An Integrated Approach to Nb_3Sn Cavities: Bronze-Route Fabrication and Laser Post-Treatment

Teng Tan, on behalf of IMP TFSRF team

2026-06-11

TTC2026 Paris

Outlines

- Motivation:
- Bronze-route Nb_3Sn
  - On small samples
  - On cavities
- Laser Treatment
- Results and discussions

Motivations

- The need for Nb_3Sn/Cu cavity: Lhe-free, low cost, compact system

氦气供应中断不可抗力声明

尊敬的客户：

基于贵我双方就氦气供应签订的气体供应协议（以下简称"供应合同"），液化空气（上海）压缩气体有限公司（以下简称"液空"或"我司"）特此致函贵司，正式向贵司通知不可抗力事件的发生。

受中东地区局势震荡（特别是涉及伊朗及周边区域的冲突）影响，全球氦气供应链正面临前所未有的挑战。由于霍尔木兹海峡的通行持续受阻、卡塔尔能源公司全面暂停其液化天然气和氦气生产，全球主要氦源的供应已受到限制，预计未来全球氦气供应将因此呈现长期性的短缺和紧张。我司的上游供应商已正式向我司发出不可抗力声明，以及其他相关的供应链问题已对产品供应造成严重影响，液空履行供应义务的能力已受到根本性的严重损害。前述前所未有的情况已超出了液空合理的控制范围，构成不可抗力事件，直接导致液空无法完全履行供应义务。目前，液空尚无法预估此次不可抗力事件的确切持续时间，但液空将尽可能及时地向贵司更新相关信息。

一旦不可抗力事件消除，我司将及时通知贵司恢复相关产品的正常供货，而本声明函并不免除供应合同项下贵司既有的义务。

我司正在积极寻求可用资源，以减轻此次不可抗力事件带来的影响并缩短其持续期间。请知悉前述努力可能会带来增加的费用，且未来情况可能会进一步发生变化（届时将根据供应合同的规定另行通知）。

贵司如有任何关于合同或供应的具体疑问，请随时与液空的专属客户经理联系。

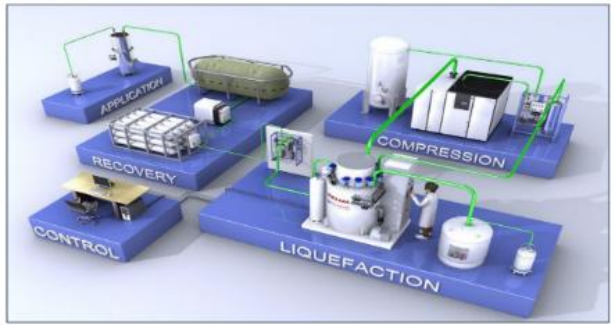
我司将继续竭诚为贵司服务，并感谢贵司对我司一如既往的理解与支持！

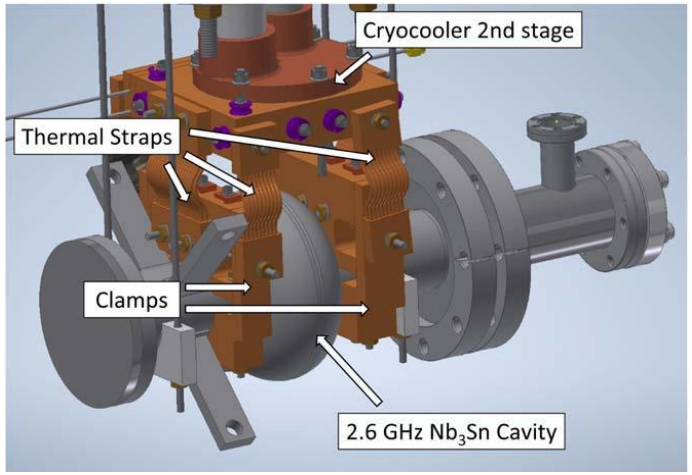
顺颂商祺。

液化空气（上海）压缩气体有限公司

2026年4月21日

Air Liquide
Linde
Air Products





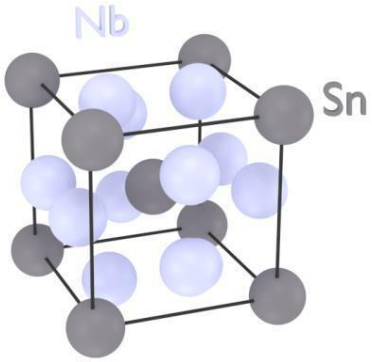
Stilin, 2023

Force Majeure Declaration on Helium Supply Interruption, Apr. 21st
Supply stopped May 1st

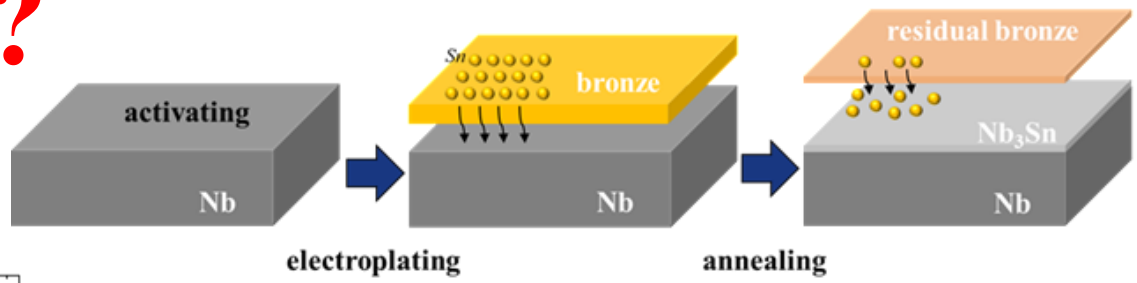
Motivations

Bronze-route Nb_3Sn

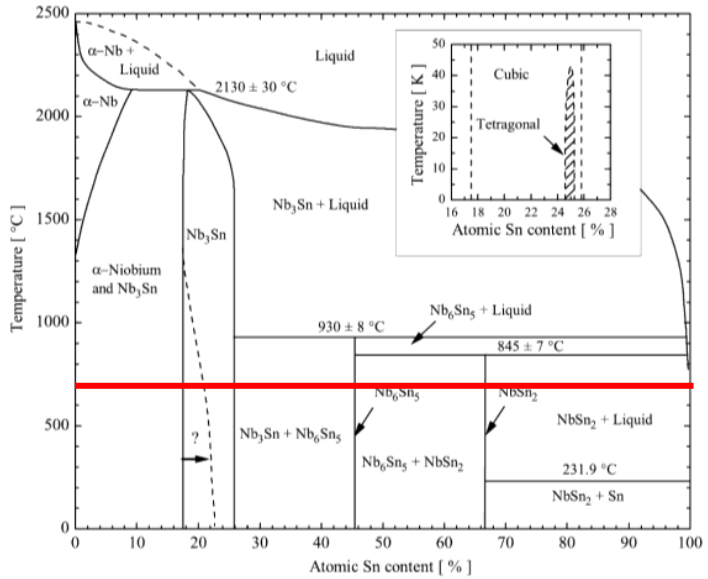
- Can we have



?

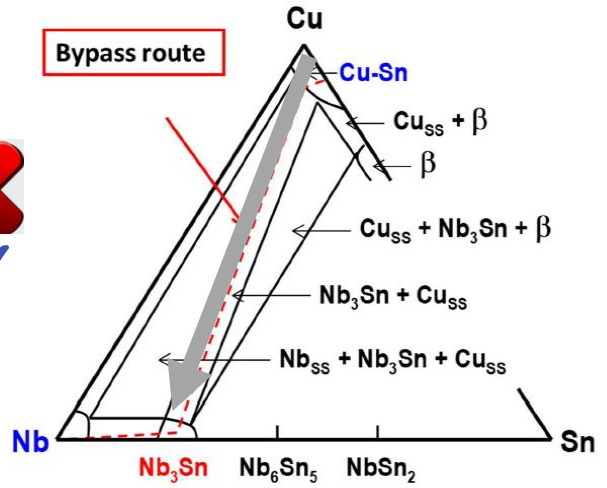


Annealing $T \leq 700°C$



Nb+Sn ✗

Nb+Cu+Sn ✓

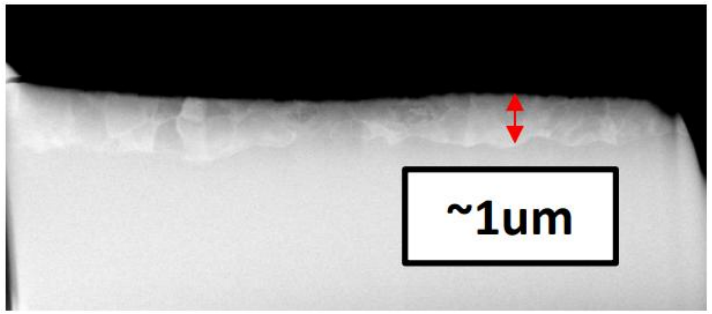


[1] RF characterization of 1.3 GHz one-cell Nb/Cu full-seamless cavities manufactured by hydroforming, M Yamankana (KEK)

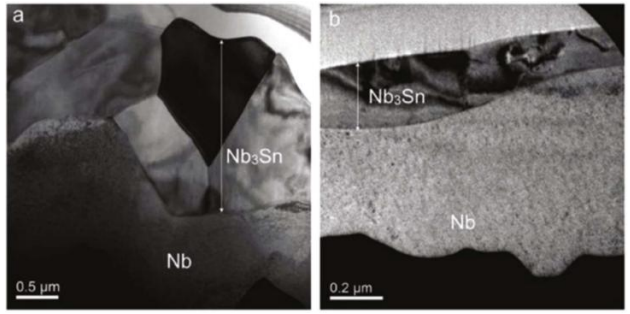
[2] L Mei, Z Du, C Guo, & C Li. (2009). Thermodynamic optimization of the cu-sn and cu-nb-sn systems. Journal of Alloys & Compounds, 477(1-2), 104-117

