Bronze route inspired Nb_3Sn thin film coatings for SRF cavities

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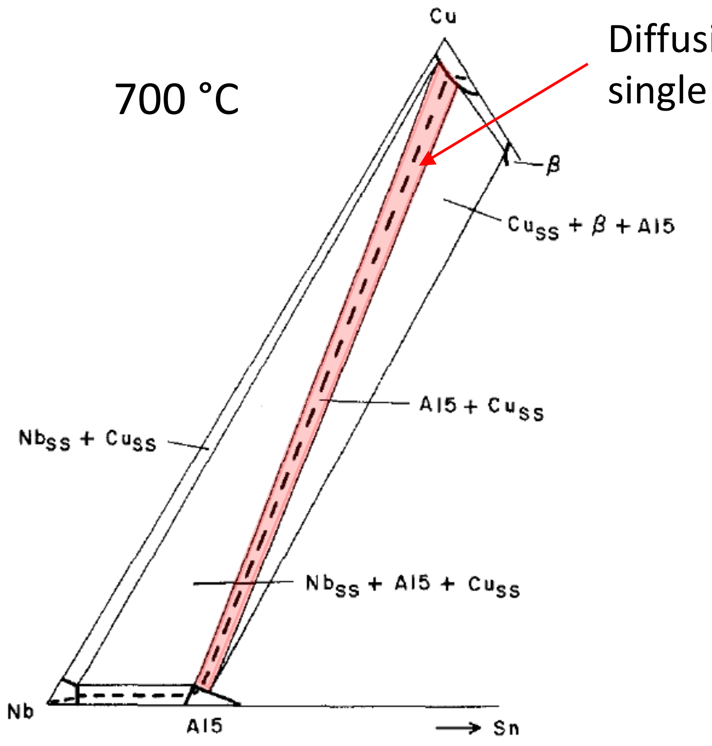
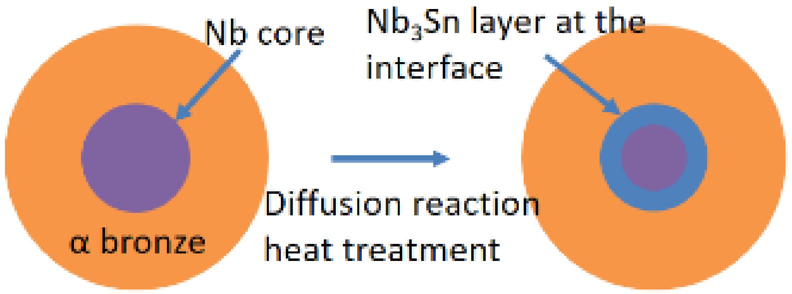
Bronze route Nb_3Sn growth

- Mature technology in wire fabrication
- Solid state diffusion reaction between Nb and Cu-Sn solid solution
- Low temperature (~650 – 800 °C) Nb_3Sn phase purity

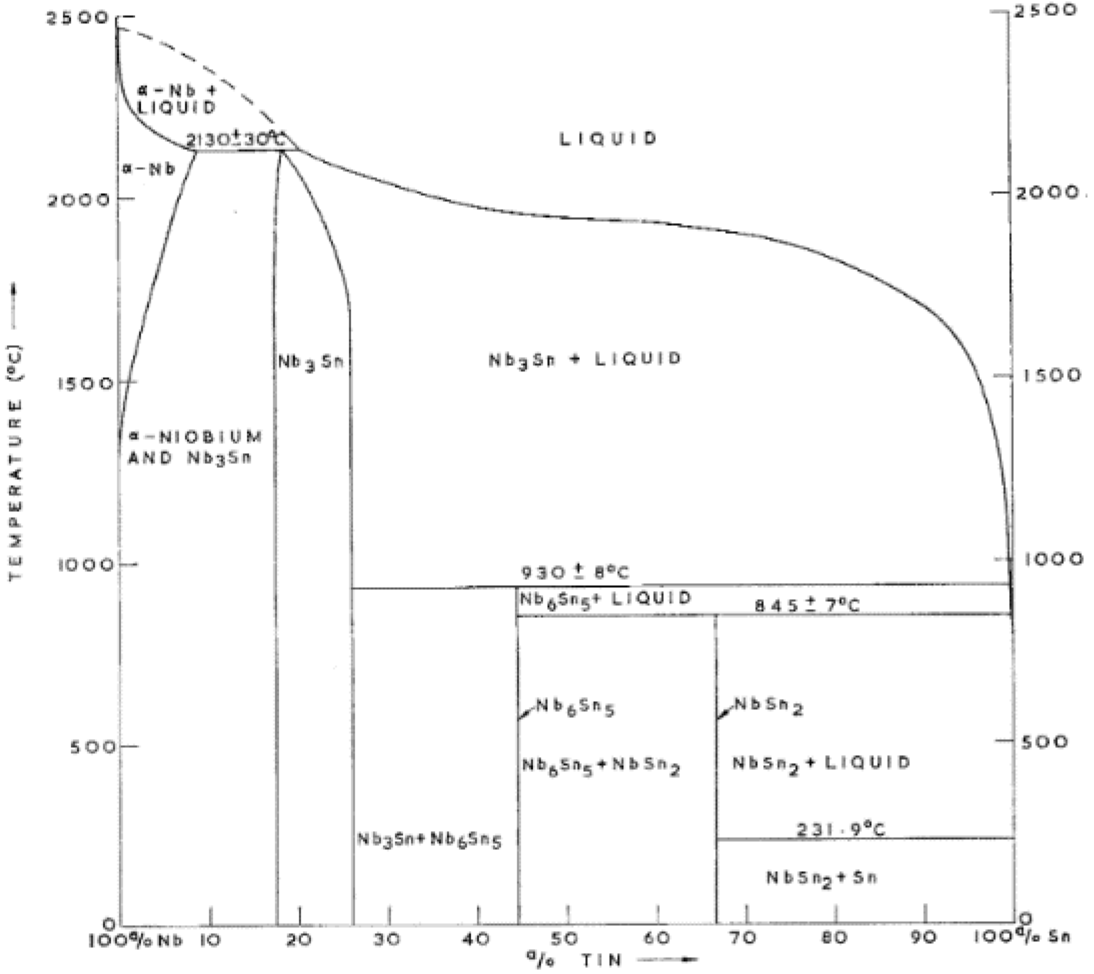


D. Dew-Hughes & T. S. Luhman Journal of Materials Science volume 13, pages1868–1876(1978)



Why investigate bronze routes?

- Move reaction window from ~1100°C to ~700°C
  - Avoid the Nb_6Sn_5 and $NbSn_2$ phases by exploiting ternary Cu-Sn-Nb system
- Make the reaction compatible with cavity bodies made from copper; avoid bulk niobium (and)
  - Possible cost and formability advantages
  - High thermal conductivity of Cu
- Avoid Sn vapor, chlorides of Sn and Nb polishing chemistry (corrosive, toxicity).

