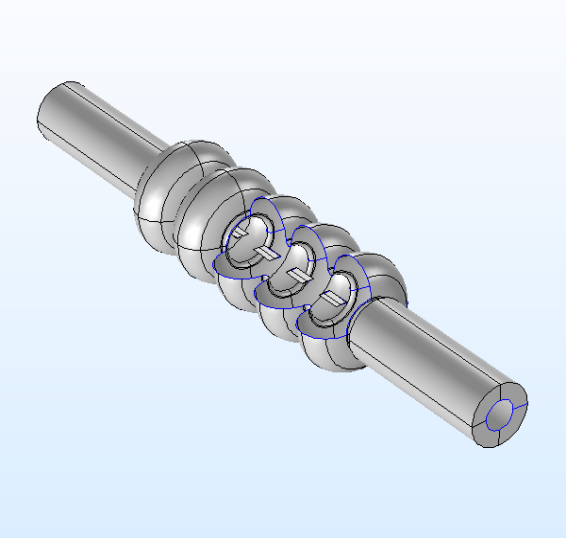
$$R_{ads/evap} = \frac{S \cdot P}{\sqrt{2\pi MRT}} \left[\frac{\mathrm{mol}}{\mathrm{m}^2 \cdot \mathrm{s}} \right]$$

Landau, Lifshitz, Vol. 5

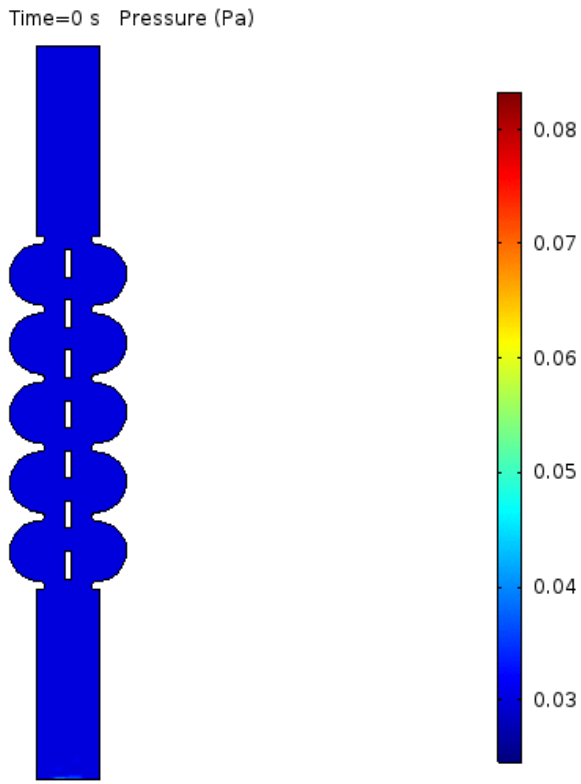
Diffusive process can be modelled by following equation:

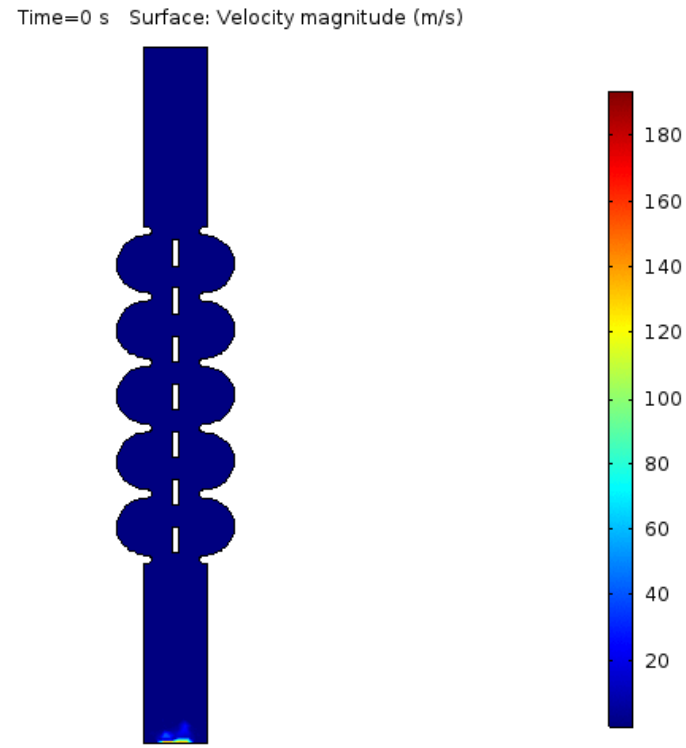
$$R_{diff} = \frac{\rho_s}{M_s} \frac{\alpha}{\tau_0} h \left(\frac{h_0}{h} \right)^{1/\alpha}$$