Motivations

- Defects on bronze-route Nb_3Sn film

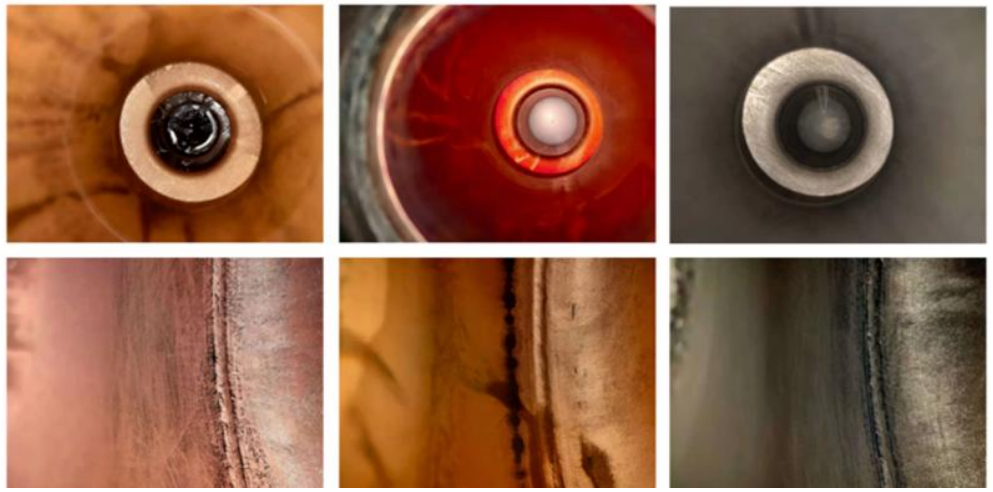


Thin layer

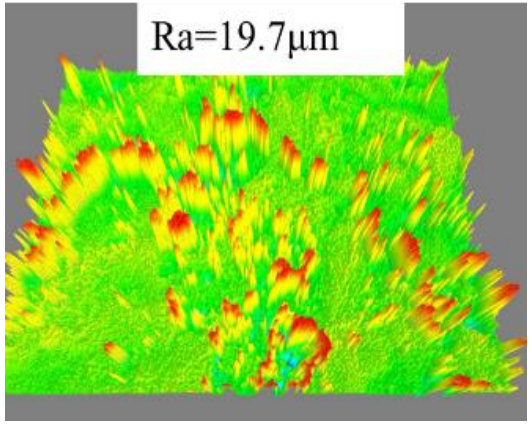


Tin-poor area

Necessitate the treatment of bronze-route Nb_3Sn



Residues from electroplating



High surface roughness

Motivations

- Laser Treatment

Sharp edge removal
Adhesion improve

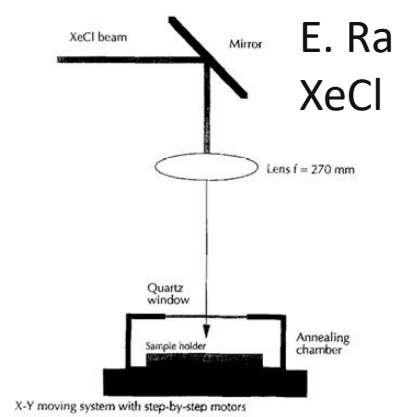
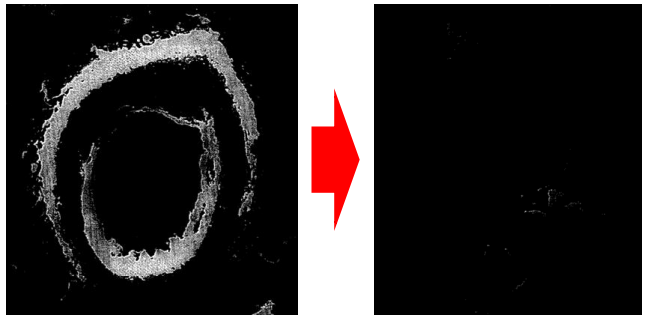
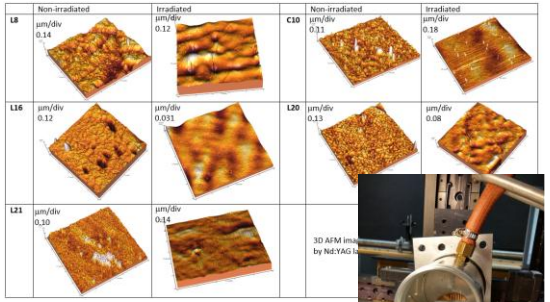


Fig. 1. Laser beam focusing system and annealing chamber. The chamber is equipped with flanges (not shown in the figure) to accommodate connections to a diffusion pumping station and to a venting valve.