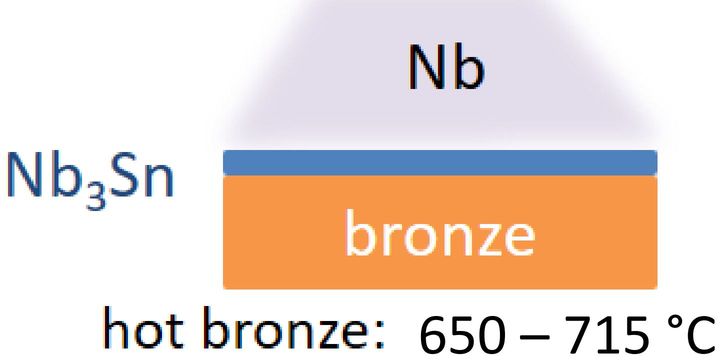


J. P. Charlesworth *et al J.* Mat. Sci.5, 580 (1970)

Nb on 15wt.% Sn bronze

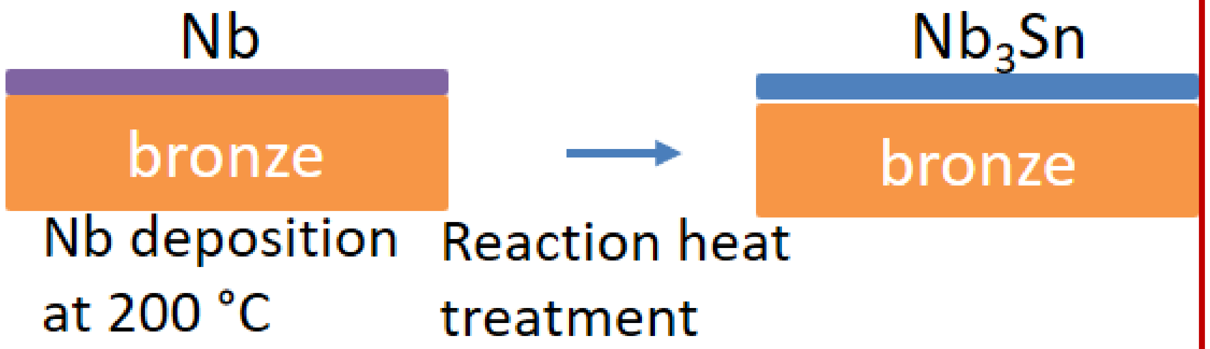
Bronze is cold-rolled and annealed at 525°C to homogenize, then mechanically polished

Hot bronze method



Route 1: Nb_3Sn forms concurrent with Nb deposition on hot bronze

Post reaction method

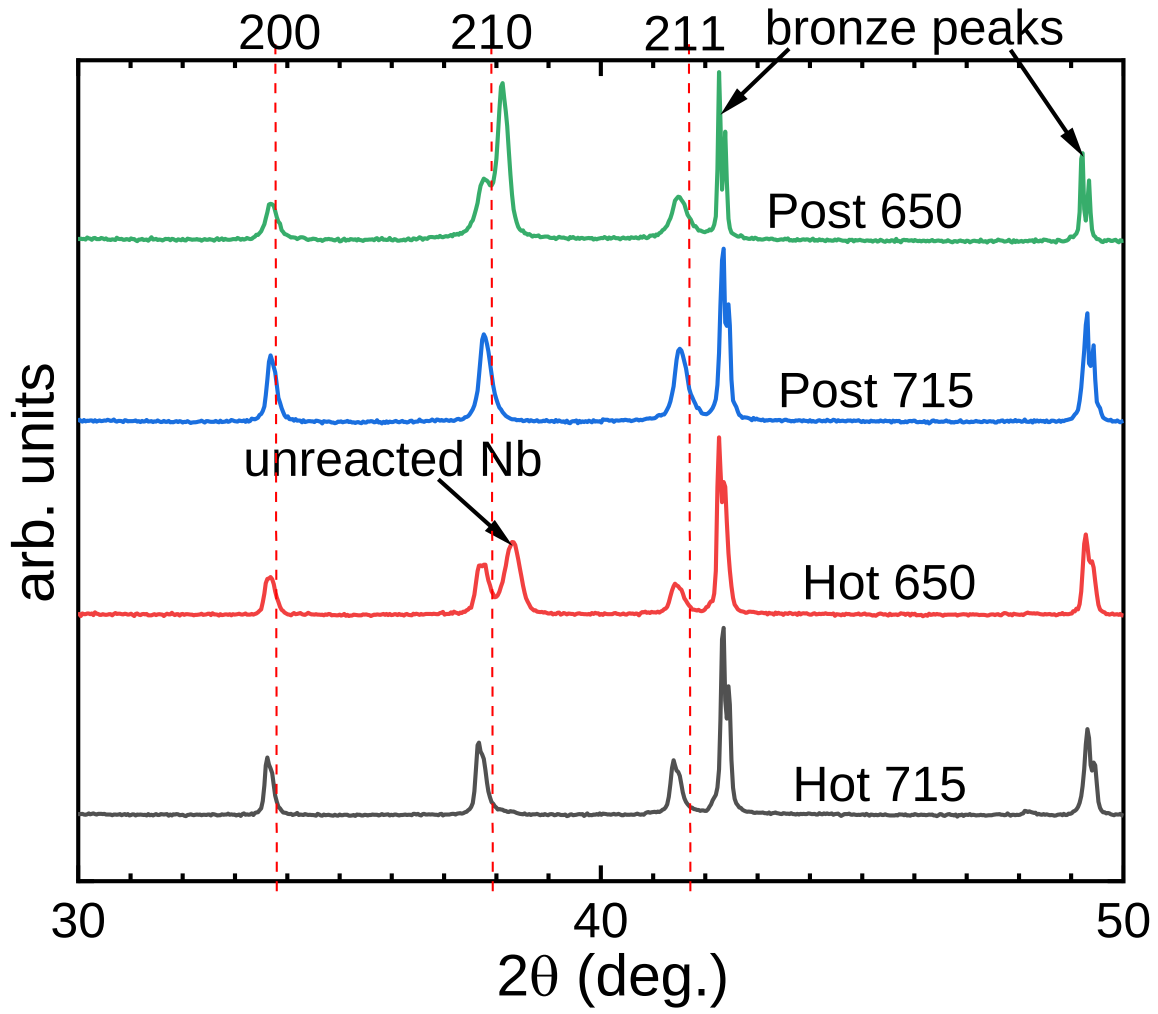


Route 2: Nb_3Sn forms during a diffusion reaction after deposition

- This route is different than wires
- Bronze surface become Sn rich
- **Very fast! 700 nm in only 22 minutes**

- This route is like wires
- *In-situ* reaction without breaking vacuum
- **700 nm in 360 minutes**

