



# Chemical analysis of coated Nb using SIMS

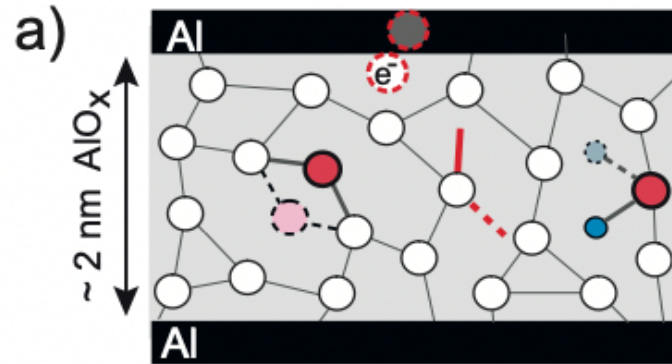
Francesco Cioni

Supervisor: Akshay Murthy

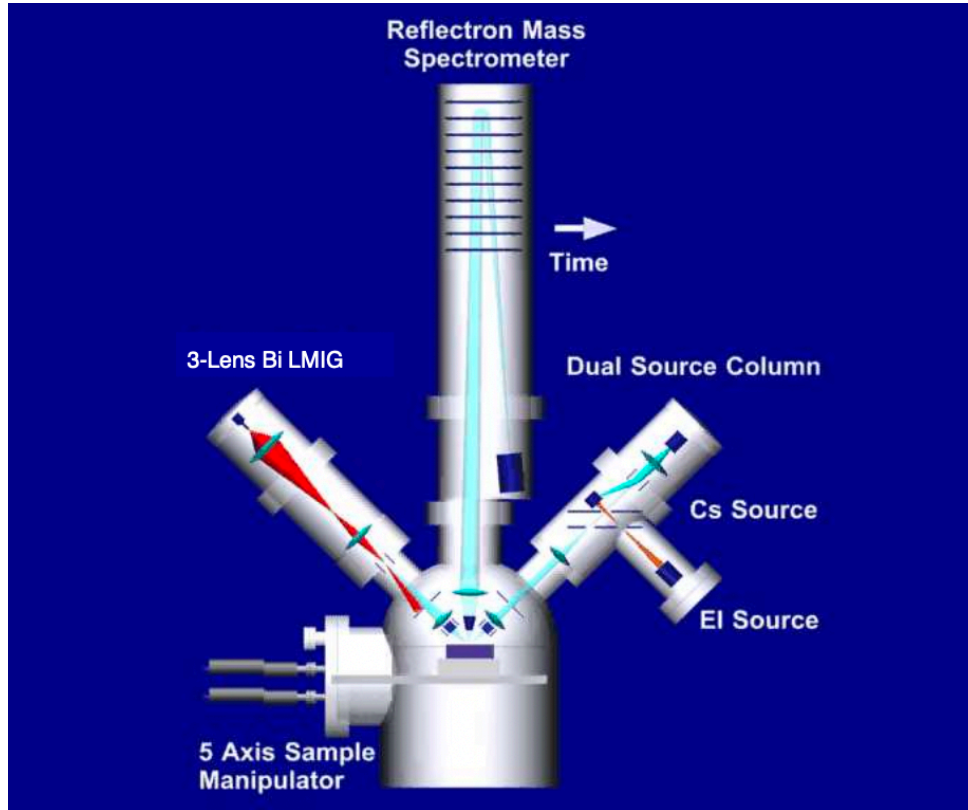
08/24/2022

- Superconducting materials are extensively employed in fundamental physics research and technology (qubits, SRF cavities)
- Native oxides on top of these materials lead to decrease in performance

- Different treatments can be used to prevent formation of these oxides
- We use SIMS to measure the effectiveness of various treatments