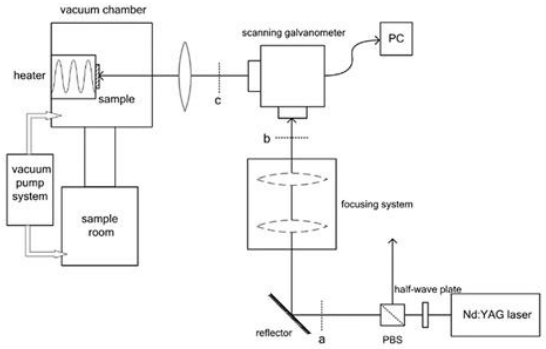
E. Radicioni et al, 1995
XeCl Nb/Cu

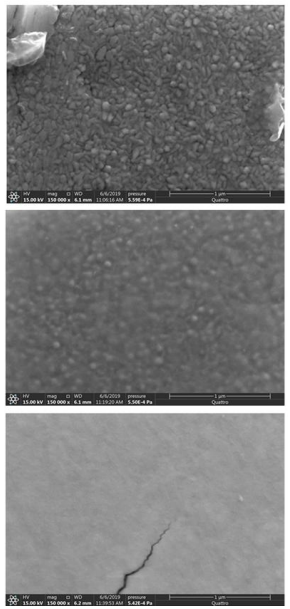


A. Medvids et al, TFSRF2018
Nd:YAG Nb/Cu

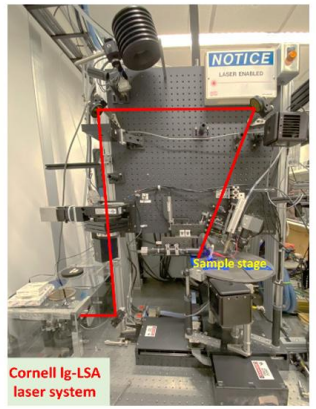


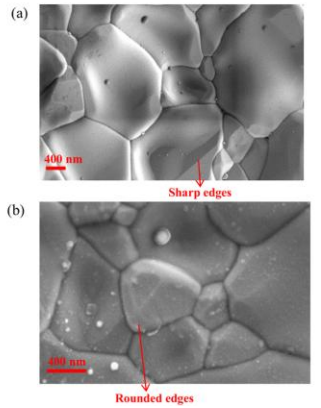
Y. Yanget al, SRF2019
Nd:YAG Nb/Cu





Z. Sun et al, ipac2021
lg-LSA laser Nb/Nb_3Sn film

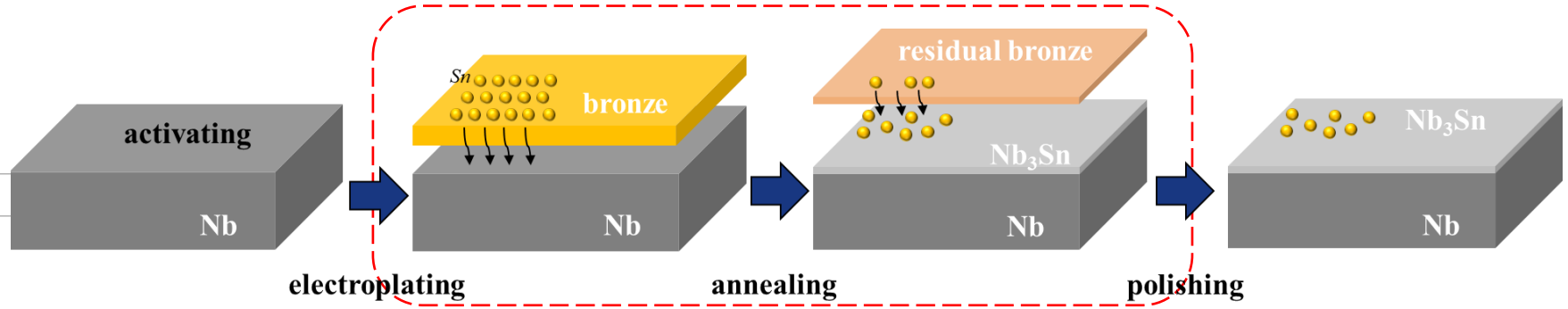


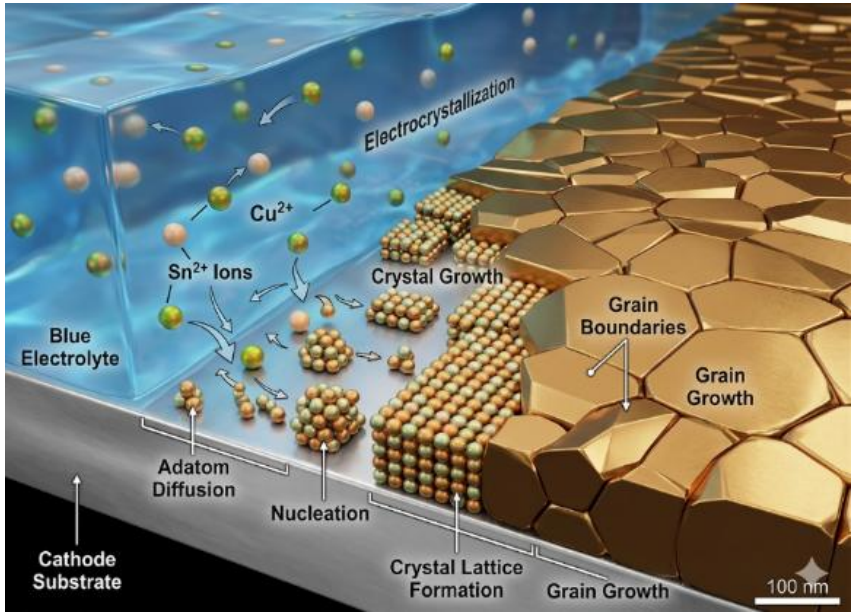


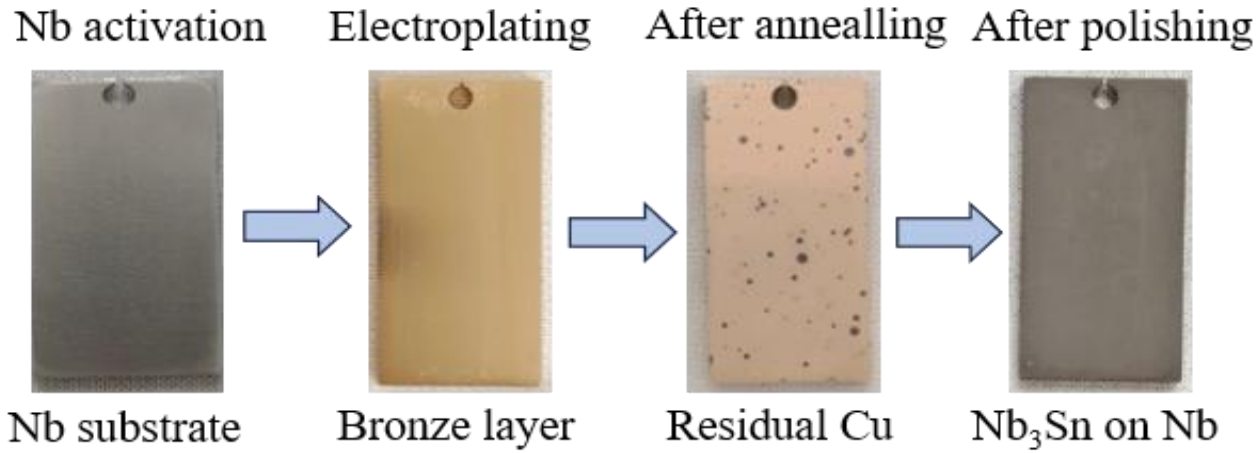
Current progress

- Fabrication of bronze-route Nb_3Sn

Chemical	Purity	Concentration
$C_6H_8O_7$	AR 99.5%	180g/L
K_2Sn0_3	AR 95.0%	20g/L
$Cu_2(OH)_2CO_3$	AR	16g/L
KOH	AR	130g/L
KH_2PO_4	AR 99.5%	17g/L



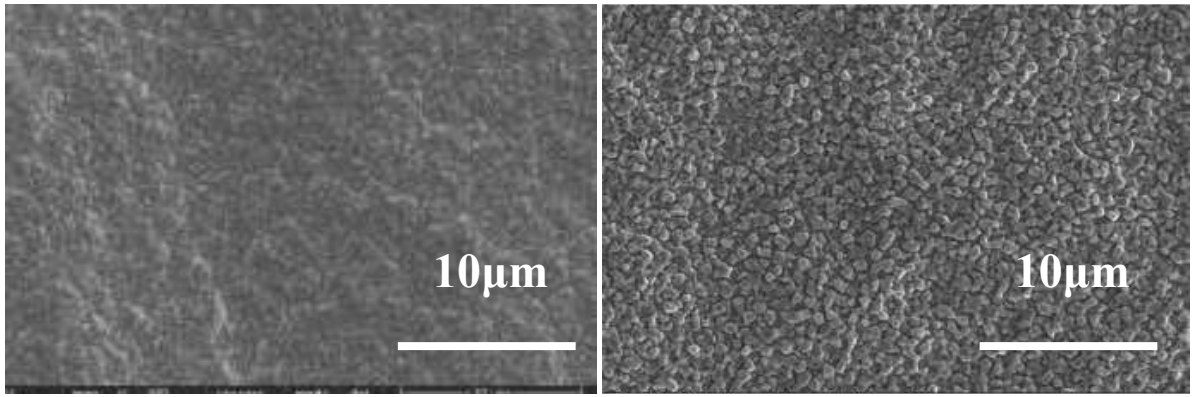




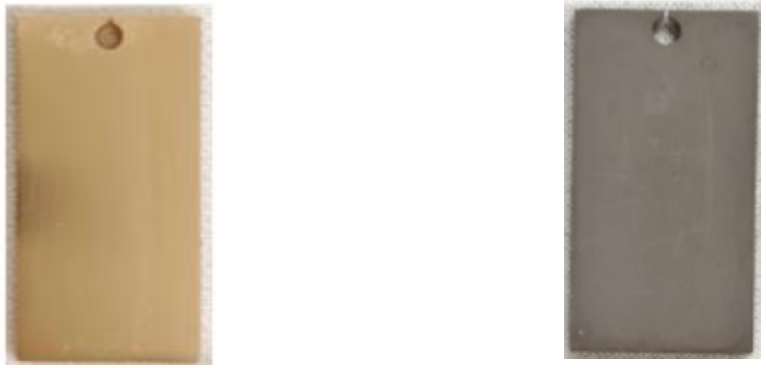
C.L.Wang, T.Teng, Y. He, et al. The impact of laser treatment on the microstructure and properties of bronze route Nb_3Sn thin films [J]. ***Applied Surface Science***, 2024

Bronze-route Nb_3Sn

- On small samples

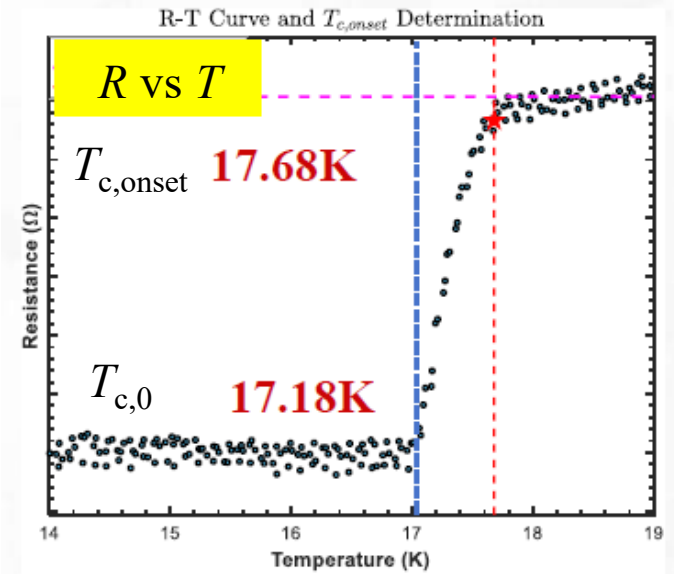


Bronze layer　　Nb_3Sn after polishing



Nb_3Sn layer composition

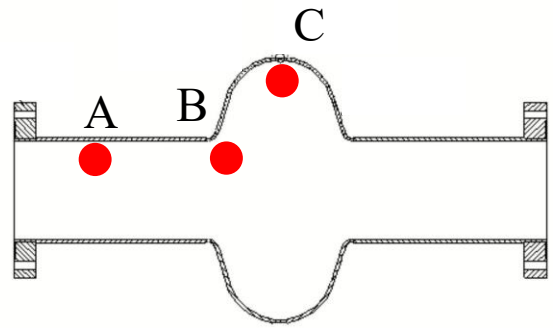
Elements	at.%
O	11.05
Nb	66.52
Sn	22.43
Nb/Sn	**2.97**