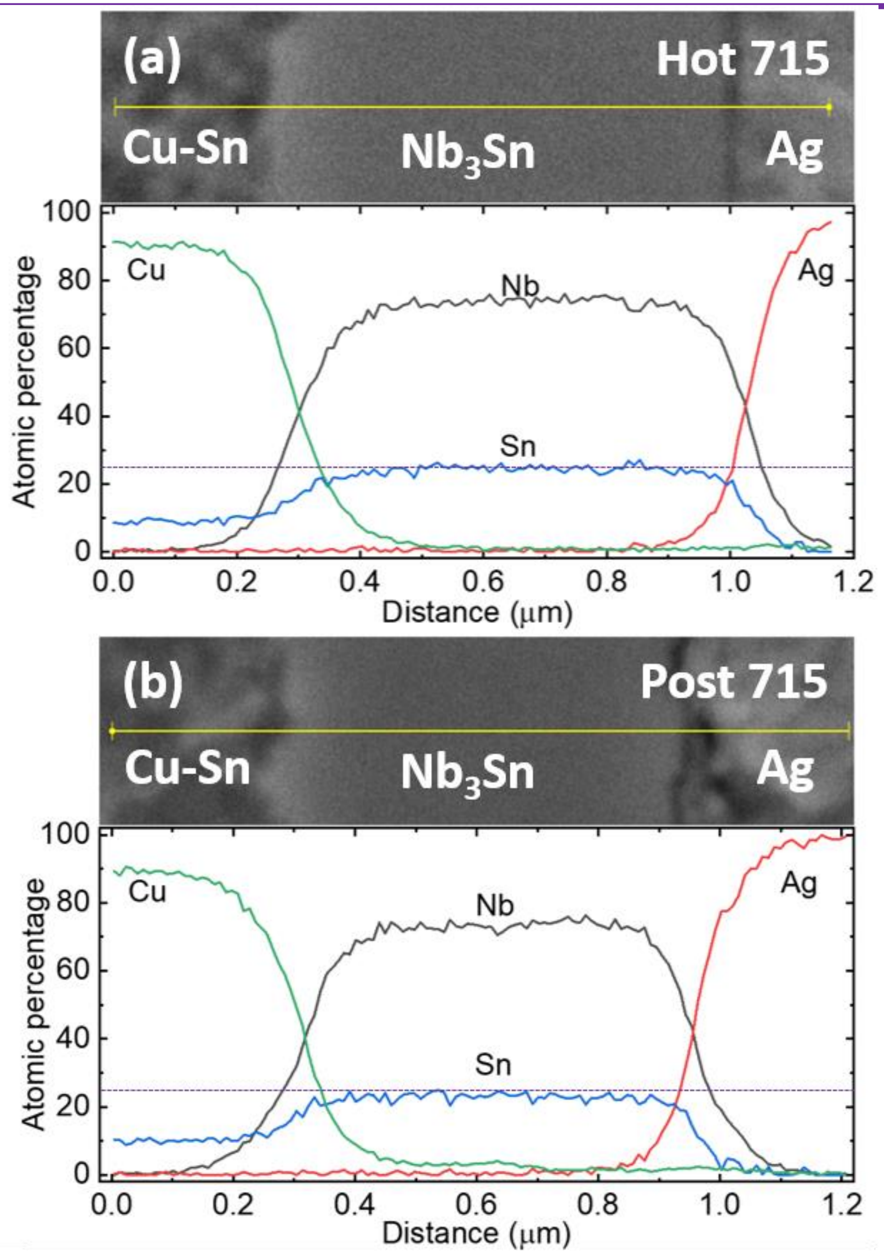
XRD shows an additional strain component for the hot bronze approach



- Full reaction to Nb_3Sn phase at 715°C
  - Unreacted Nb at lower reaction temperature
- Strain in hot bronze samples ~ -1.2%
- Strain in post-reaction samples ~ -0.9%
- CTE mismatch (715 °C → 25°C) creates –0.7% strain (for 10%wt. Sn bronze)
- Hot bronze samples contain additional strain component
  - Strain determined from lattice parameter by peak fitting and Poisson's ratio

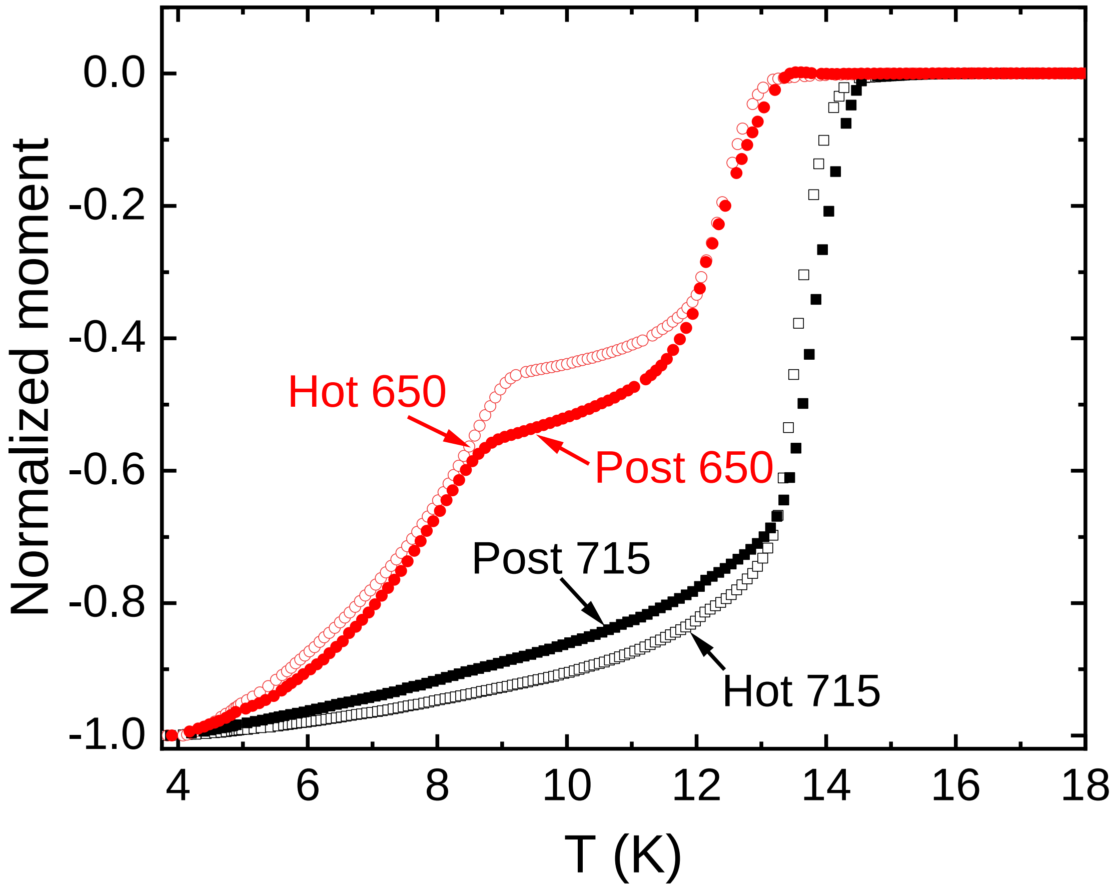
Hot bronze route gives Sn-rich Nb_3Sn ?!

- Hot bronze Sn - ~26%
- Post-reaction - ~ 24%
- Nb:Sn ratio from point scans in center of layer
- Tin-rich Nb_3Sn is not common for bronze reactions
- Relatively constant Sn content across thickness