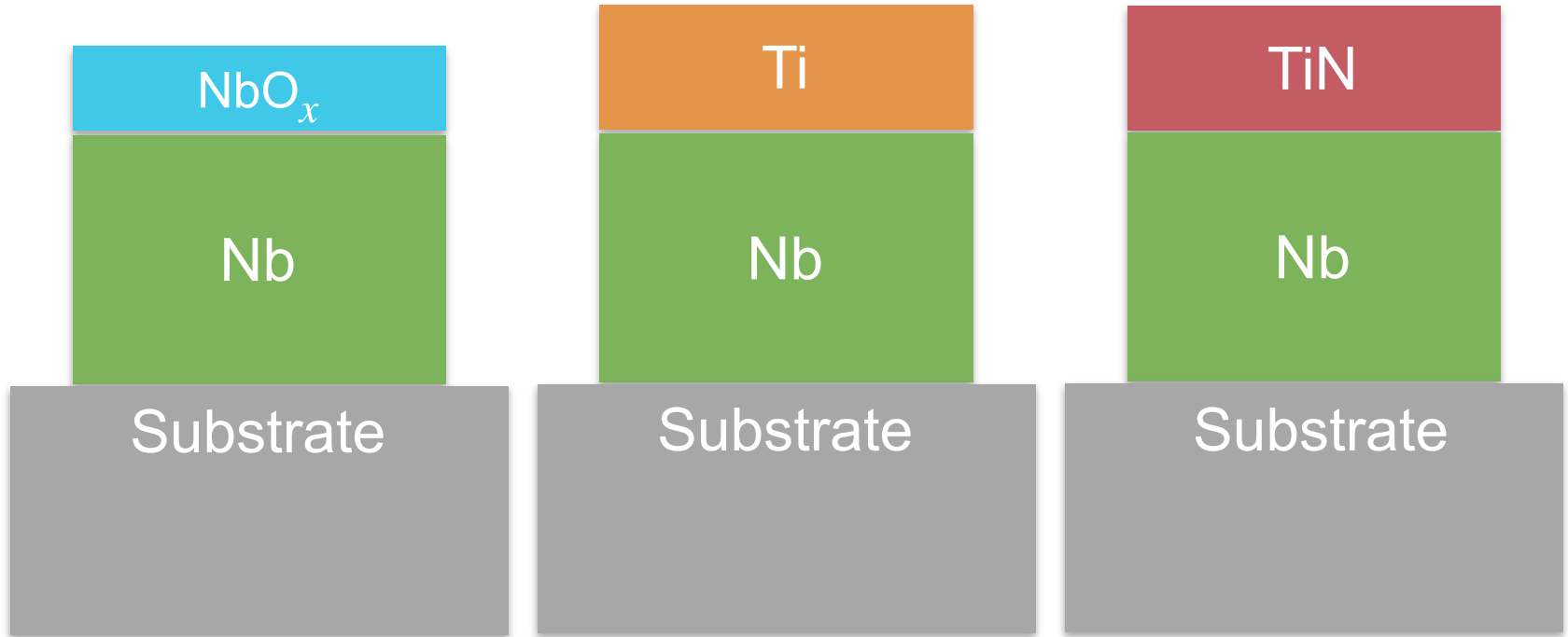


# Secondary Ion Mass Spectrometry (SIMS)



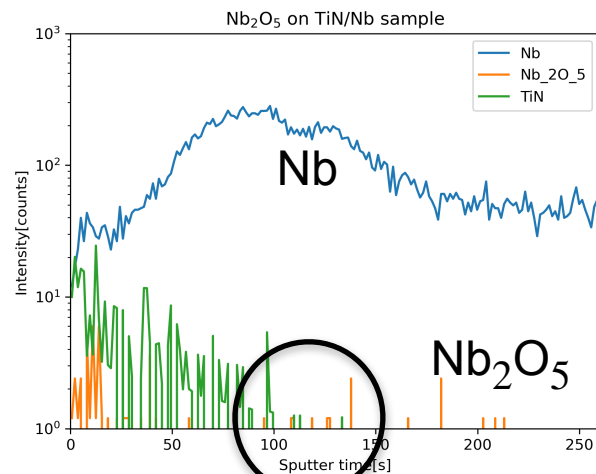
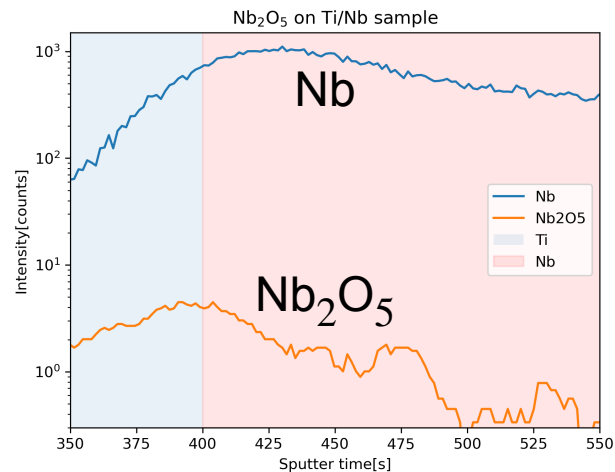
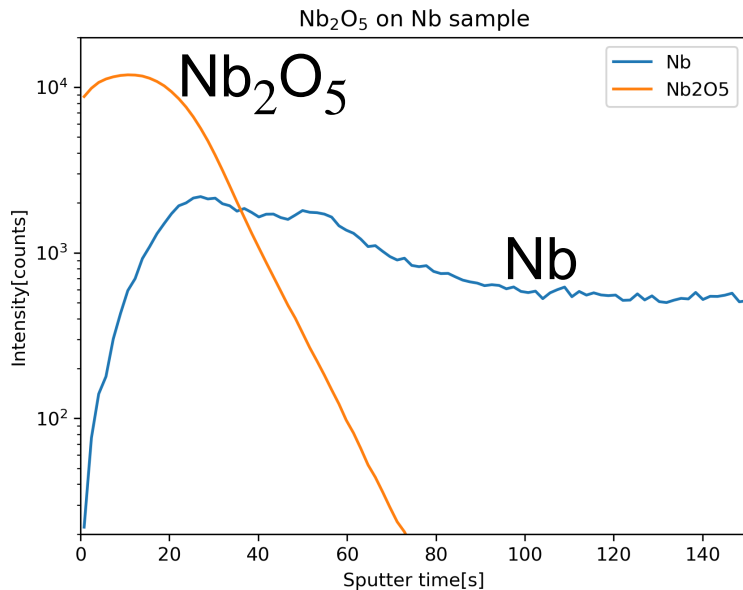
- Depth profiling of thin films
- Parts per million chemical understanding of the compounds present in the sample
- Detection of all elements (even very light ones)

An additional layer deposited on top of Niobium could prevent the formation of lossy Nb-oxides



# Effectiveness of the method

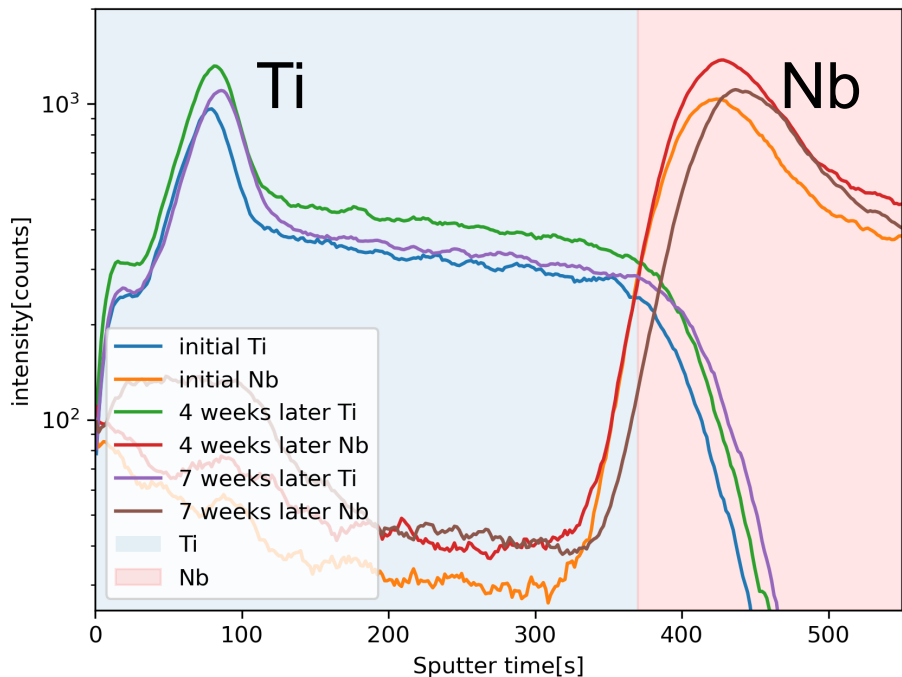
Reduction by more than three orders of magnitude in  $\text{Nb}_2\text{O}_5$  counts