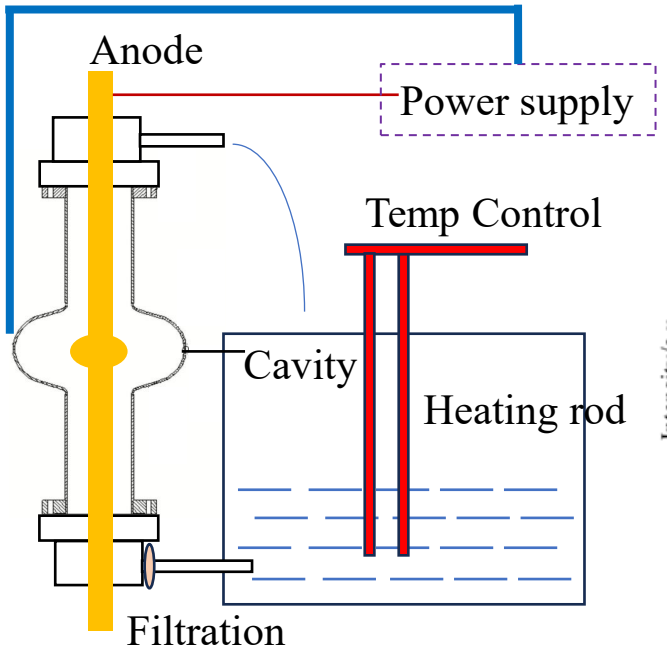


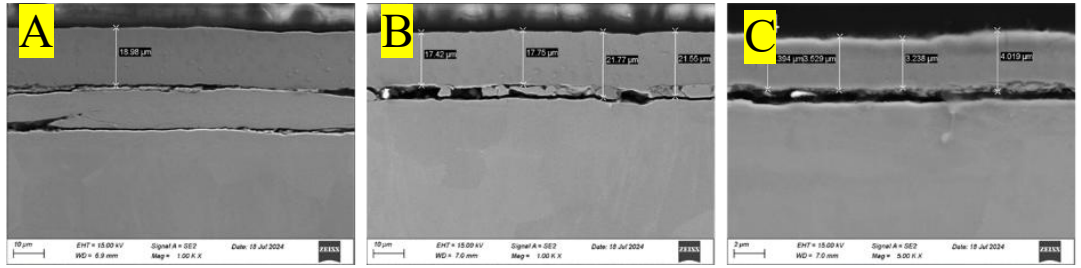
Bronze-route Nb_3Sn

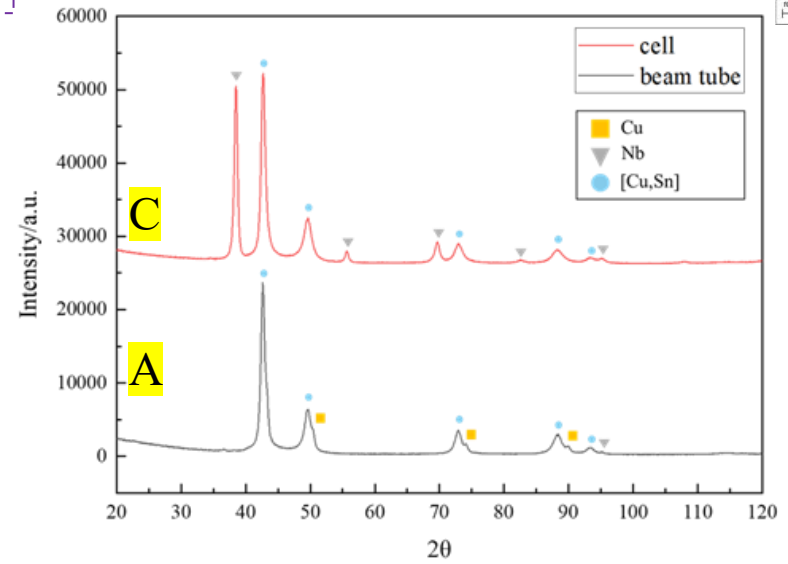
- On cavity

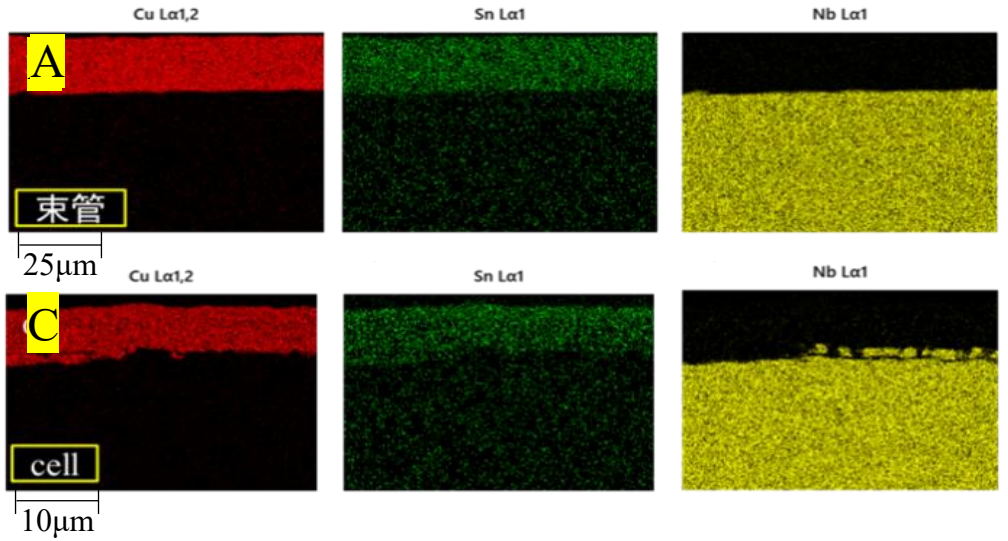
First run:
A: 2.10 μm
C: **0.35** μm
Too thin on equator





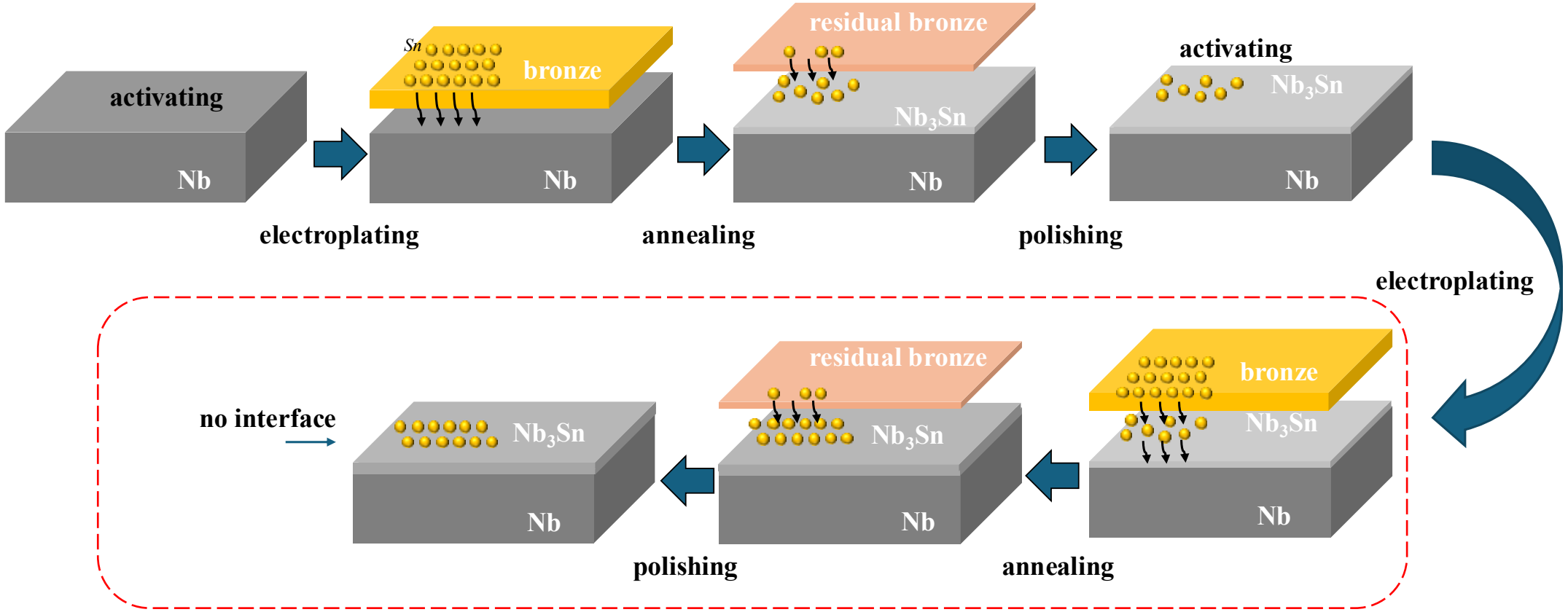






How to make the film on eq. thicker?

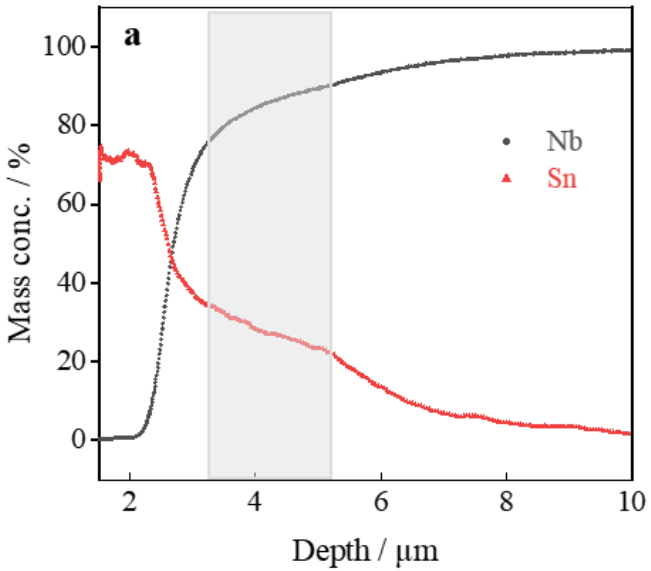
- Repeat deposition: make tin richer



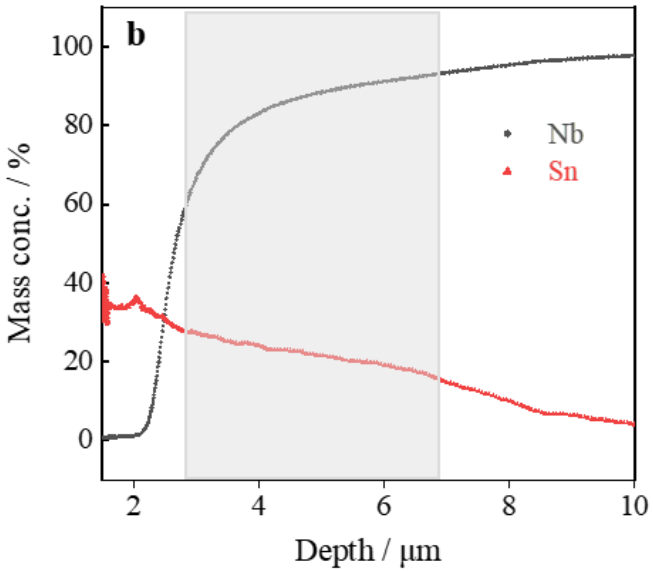
2 x electroplating

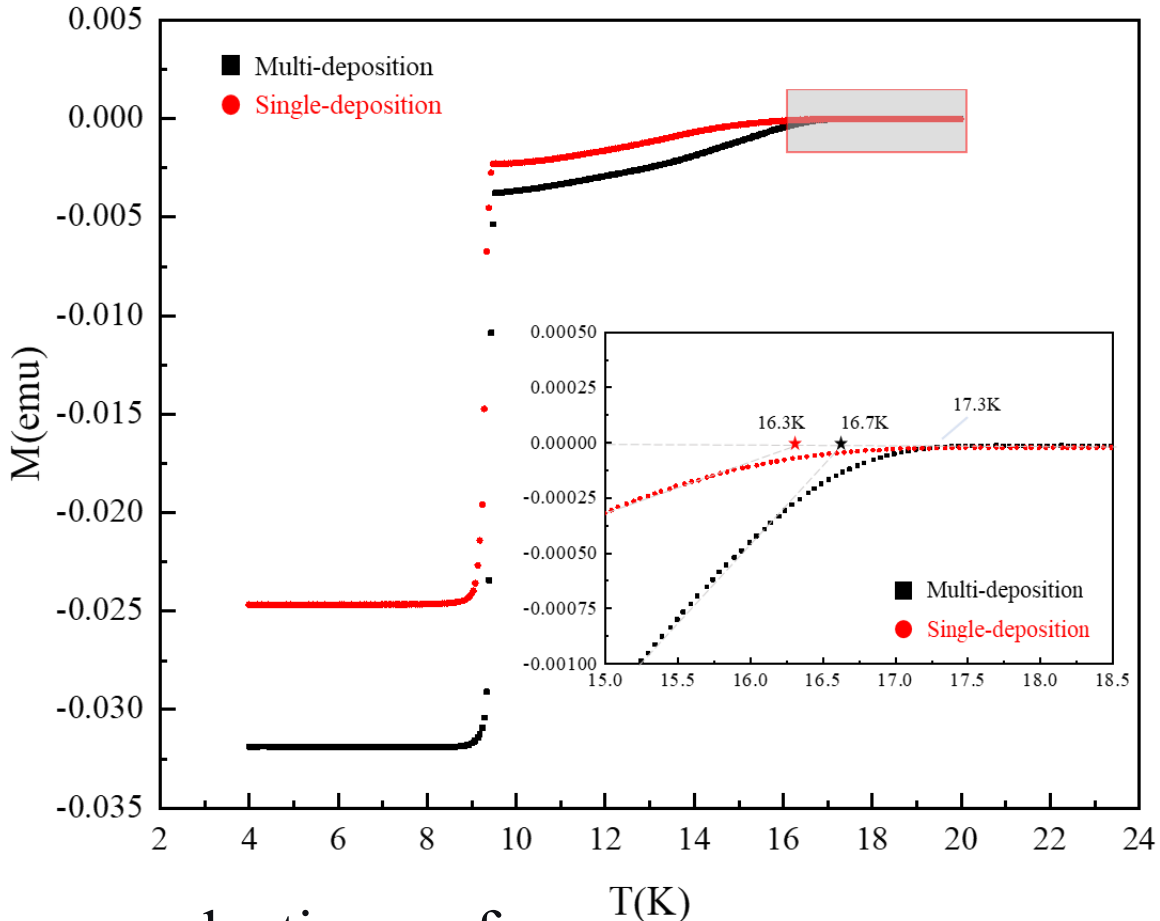
- Repeat electroplating on Nb_3Sn layer,

Sample with 10 μm bronze (single-dep.)