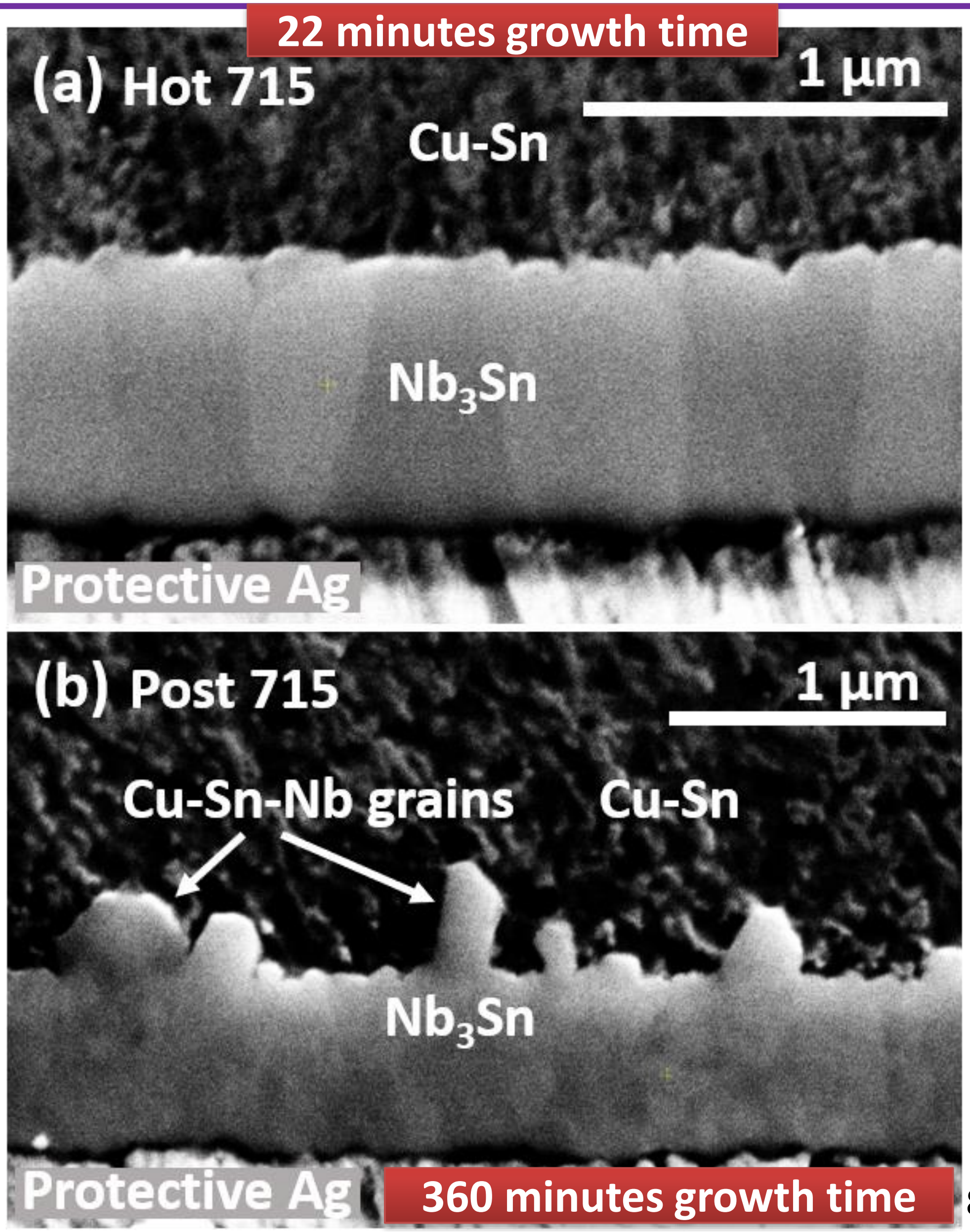
Similar T_c in both cases!

- Strain affects T_c of Nb_3Sn
  - At zero strain & 25% Sn, T_c is ~18 K
- Similar T_c in both approaches, T_c ~14–16 K due to strain from CTE mismatch and intrinsic strain
- At lower temperature, unreacted Nb-> low Sn activity



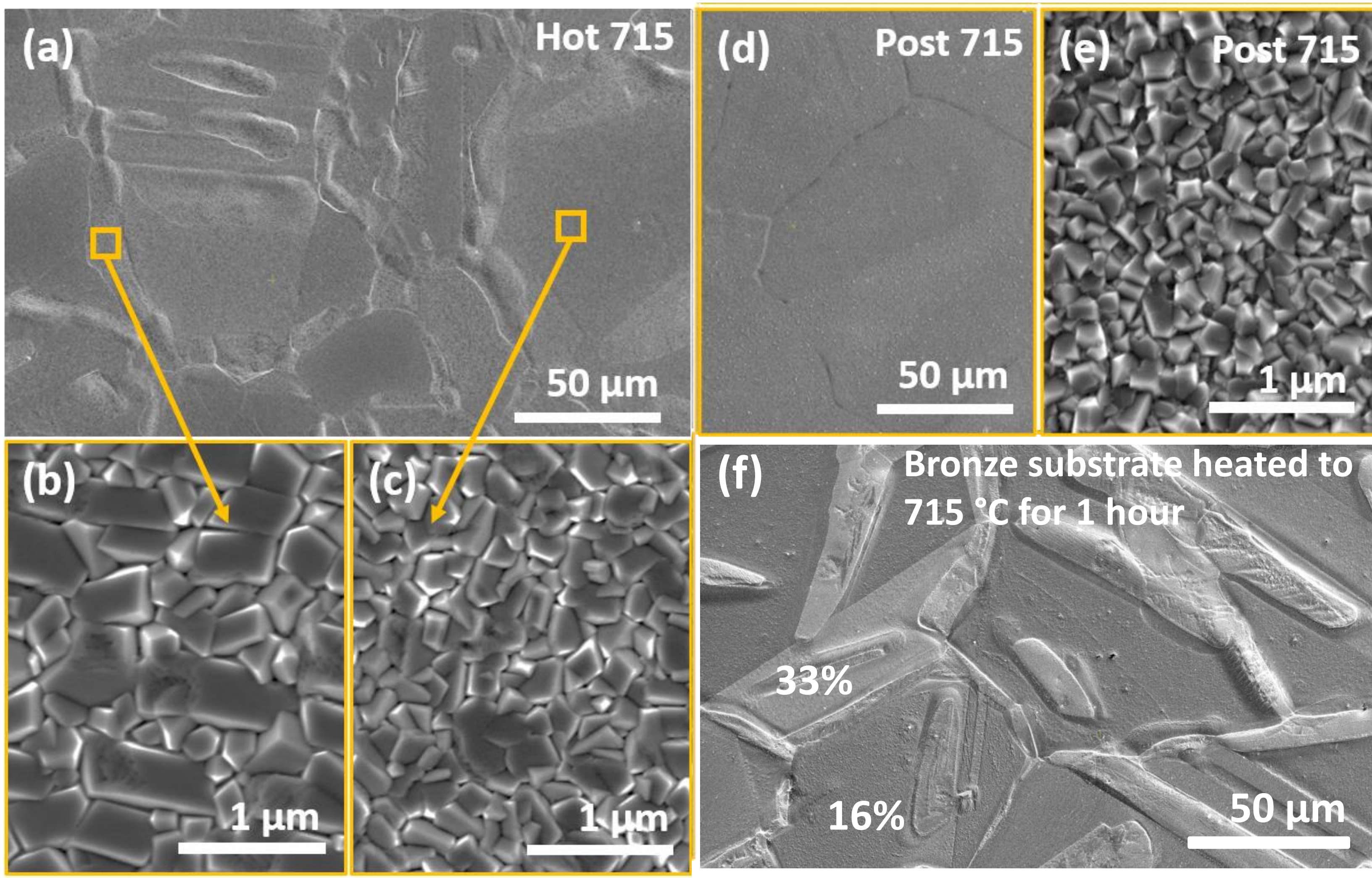
Columnar grains in hot bronze samples

- Columnar grain growth in hot bronze sample -> zone 2 in Thornton SZD
- Smaller grains in post-reaction samples
- No cracks



Larger Nb_3Sn grain in hot bronze samples

- Larger Nb_3Sn grains in hot bronze case
- Surface avg. roughness is ~10 - 15 nm in 100 um^2
- Effects from underlying bronze substrate Sn contents seen in hot bronze samples
- No cracks