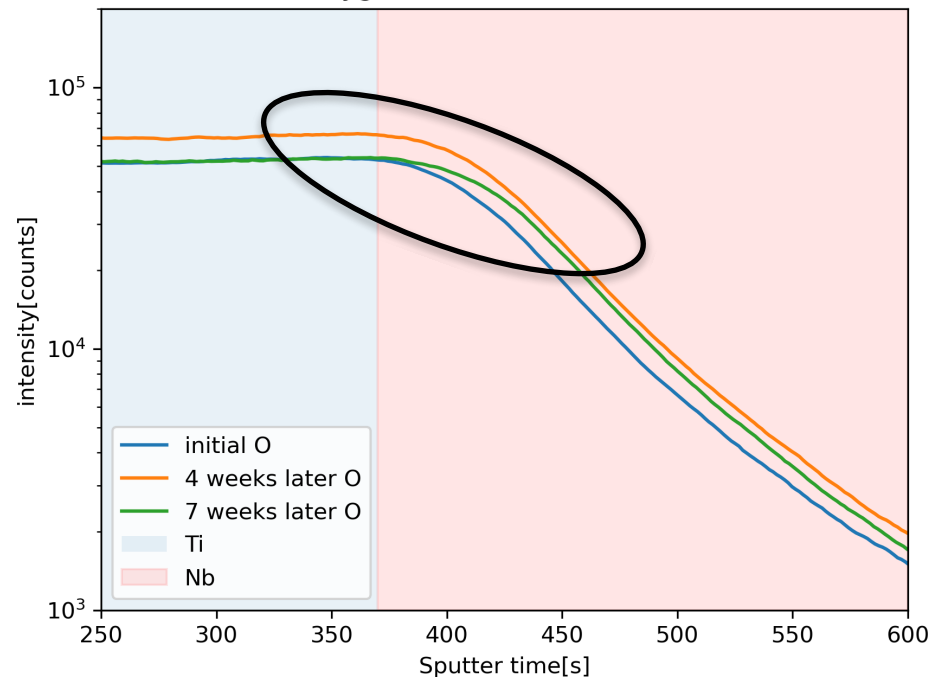
How long are these treatments effective for?

# Ti on Nb system - time study

Ti/Nb interface

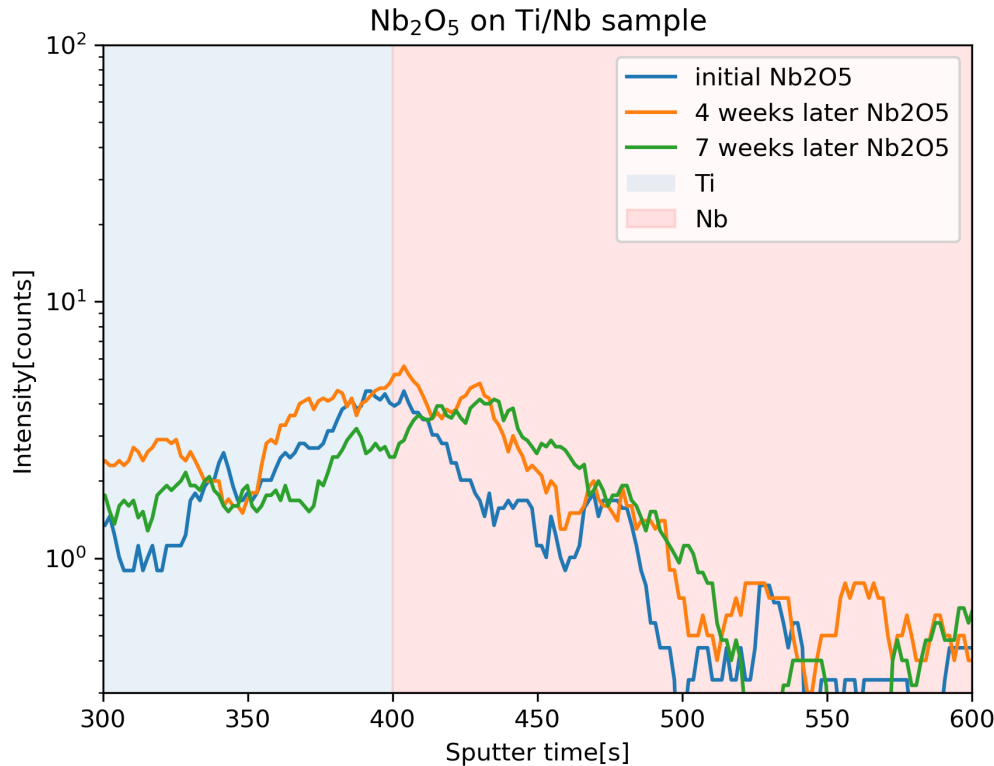


Oxygen at the Ti/Nb interface



- Distinct Ti/Nb separation at the interface
- Minimal O diffusion over time into the Nb