After another10 μm bronze (multi-dep.)

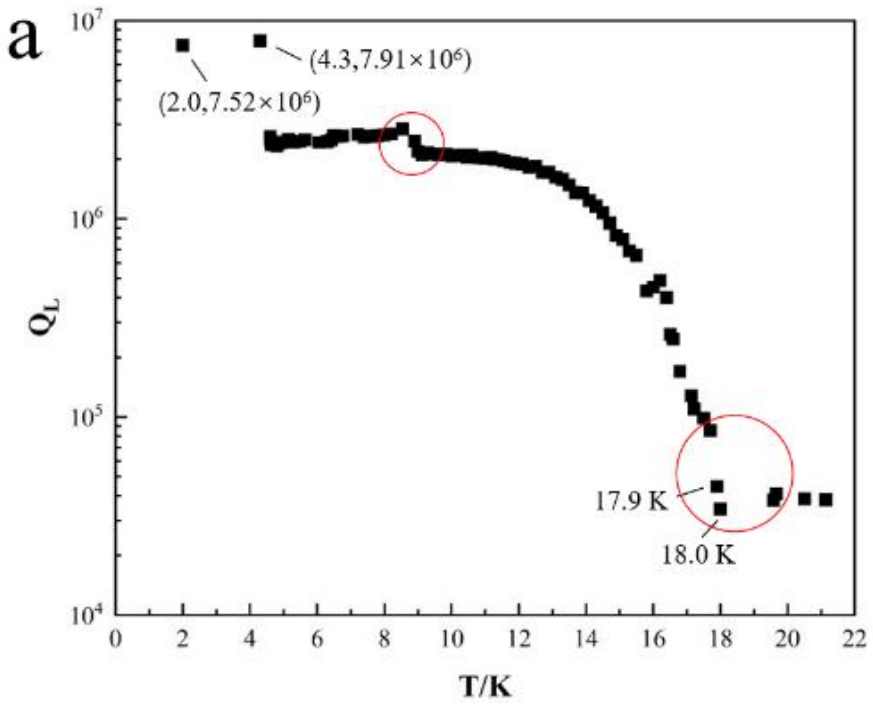


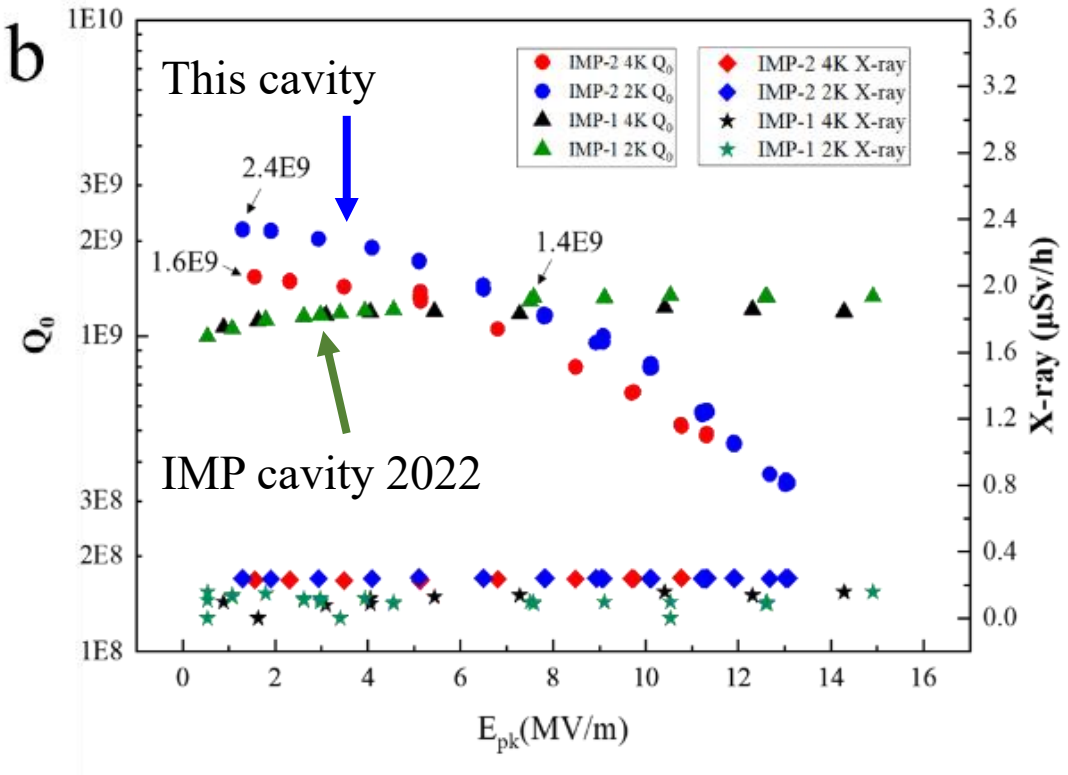


- Enables more precise control of tin supply
- Reduces thermal stress and cracking
- Improves the stoichiometry and microstructure of Nb_3Sn films, thereby enhancing their superconducting performance

Bronze-route Nb_3Sn

- On cavity





Pros: higher low field Q_0;
higher $T_{c,onset}$ from Q_L vs T

Cons: worse Q-slope
clear difference between 4K and 2K

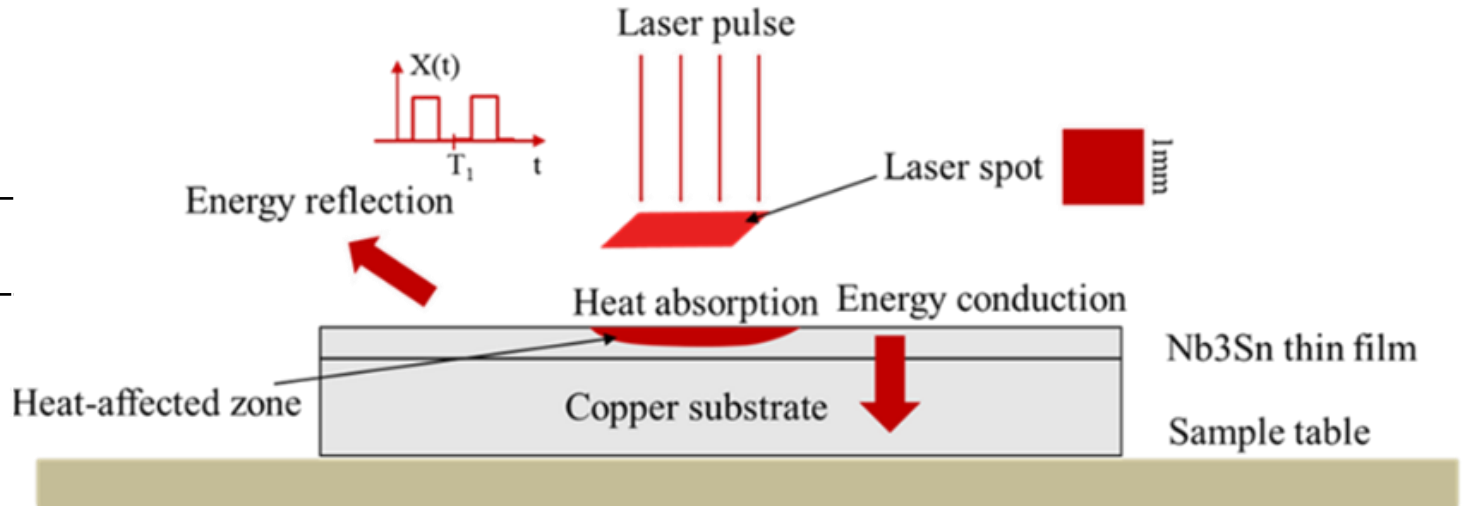
possible cause:
multi-dep.?
exposed Nb or still thin area

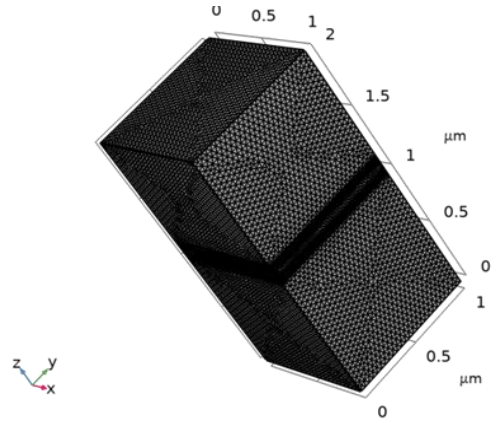
Laser Treatment

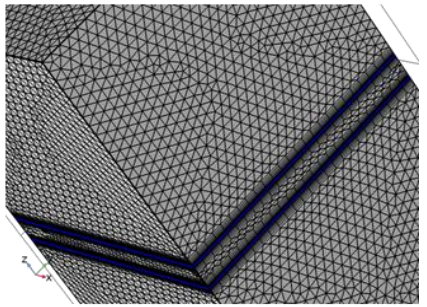
■ Laser system setup

Raycus fiber laser

Para.	Value
Pulse energy	Max. 30 mJ
Pulse width	10-30 ns
Rep. rate	10 kHz
Spot size	1 mm^2
Power flux	1 MW/mm^2