where $h(\tau) = h_0(\tau/\tau_0)^\alpha \qquad \alpha \approx 0.38$



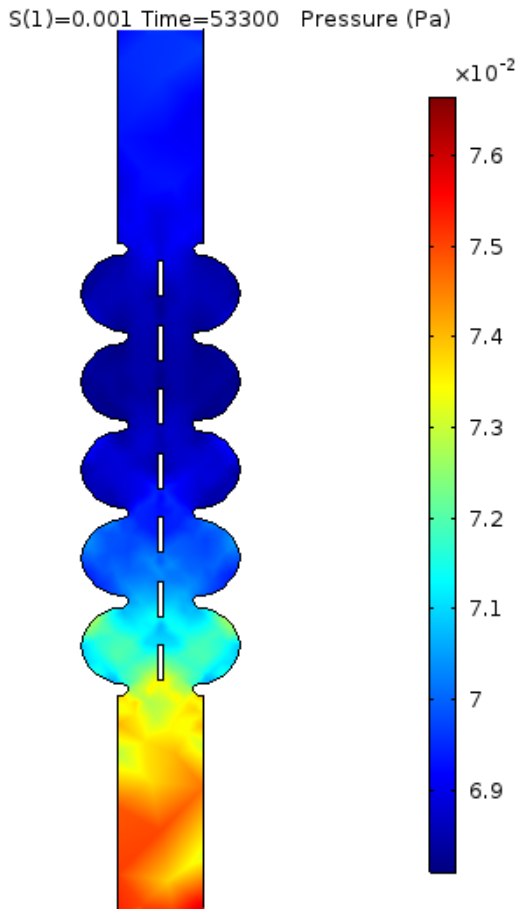
Pressures and velocities

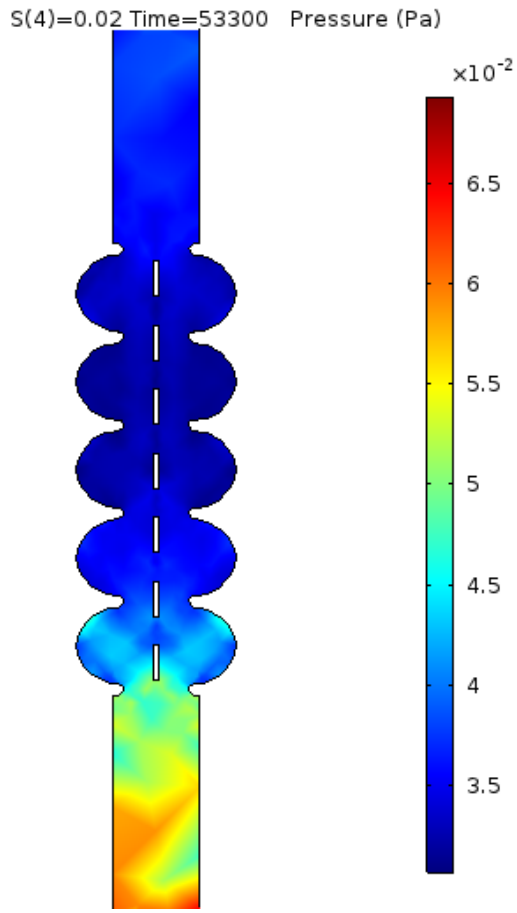


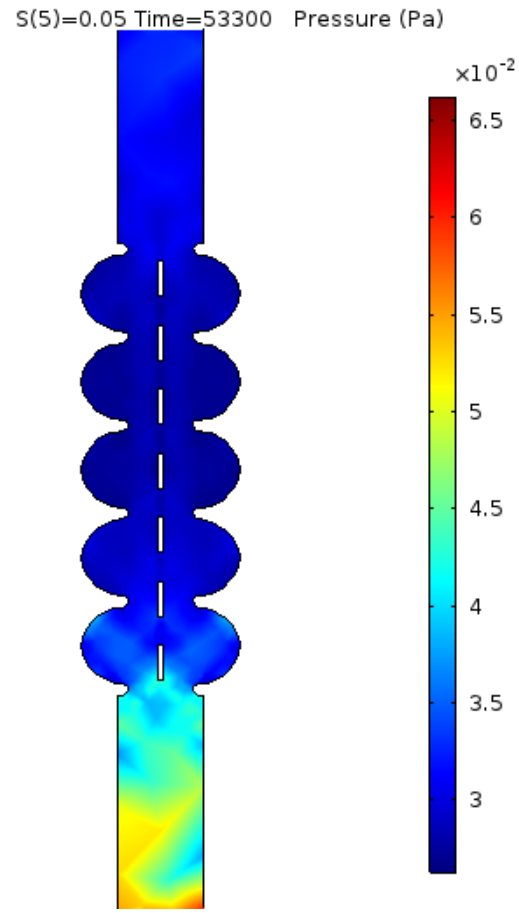


The process of tin entering the cavity during first few milliseconds after connecting the cavity to the tin source. In the beginning there is a vacuum inside the cavity, but as time goes, tin enters, and at rather high velocities comparable to the average speed of the molecules. This process takes about 10 milliseconds; tin saturates and velocity drops to much lower values.