# Ti on Nb system - time study

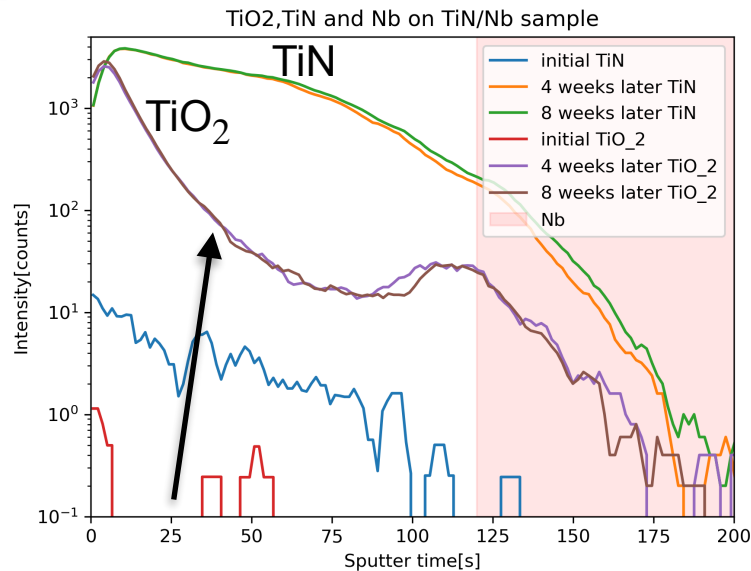
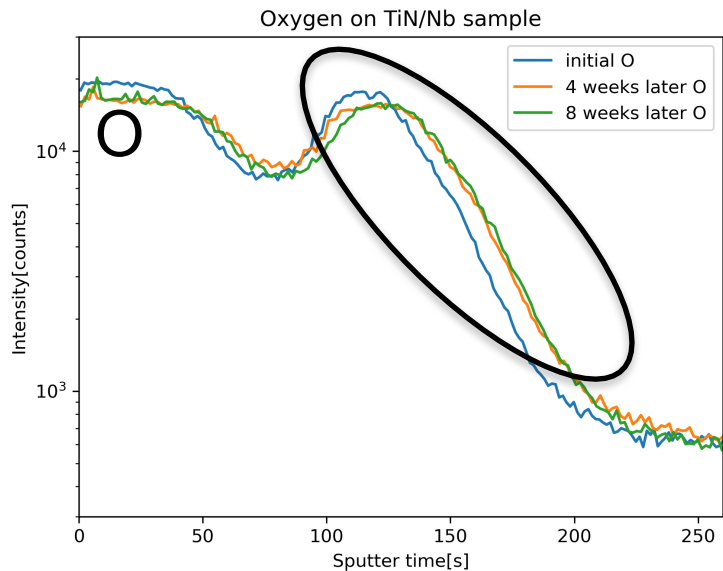


- No evidence of NbO<sub>x</sub> growth during the 7 weeks
- The Ti/Nb system is very stable!!



# TiN on Nb system - time study

## 3 different measurements 4 weeks apart



- Some O diffusion into the Nb during the first 4 weeks
- Increase in TiO<sub>2</sub> signal during the first 4 weeks
- Oxides growth seem to stop in less than 4 weeks

# How does heating affects the sample?

# In situ SIMS heating experiment

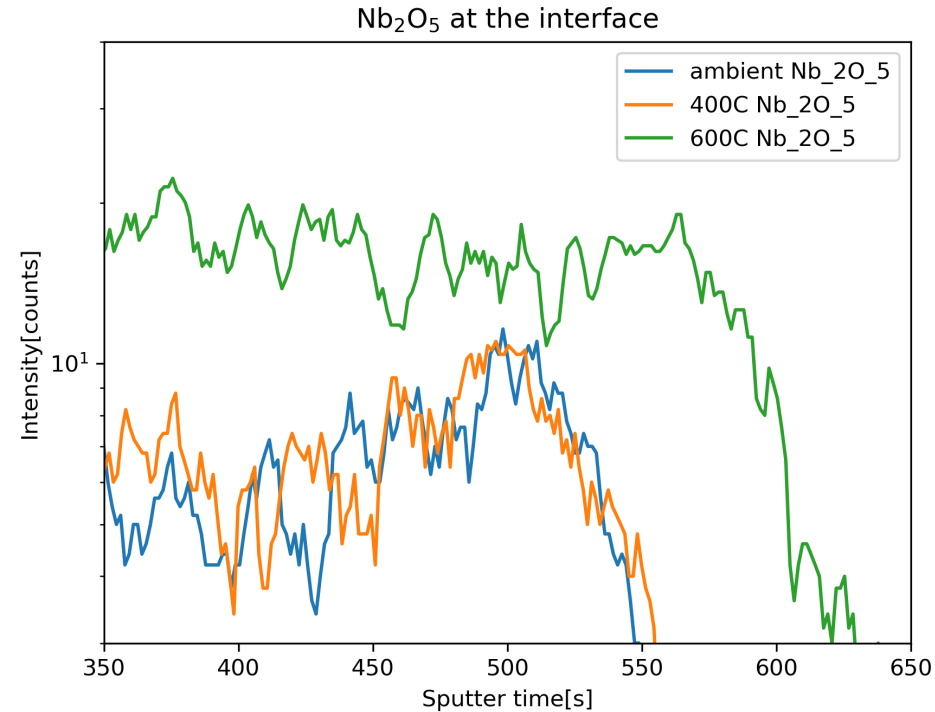
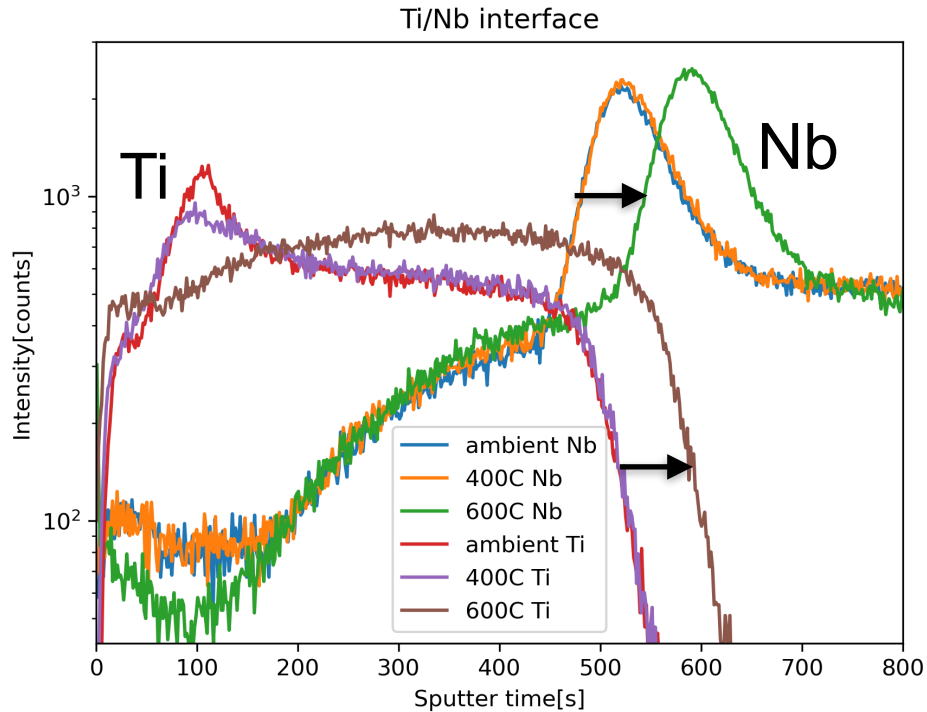
6 measurements in total