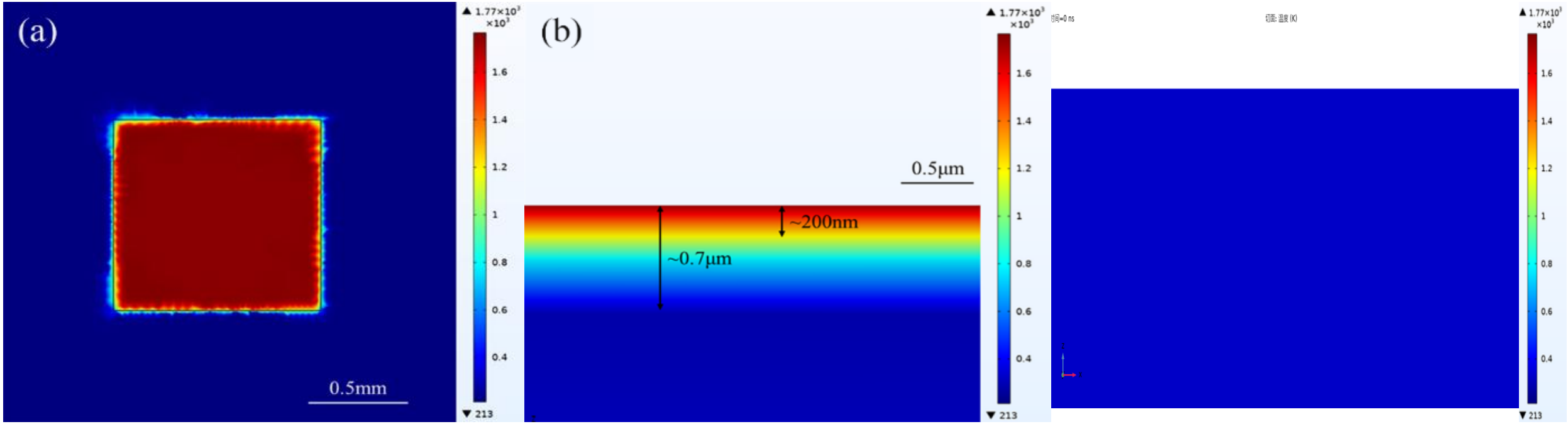






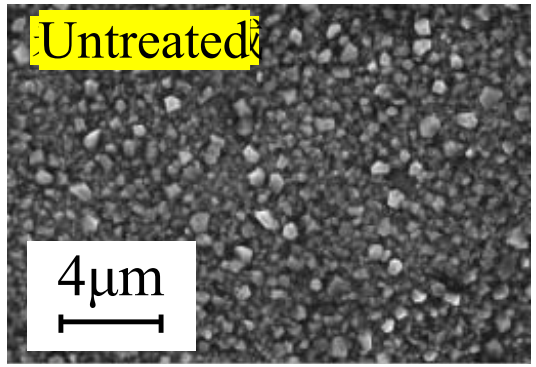
Laser heat effect

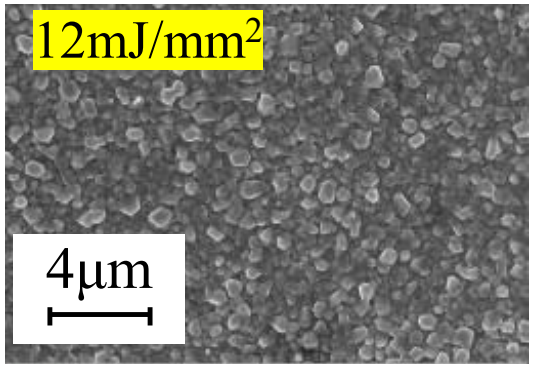
- Very small transverse HAZ
- ~0.7 μm deep HAZ

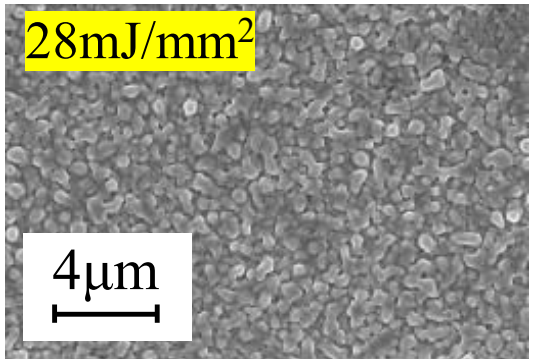


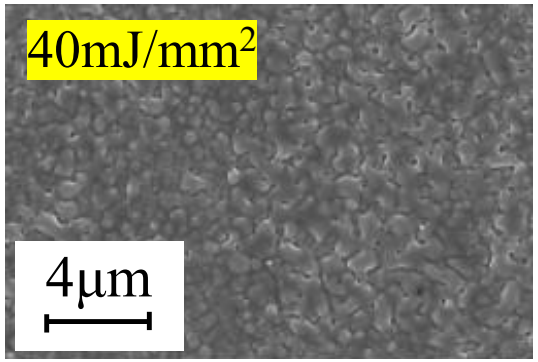
Energy deposition

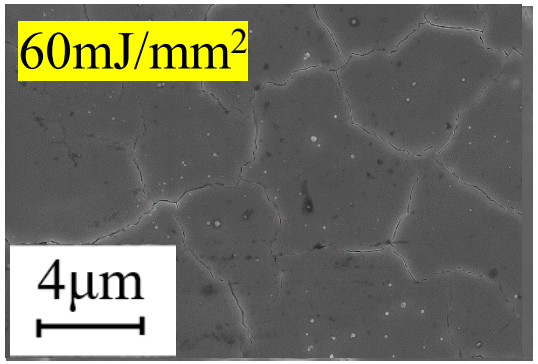
- @ 30ns pulse width
- > 40 mJ/mm² will cause crack







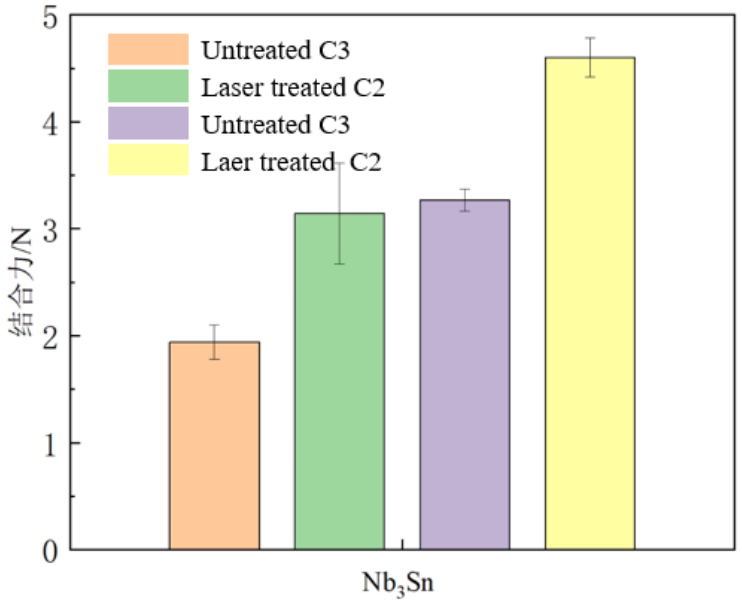


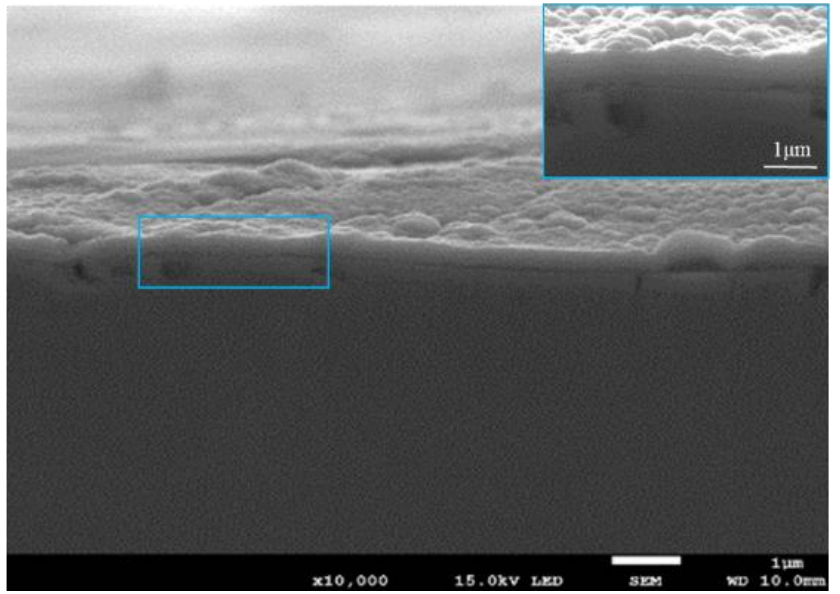


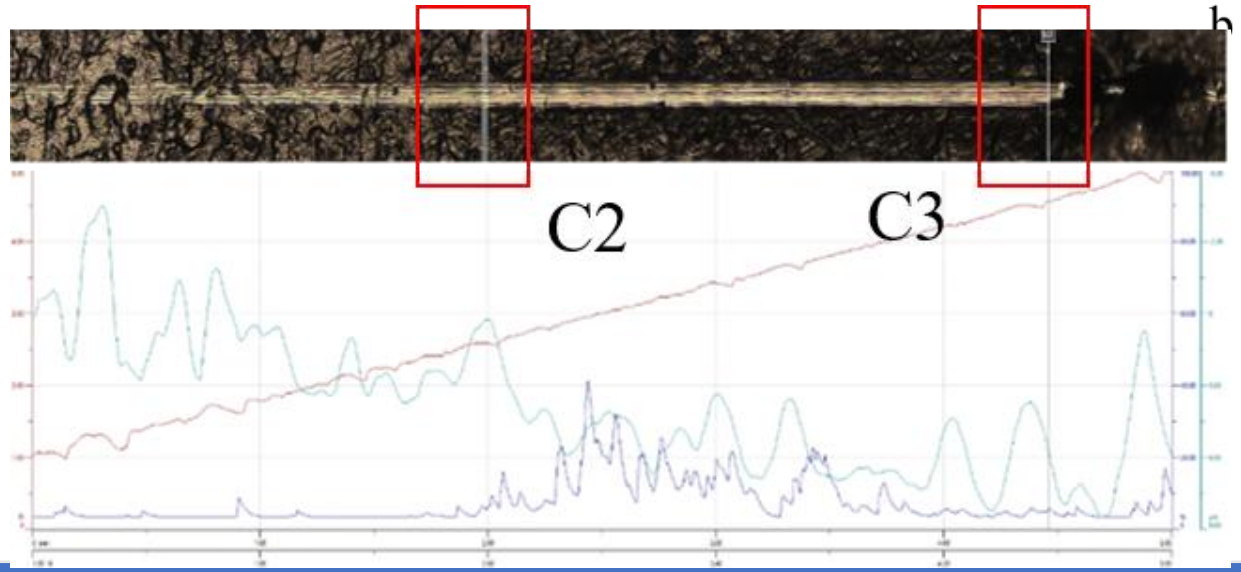
Para.	Value
Pulse width	30 ns
Rep. rate	10 kHz
Pulse energy	3 - 15 mJ
Energy flux	12 - 60 mJ/mm²