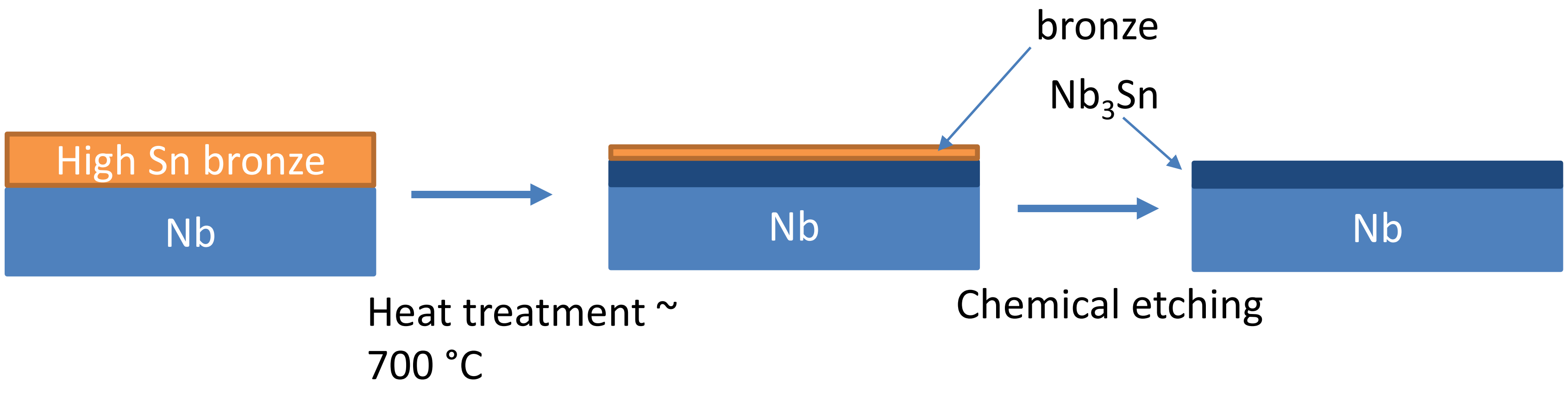


Discussion – Nb on hot bronze

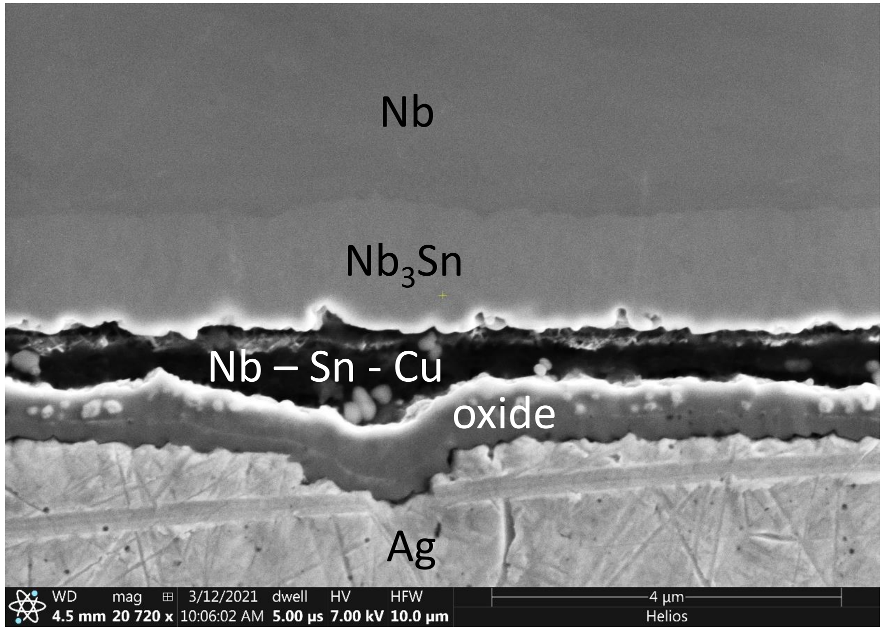
- Tin-rich Nb_3Sn: 26% suggested by EDS
- But *same* T_c as for post-reaction, which EDS suggested was only 24% Sn
- Why?
  - Excess strain seen from XRD
  - Zone 2 in Thornton SZ diagram
  - **Is the excess strain due to a new growth mode? We think so: high mobility Volmer-Weber growth**
  - If so, this is new, and it is not available in solid-state reactions

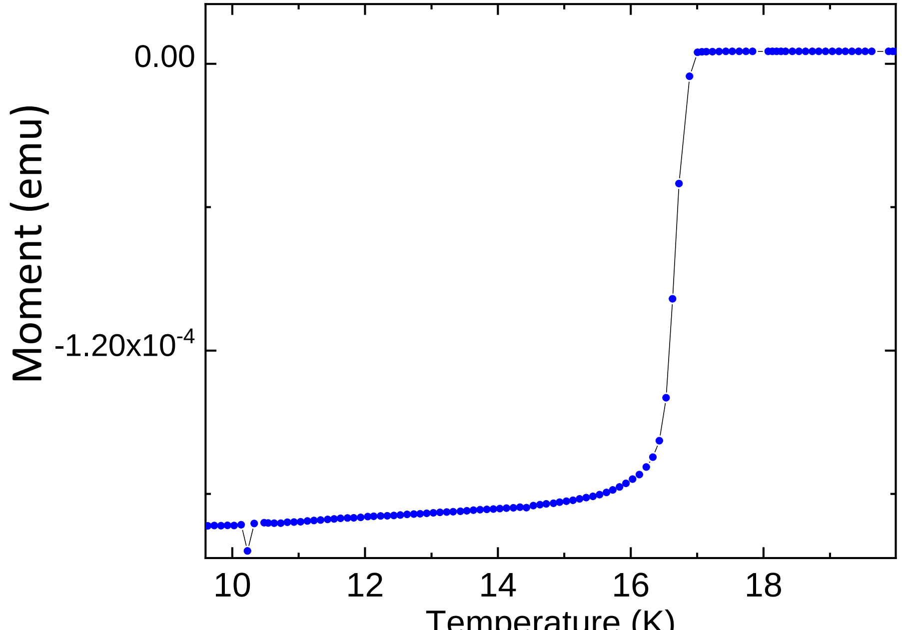
Bronze on Nb

- Evaporation of bronze reduces steps involved
- Sn gradient in the Nb_3Sn layer, 25% to 18%
- Susceptible to oxidation



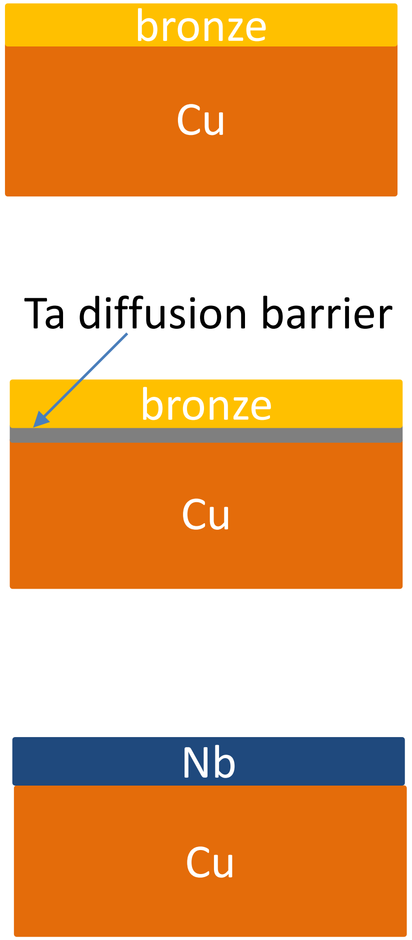
2 µm 40% Sn bronze layer on Nb + 6 hours at 700 °C