- 2 for reference before any heating
- 2 after 2.5 hours at  $400^{\circ}\text{C}$  in UHV
- 2 after 2 hours at  $600^{\circ}\text{C}$  in UHV

Similar kind of study on pure Nb samples in [2],[3],[4]. Improvements in SRF cavity performance were studied.

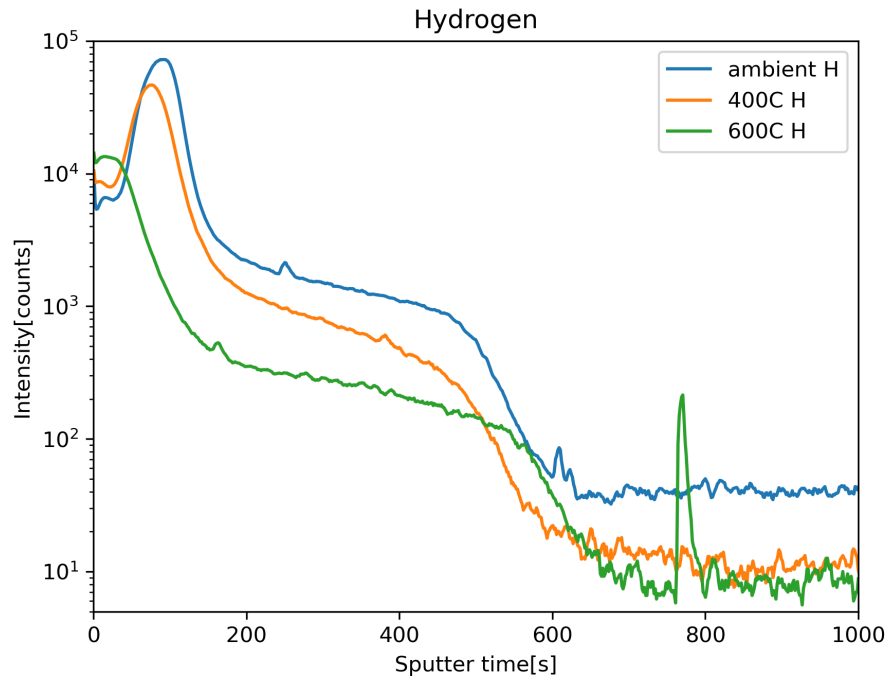
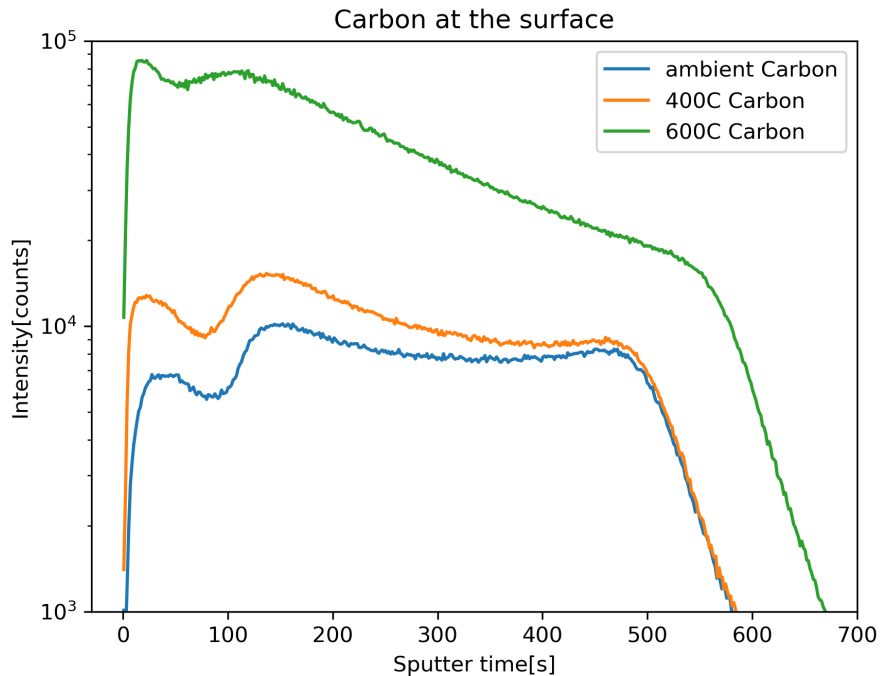
- [2] A. Romanenko et al. “Three-Dimensional Superconducting Resonators at  $T < 20$  mK with Photon Lifetimes up to  $\tau = 2$  s” (2020)
- [3] A. Bose et al. “Evolution of surface oxides and impurities in high vacuum heat treated Nb: A TEM and TOF-SIMS in-situ study, mechanism and repercussions on SRF cavity applications” (2020)
- [4] D. Bafia et al. “Magnetic Suboxides as a Source of Two-Level System Losses in Superconducting Niobium” (2022)

