Impact of Annealing on the Chemical and Superconducting Properties of Ta Thin Films

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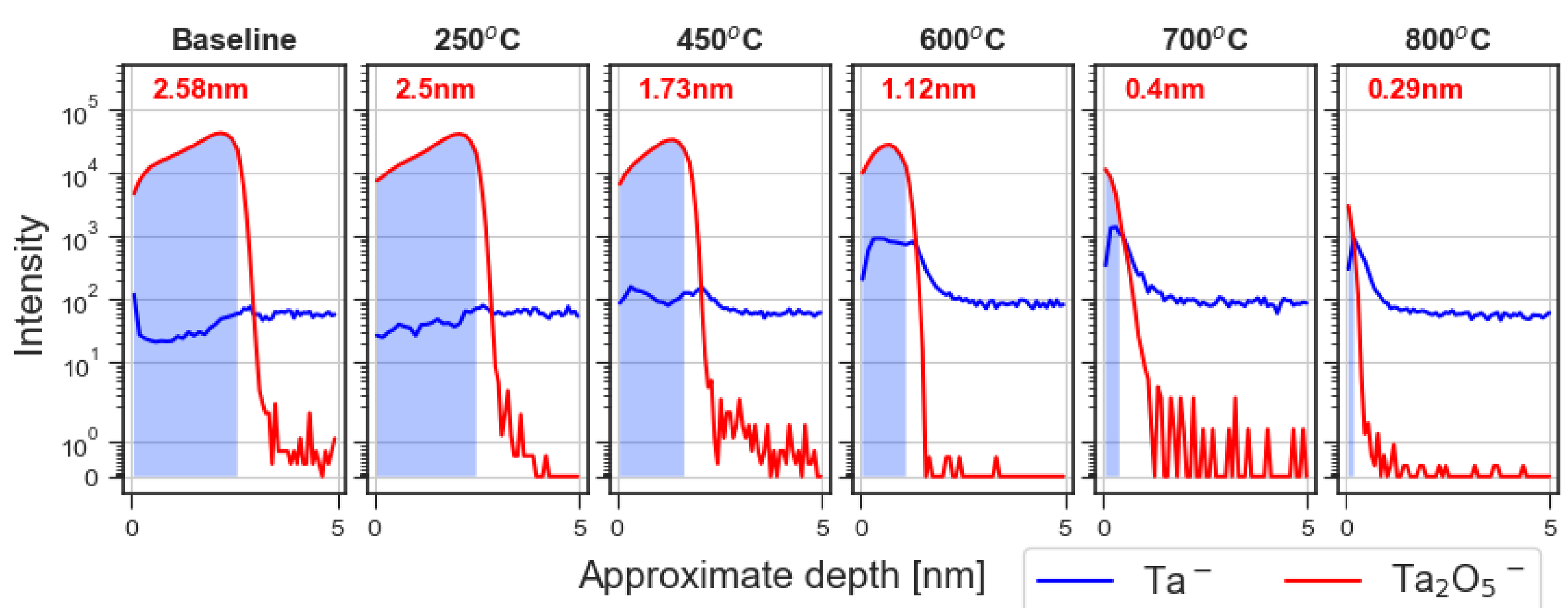
Overview

Native oxides on the superconducting capacitor plates of qubits introduce dielectric loss ultimately limiting the qubit coherence times. Encapsulating Nb qubits with other metals, Ta, Au, and Re, has shown to extend the lifetimes, and annealing SRF cavities to dissolve the oxide is known to further increase quality factor. Ta-based qubits outperform Nb devices, thus reducing the native oxide could results in improvements.

In this work, Ta thin films were annealed to dissolve the surface oxide and the resulting changes in chemistry and superconducting properties were examined. The goal is to determine how annealing affects the Ta thin film and assess whether this method can be utilized in future fabrication processes.