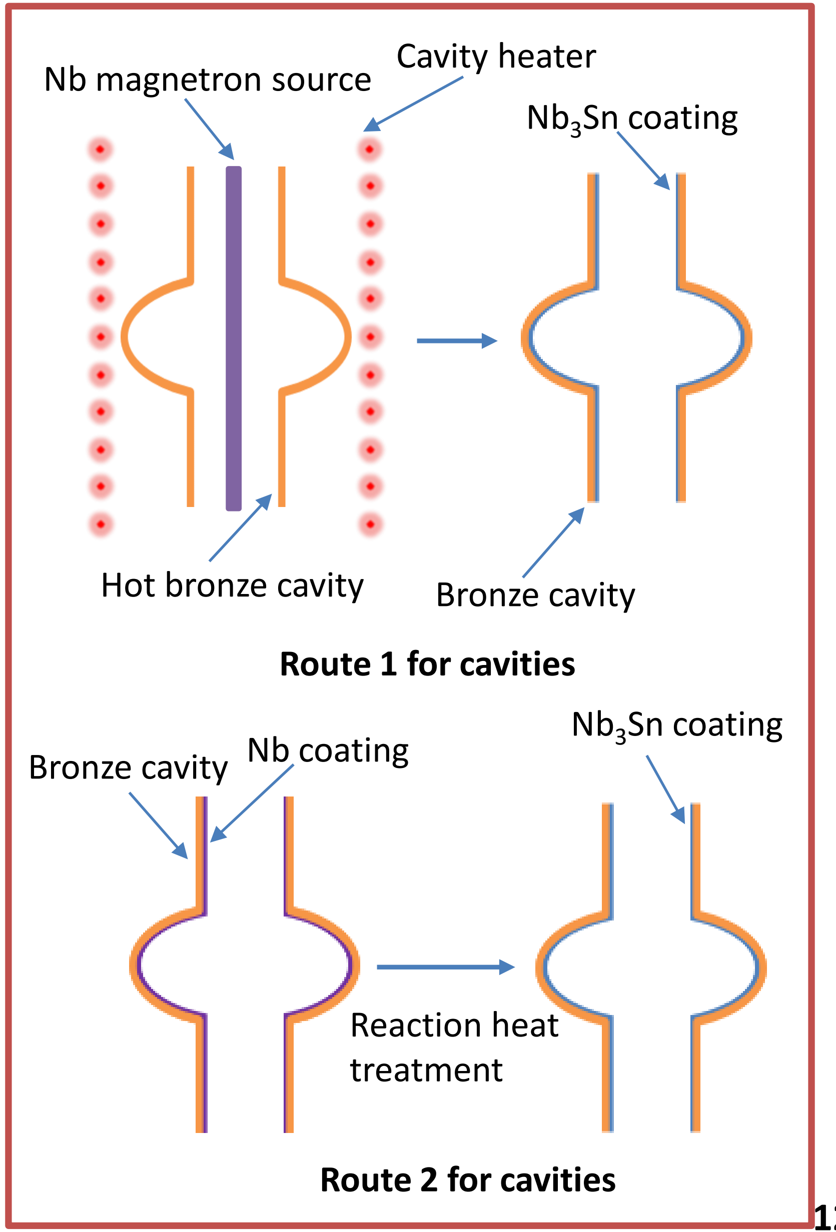




How to use Cu substrate and scaling to cavities

- 2 – 5 µm high Sn bronze layer is enough to produce ~1-2 µm Nb_3Sn layer
- Diffusion barriers -> stop Sn diffusion into Cu
- Bronze/Ta/Cu can be used in hot-bronze or post-reaction method
- Nb_3Sn grain size can be controlled with Sn content in bronze layer
- Nb/Cu can be used with bronze evaporation + heat treatment+etch approach
- Process can be scaled to cavity coating easily





Summary

- Deposition of Nb onto hot bronze seems to be very promising
  - Tin-rich coating
  - Rapid growth of layer
  - Zone 2 grain structure

- A wide range of substrate configurations is possible
  - Diffusion barriers and CTE adjustments
  - Compatibility with external copper bulk