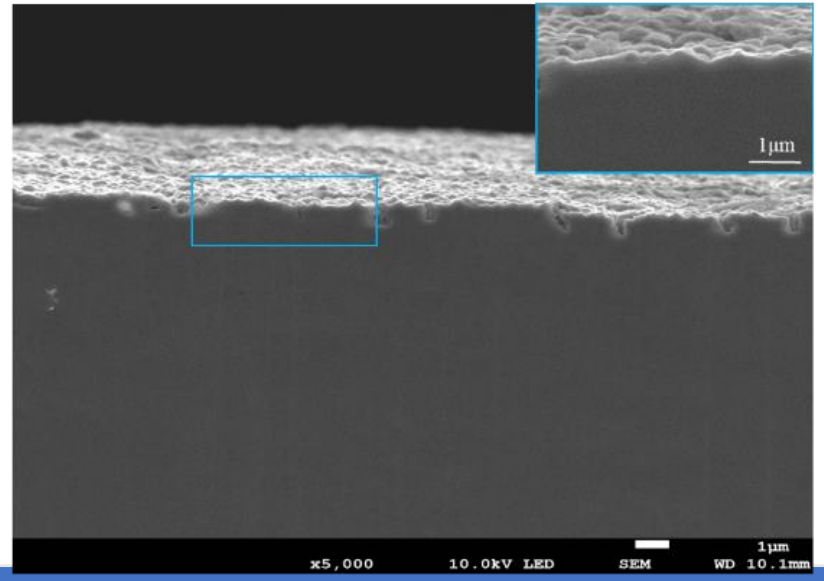
Improved adhesion

Adhesion improved by 30%



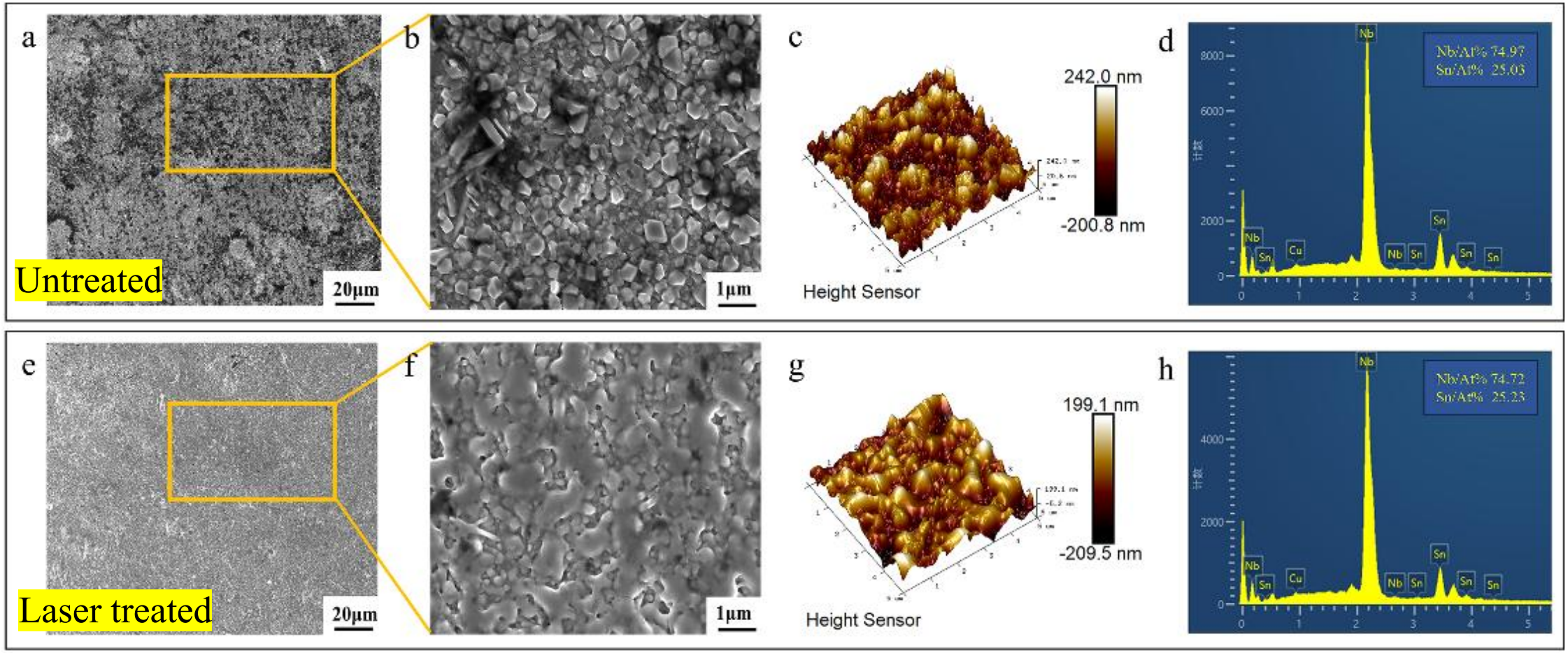






Reduced R_s

Sharp edge disappeared, R_s reduced by 17%

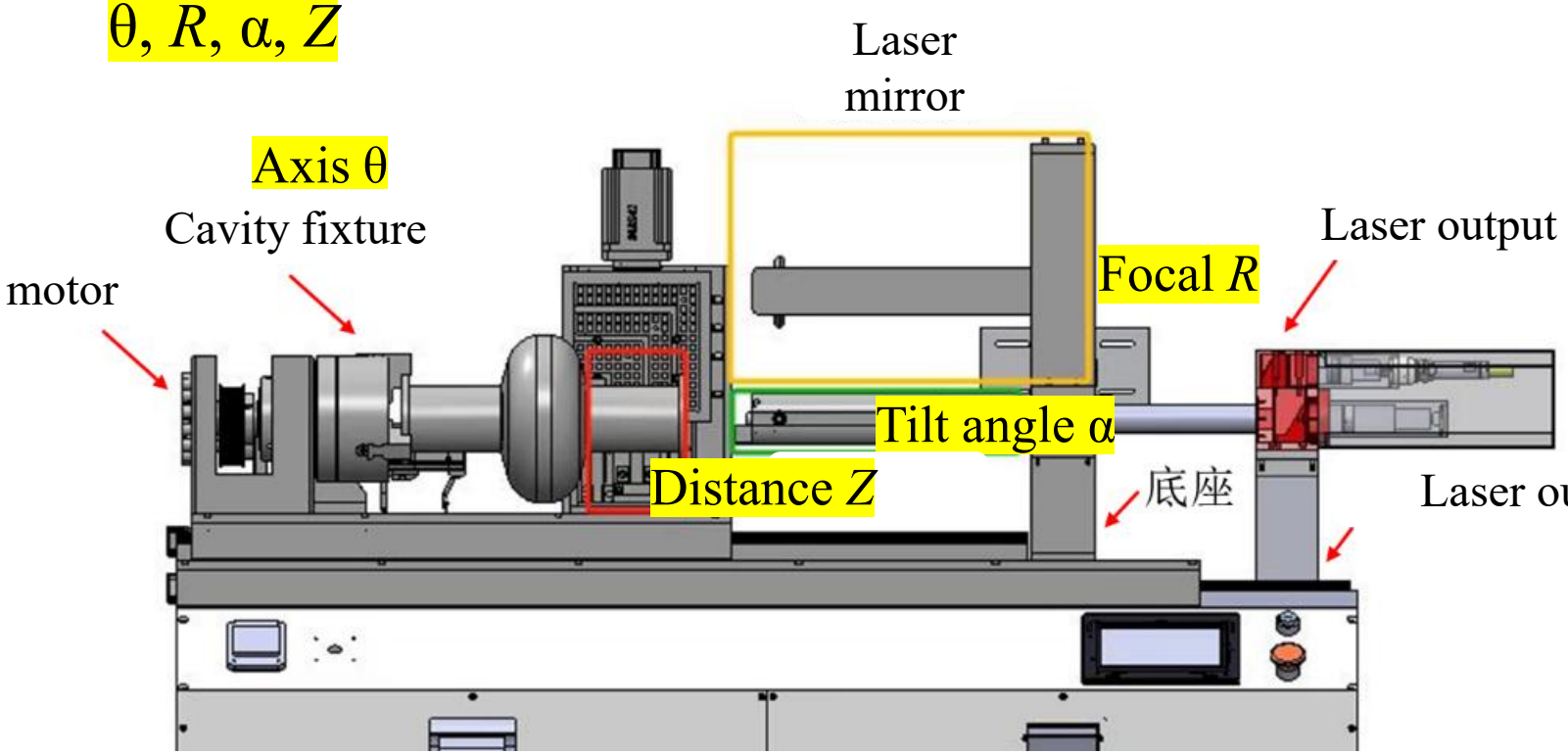


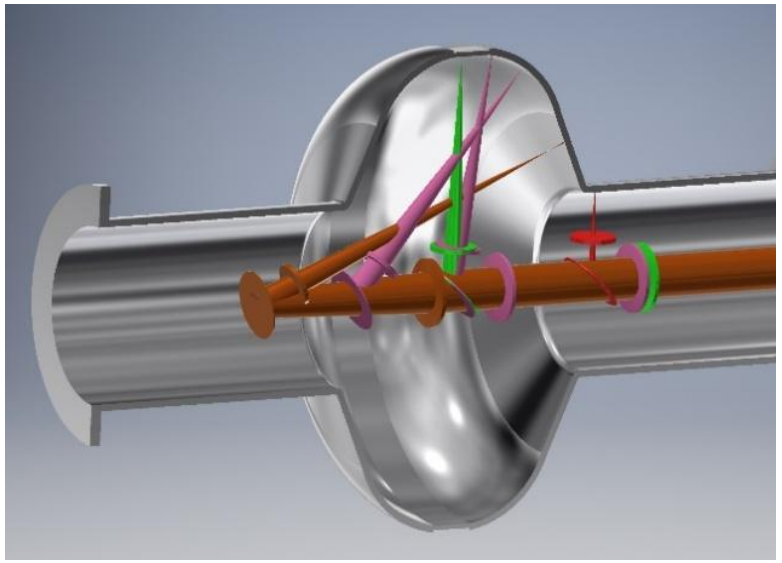
Laser treatment on the whole cavity

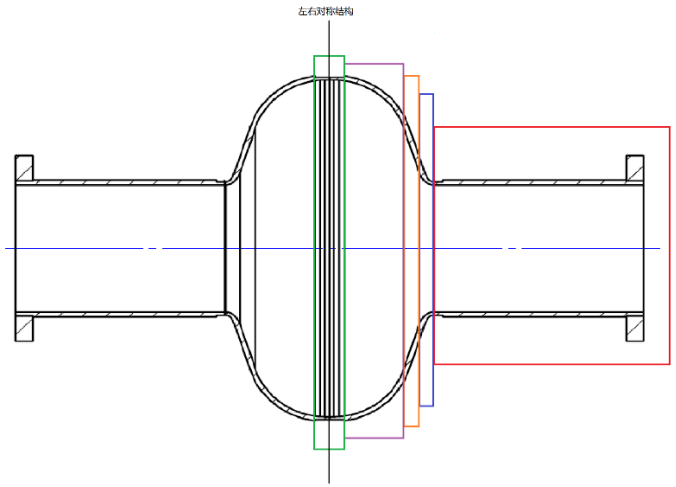
- How to deposit laser energy uniformly throughout the cavity

4 adjustable parameters:

θ, *R*, α, *Z*







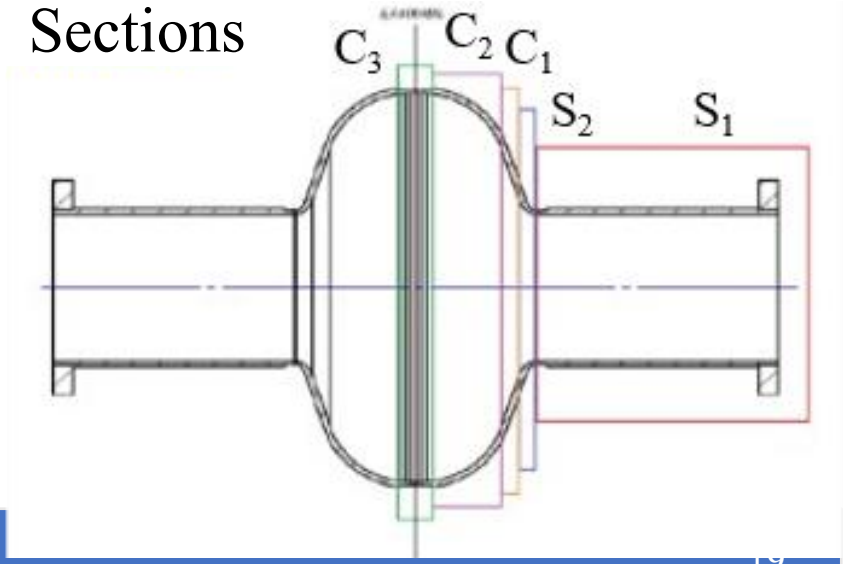
Laser treatment on the whole cavity

- How to deposit laser energy uniformly throughout the cavity
  - S1 always the easiest
  - Initial scanning met problem on other sections
  - The precision of motors and control need fine tune

After parameter tuning

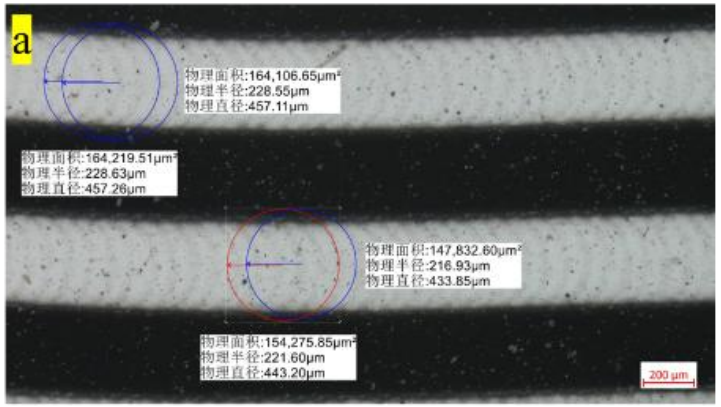
S_1 S_2 C_1 C_2 C_3