# Ti heating studies



- 600C treatment causes changes in the shape of Ti signal and location of the interface. The origin of such changes is unclear

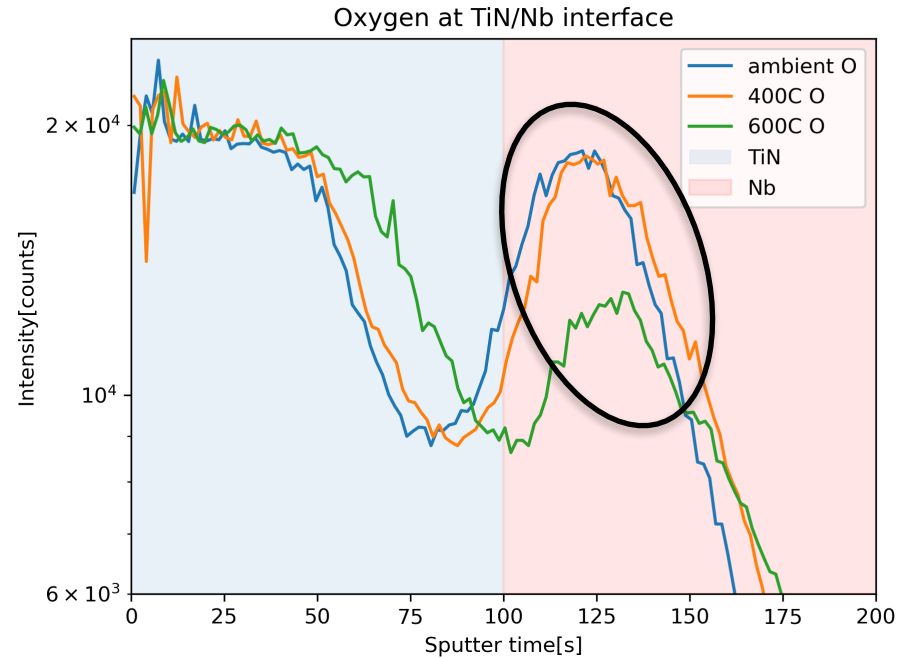
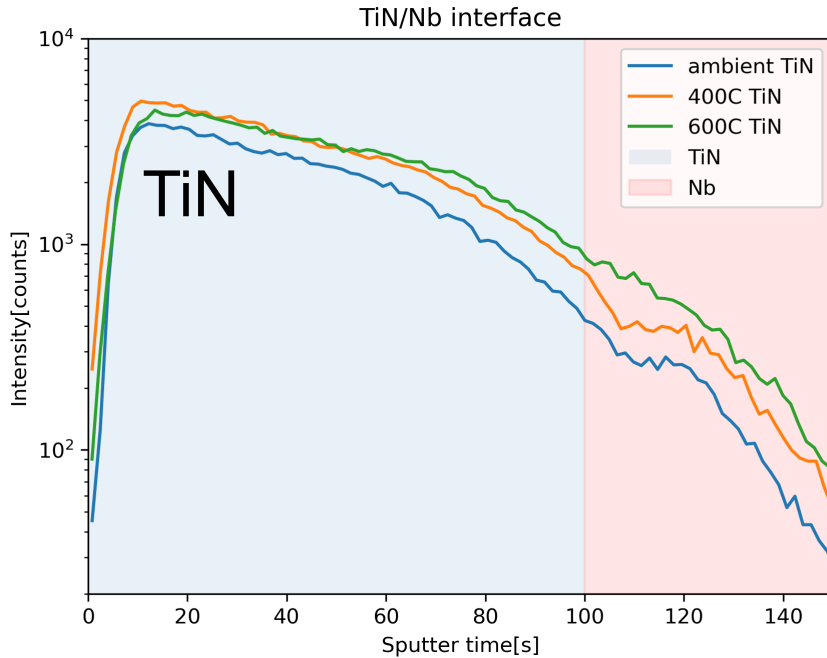
# Possible origin of structural change following 600C heat treatment



- Possible C incorporation after 600C ( $\text{TiO}_2$  into  $\text{TiC}$ ) may be the cause of structural changes
- H counts appear to decrease with annealing

# TiN heating studies

The same heating cycles were repeated for TiN coating



- Minimal diffusion of Ti into Nb with increasing temperature
- Small decrease in Oxygen at the TiN/Nb interface after 600°C

# Summary

- The method is effective in preventing the formation of Nb-oxides
- Time study results did not see any significant  $\text{NbO}_x$  growth in 7-8 weeks
- The Metal/Nb interface seem very stable after heating cycles. Further measurements are needed to confirm the origin of some structural changes
- Oxides reduction is observed after 600C heating cycles