- Schemes for scaling to cavities are in progress

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Backup Slides

Typical stress development in high-mobility VM growth

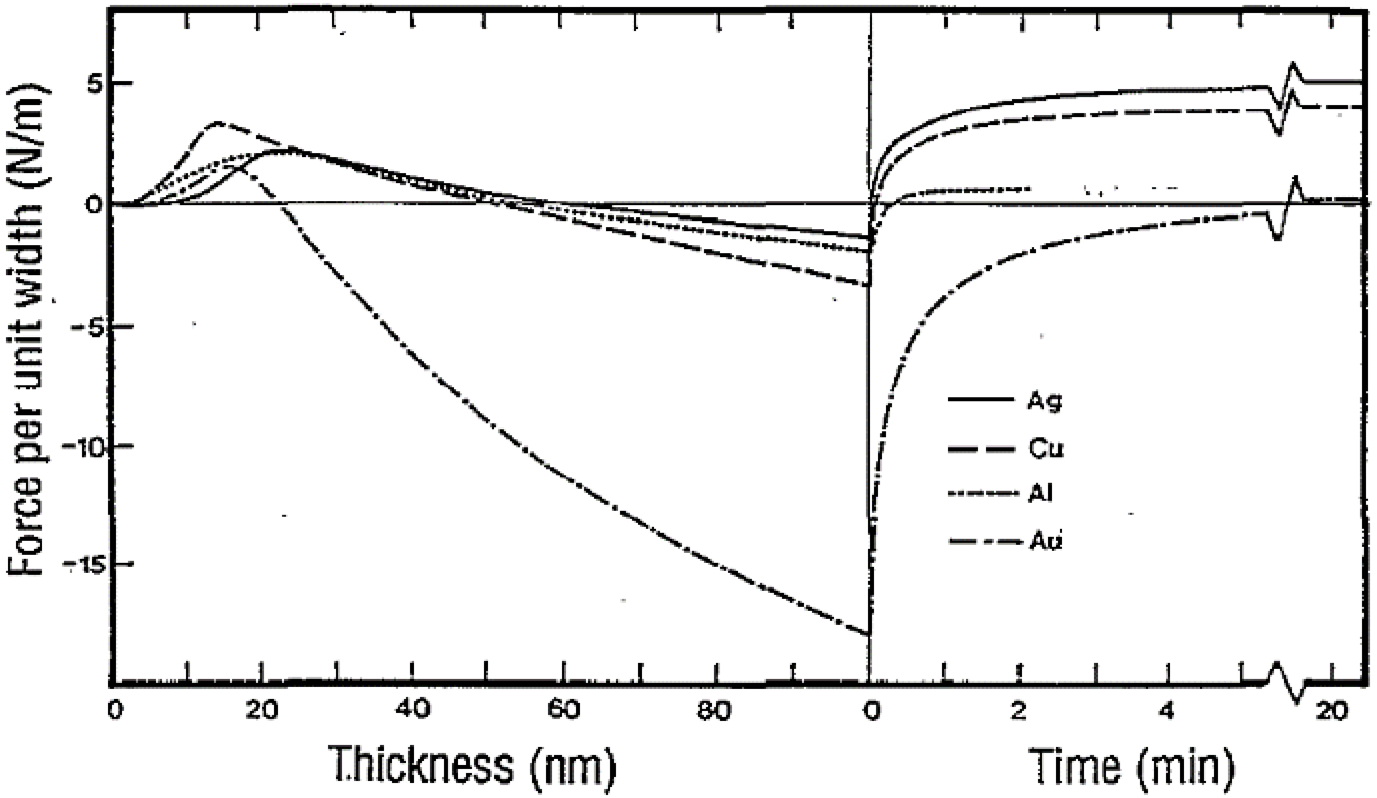
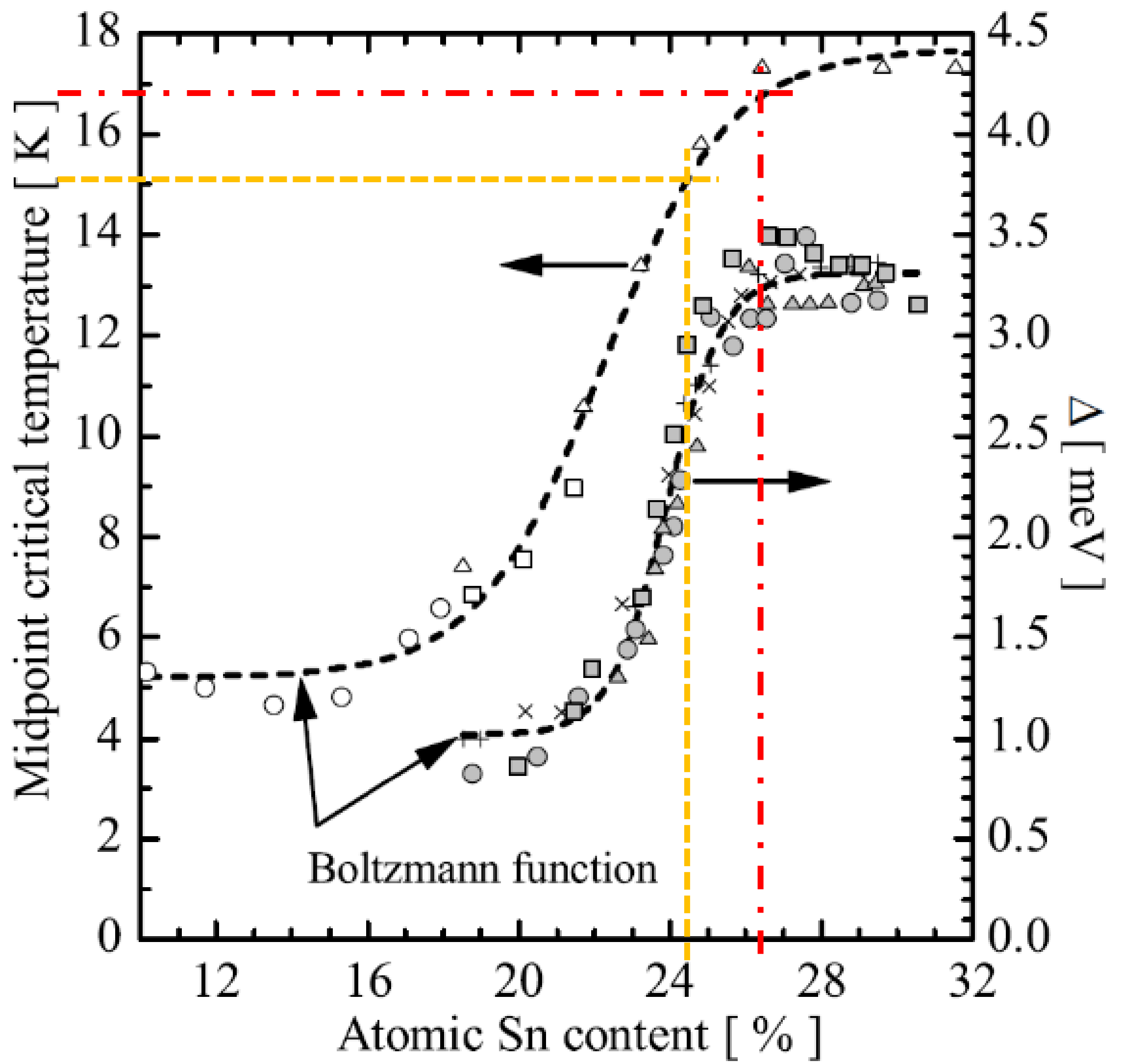


Figure 9. High-mobility Volmer–Weber growth: film forces per unit width against mean thickness (left-hand side) and time (right-hand side) of Ag, Cu, Au (from [16]) and Al films (from [9] by courtesy of R Abermann) UHV deposited at room temperature onto MgF_2 coated glass substrates.

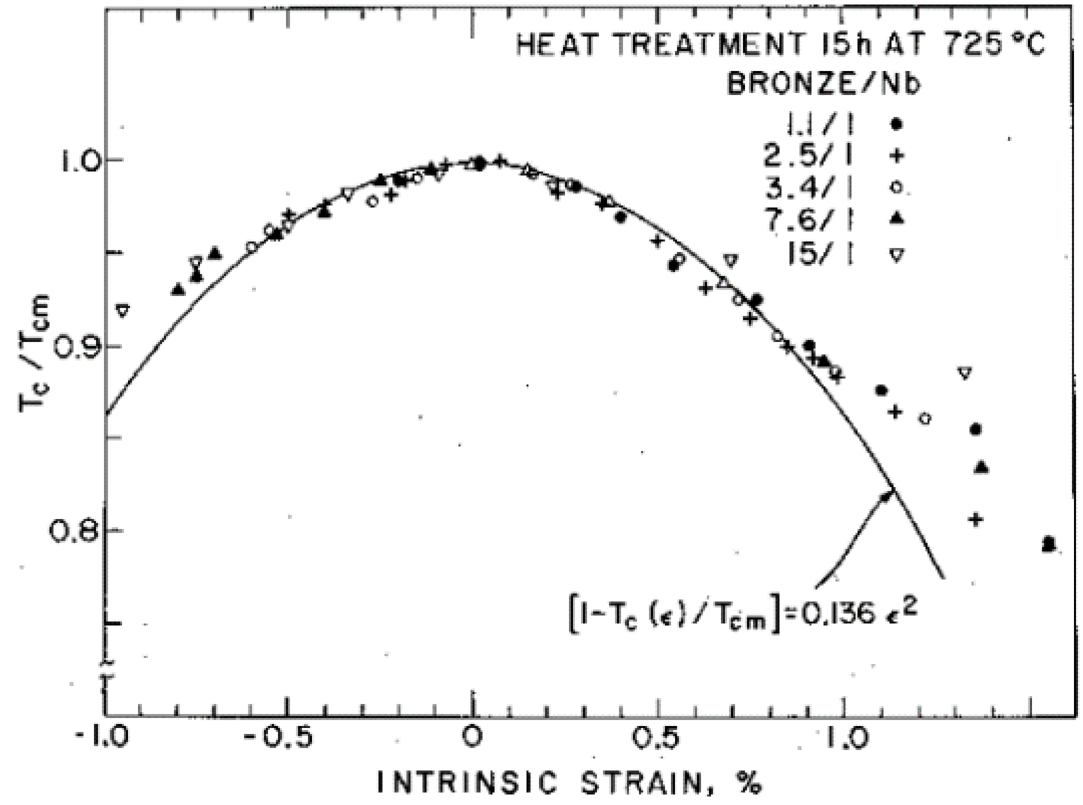
Koch R 1994 *J. Phys.: Condens. Matter* 6 9519