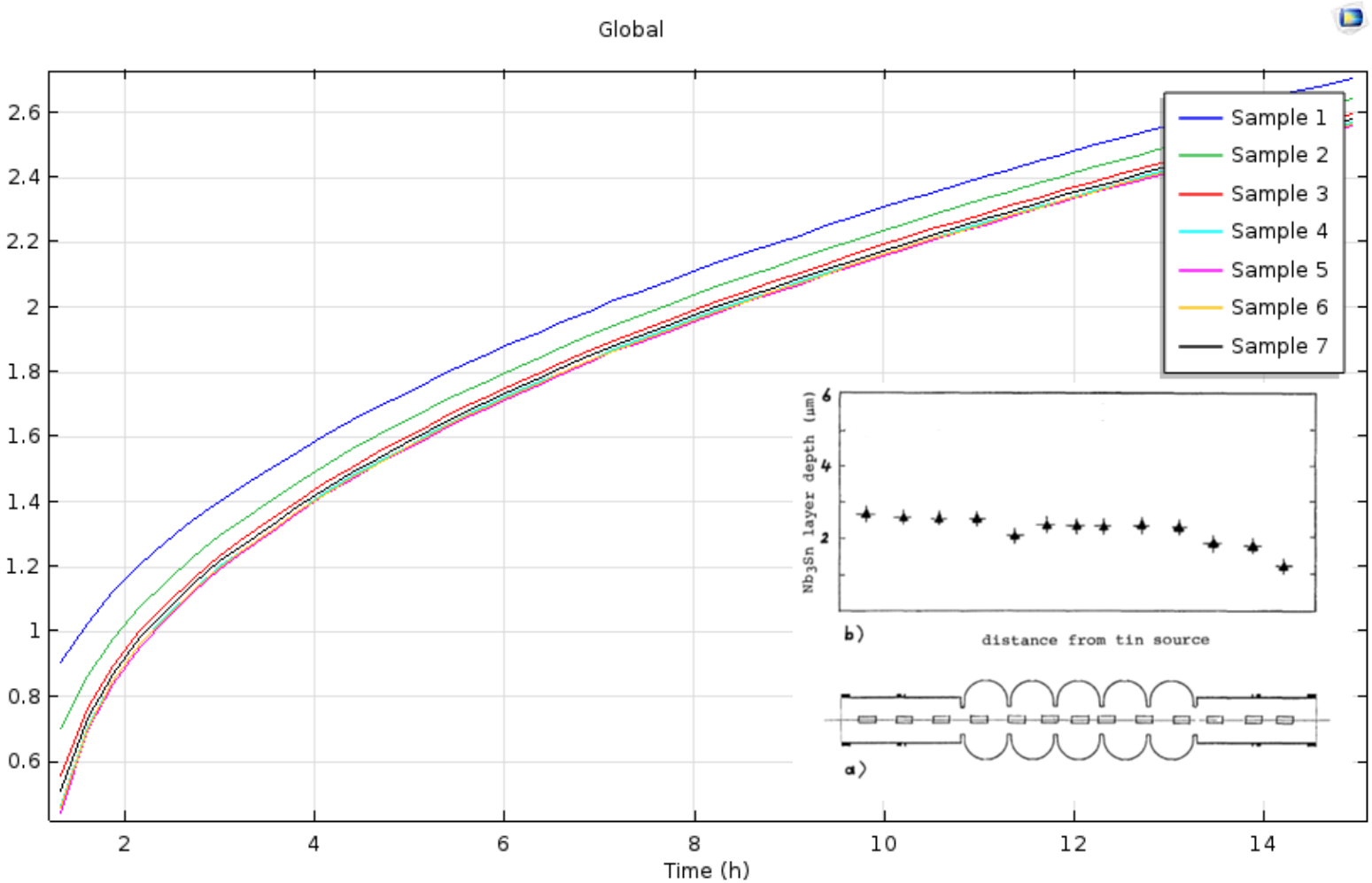
Pressure distribution with different SC





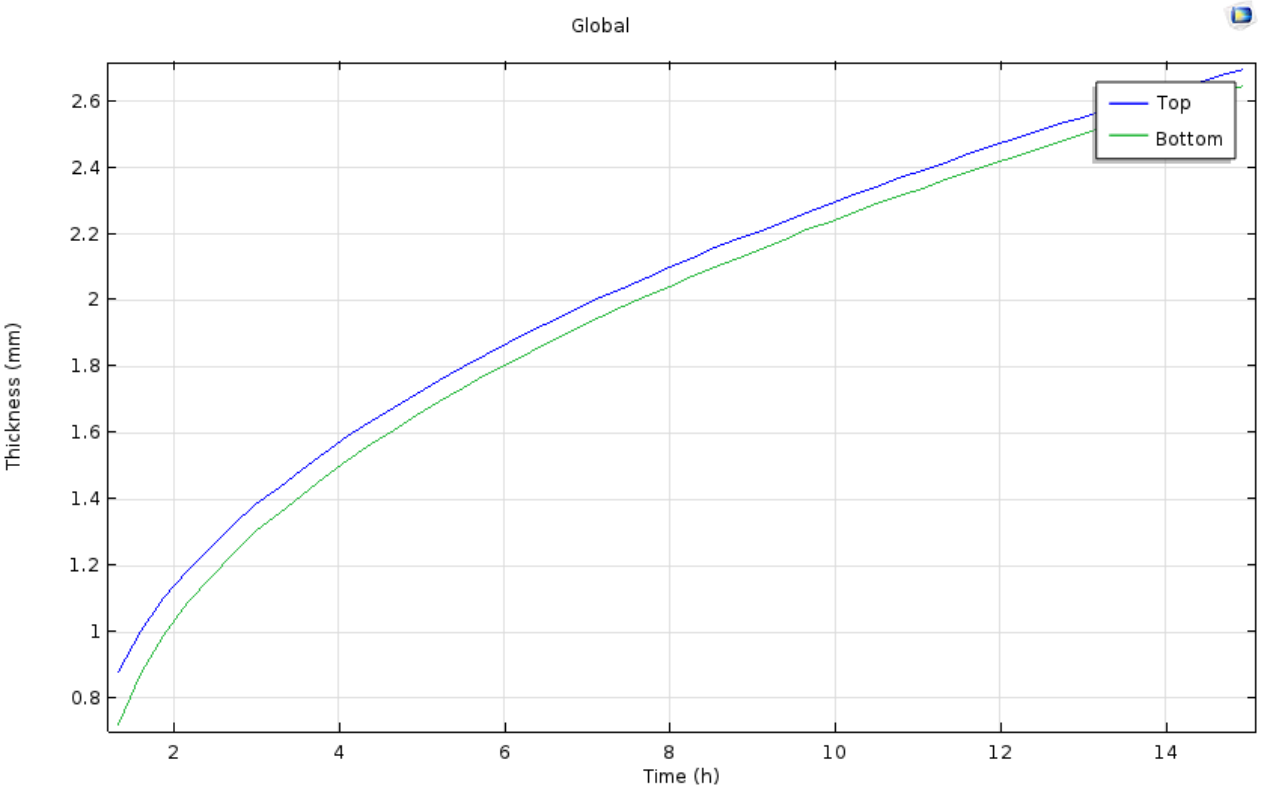


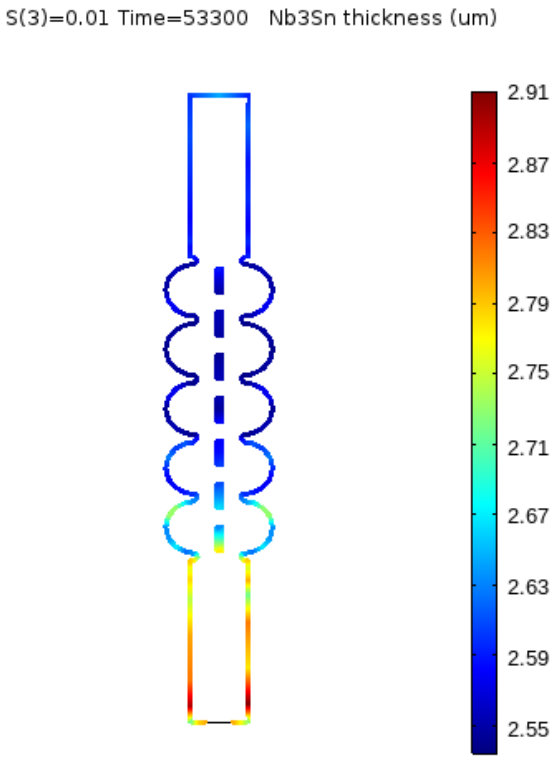
Thickness in different cells



From M.Peiniger and et al. "Work on Nb3Sn cavities at Wuppertal"
Proc.SRF3, Argonne, pp. 503-532, 1988

The uniformity in one cell





Summary

- We simulated the process of Nb3Sn deposition on the surface of Nb cavity
- Built reasonable model which takes into account the liquid tin appearing on the surface and its diffusion into Nb.
- Examined the distribution of pressure with various sticking coefficients, of thickness between samples and uniformity of cells
- Managed to find values of SC which reproduced the Wuppertal experiment.

Plans:

- Perform more simulations with different geometries and temperatures
- Ultimately, find optimal values to obtain the most uniform distribution of Nb3Sn

Thank you for your attention!