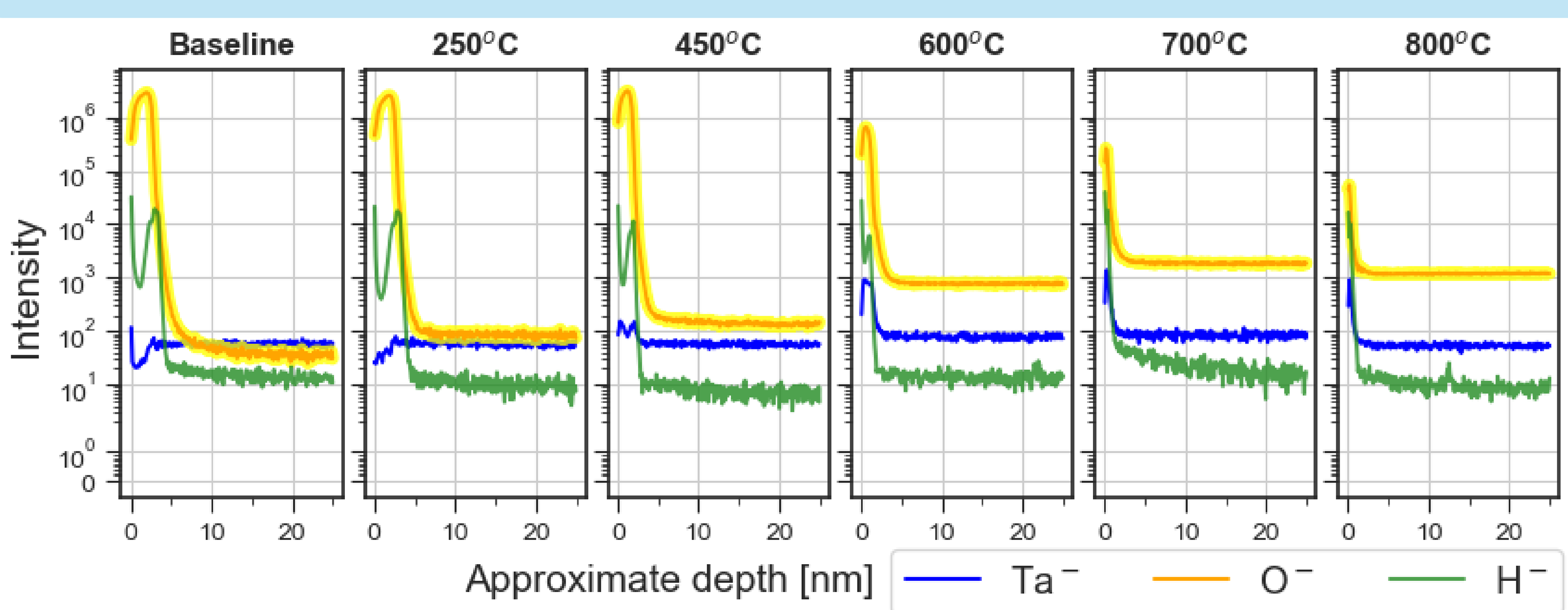
Oxide Dissolution



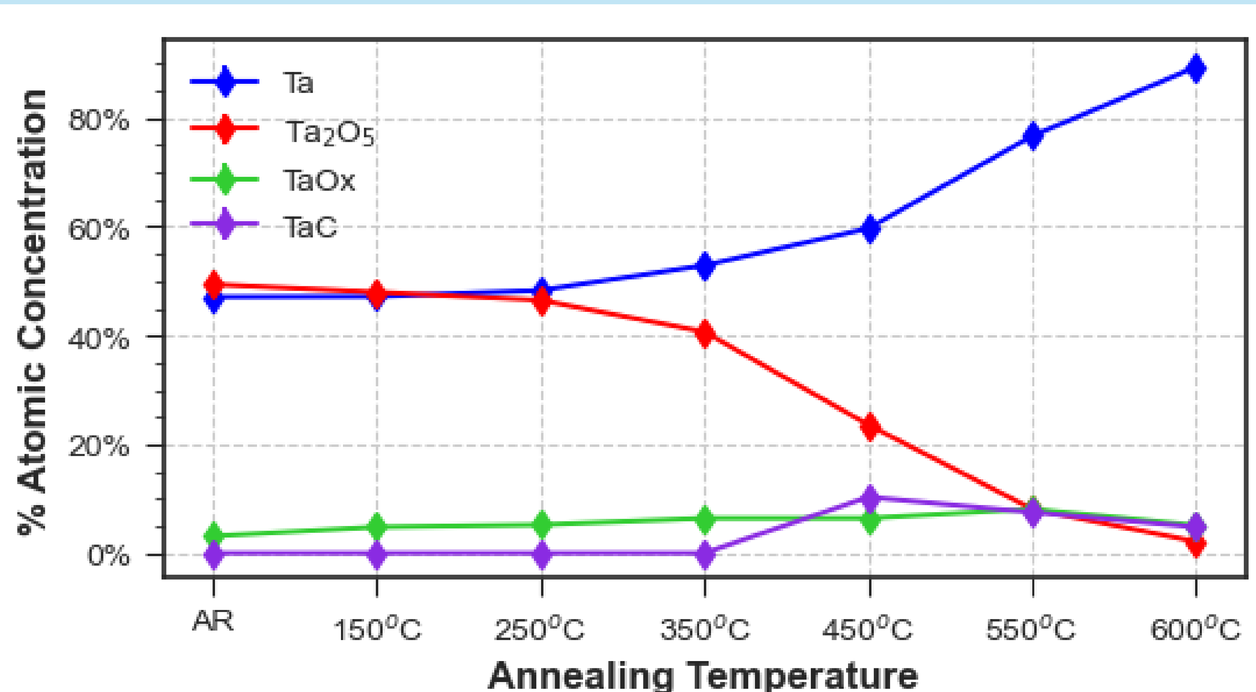
Impact on the chemistry