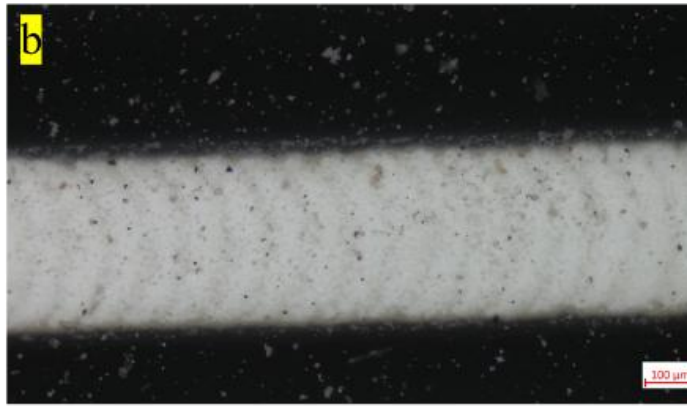
Sections

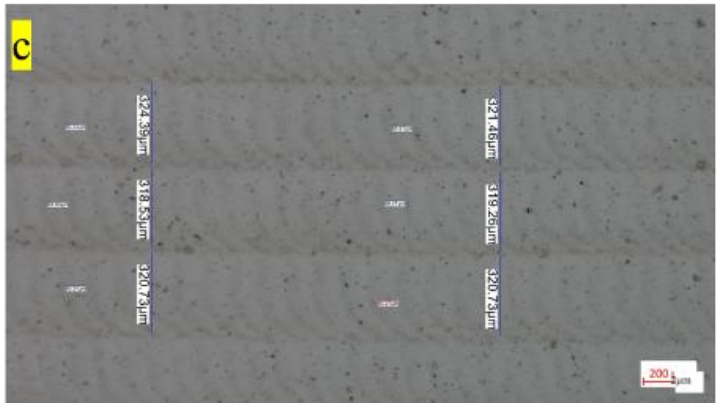


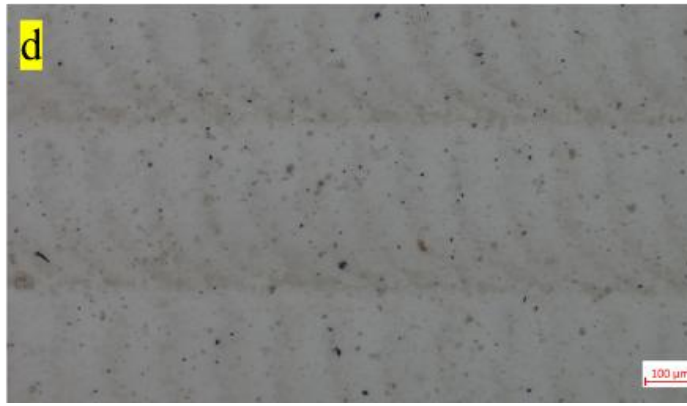
Laser treatment on the whole cavity

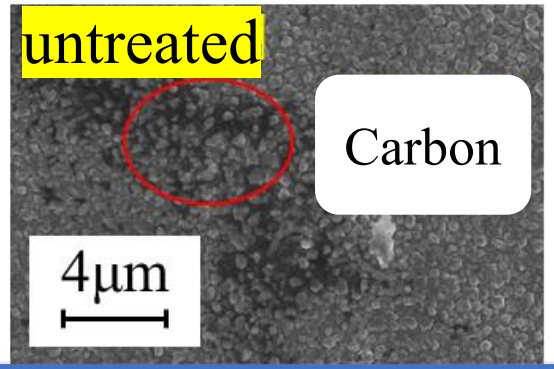
- Final processing effects
  - Continuous scan trace
  - Fixed overlap rate
  - Controllable energy deposition
  - Successful removal of carbon contamination

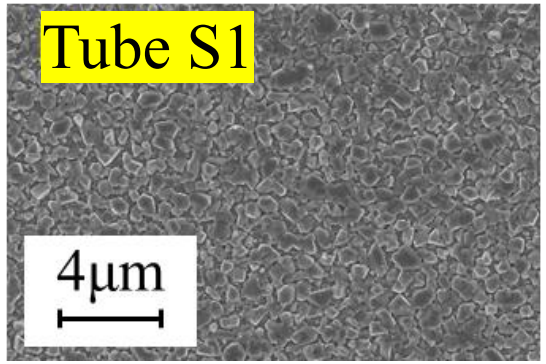


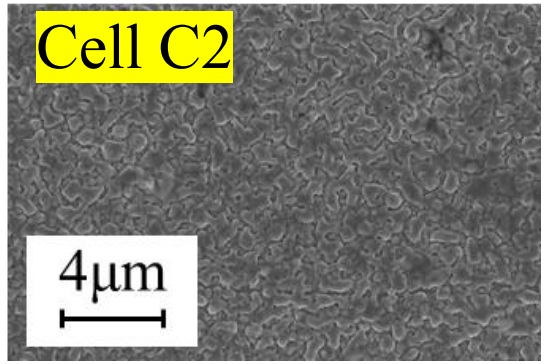












Conclusion

- Bronze-route Nb_3Sn thin film: promising approach to compact SRF machine.
- Multi-deposition process: no negative behavior on small samples but degrade the cavity performance.
- Laser treatment: improve adhesion and flatness.
- Full-cavity scan: achieve full coverage with tuning of 4 parameters set. Influence on cavity performance TBD

Thank you for you attention