# Bibliography

- [1] C. Muller et al. “Towards understanding two-level-systems in amorphous solids - Insights from quantum devices” (2017)
- [2] A. Romanenko et al. “Three-Dimensional Superconducting Resonators at  $T < 20$  mK with Photon Lifetimes up to  $\tau = 2$  s” (2020)
- [3] A. Bose et al. “Evolution of surface oxides and impurities in high vacuum heat treated Nb: A TEM and TOF-SIMS in-situ study, mechanism and repercussions on SRF cavity applications” (2020)
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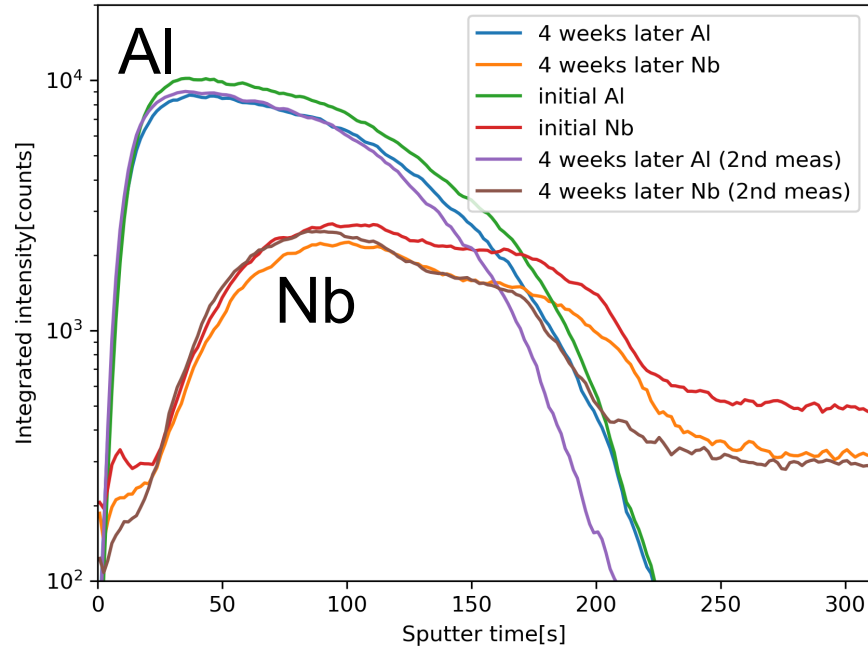


# Thank you for listening!

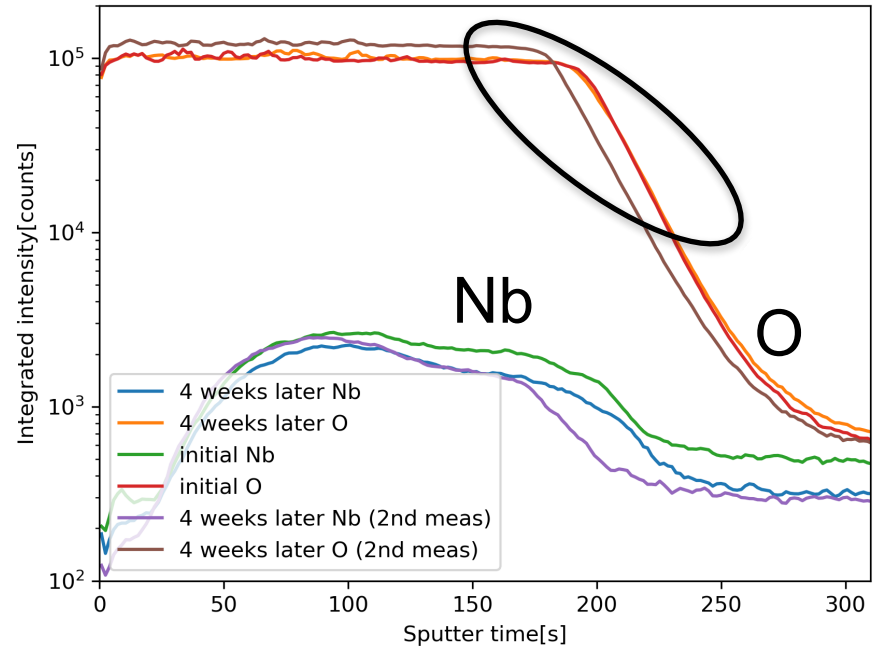
Special thanks to Akshay, Silvia and  
5 Sauk Circle