T_c vs Sn content

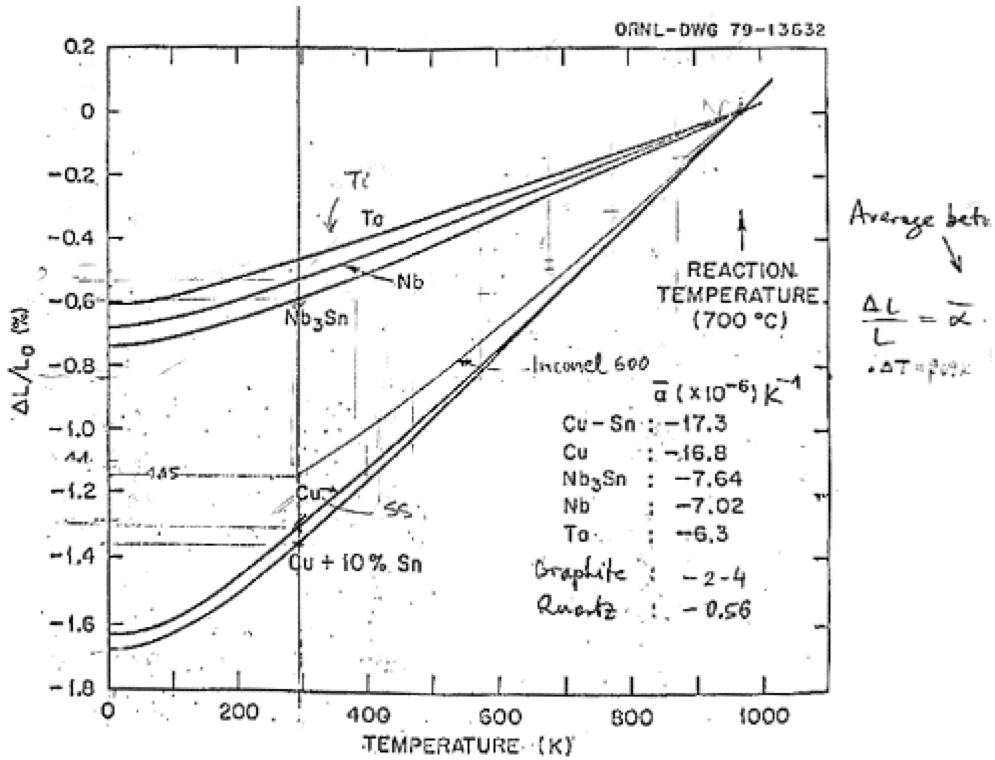


Moore D, Zubeck R, Rowell J and Beasley M 1979 *Phys. Rev. B*
A Godeke 2006 *Supercond. Sci. Technol.* **19** R68

CTE mismatch

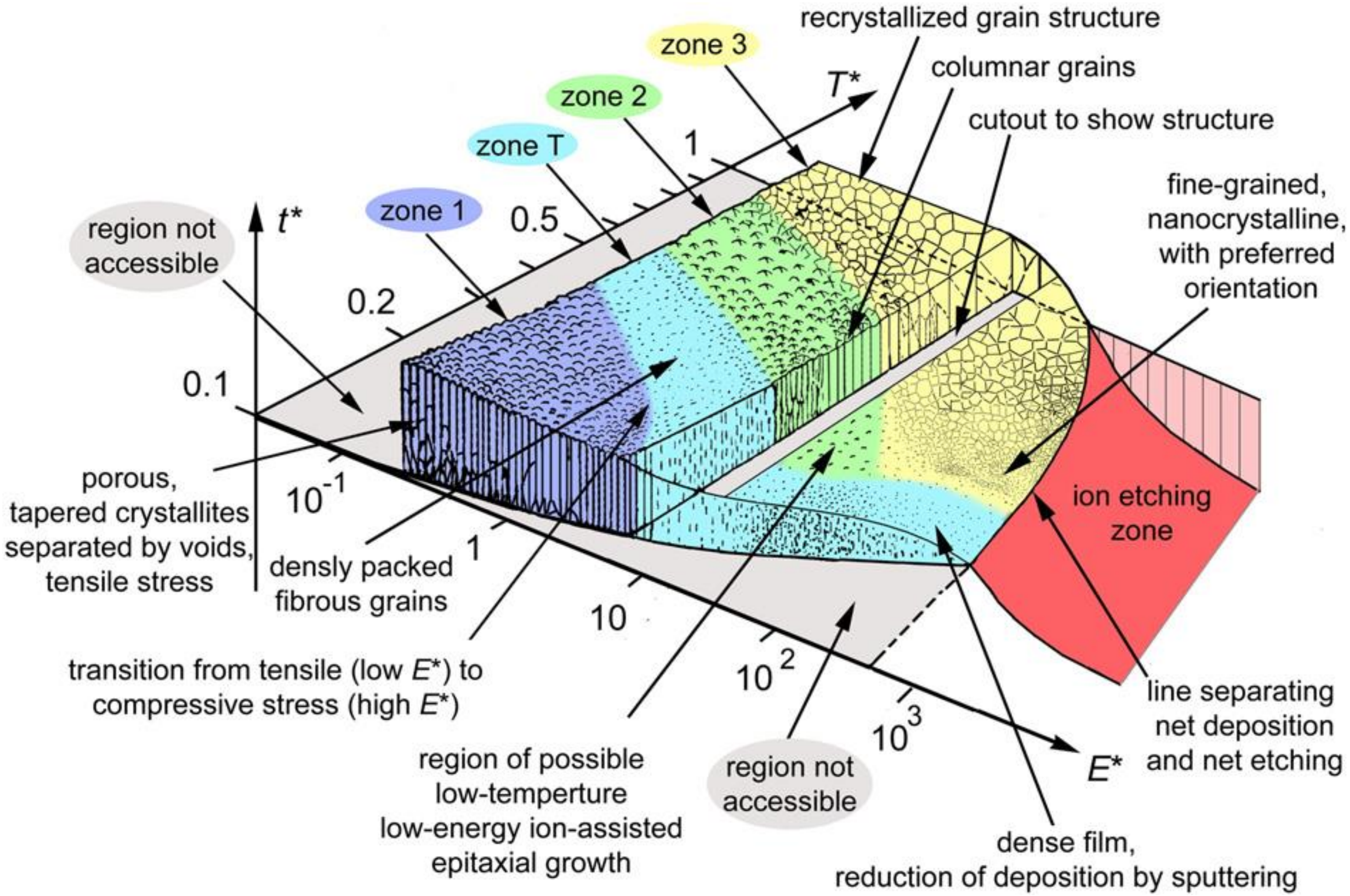


D. O. Welch, *Adv. Cryo. Eng.*, ***26***, *pp. 48-65, 1980*



CTE mismatch between Nb_3Sn and common substrates

SZD



A. Anders Thin Solid Films 518 (2010) 4087–4090

Proposed deposition chamber