# Al coating data

Al/Nb interface



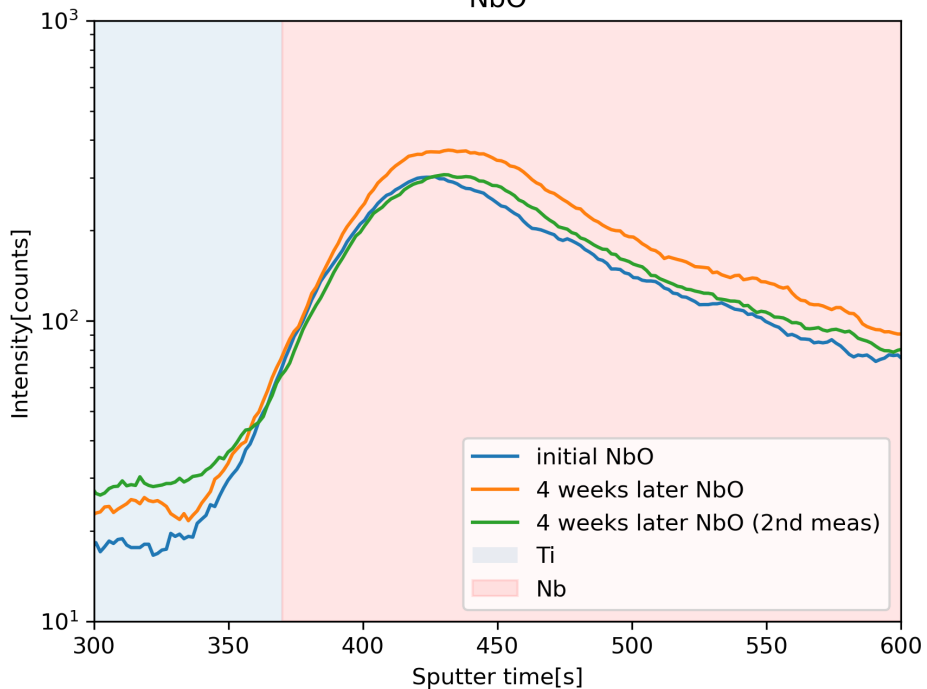
Oxygen at the Al/Nb interface



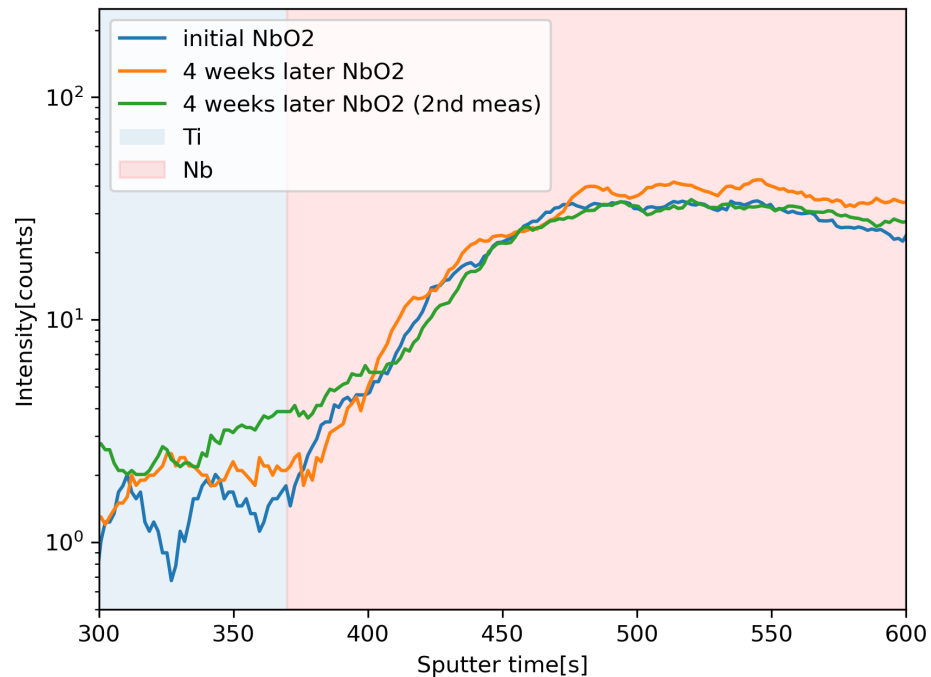
- No O diffusion or change in time in the  $\text{NbO}_x$
- Bad Al/Nb separation probably due to alloying of the two

# Ti coating

## NbO

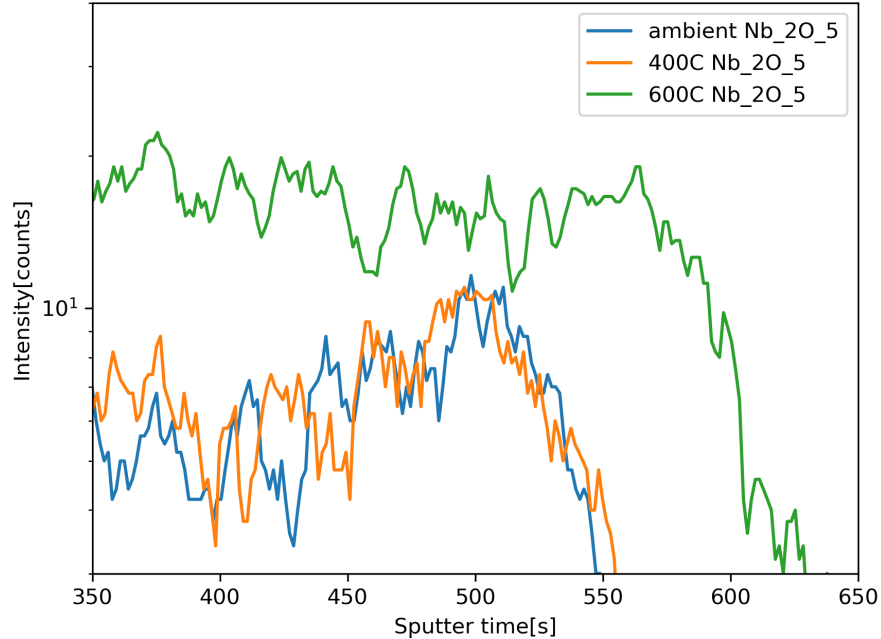


## NbO2

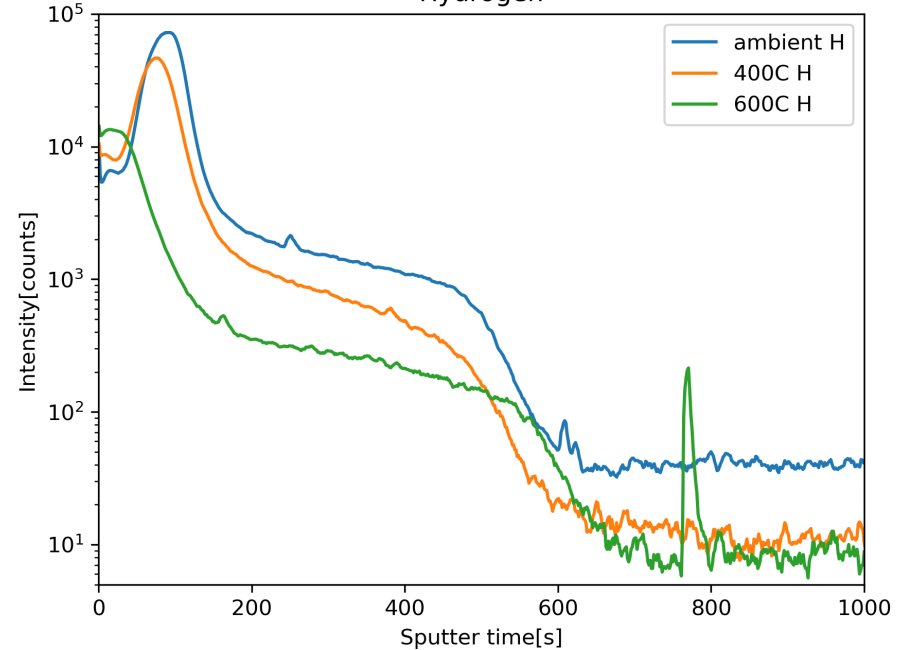


# Ti heating studies

Nb<sub>2</sub>O<sub>5</sub> at the interface



Hydrogen



- Small increase in the Nb<sub>2</sub>O<sub>5</sub> counts after 600°C
- Decrease in Hydrogen contribution at the surface after each heat treatment