Annealing causes:

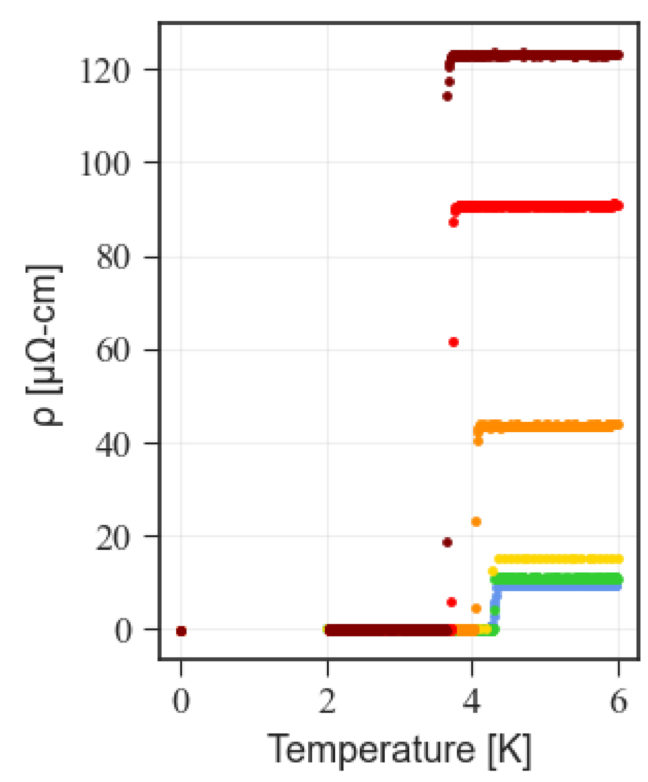
- ❑ Increase in oxygen conc within the film
- ❑ Degassing of hydrogen

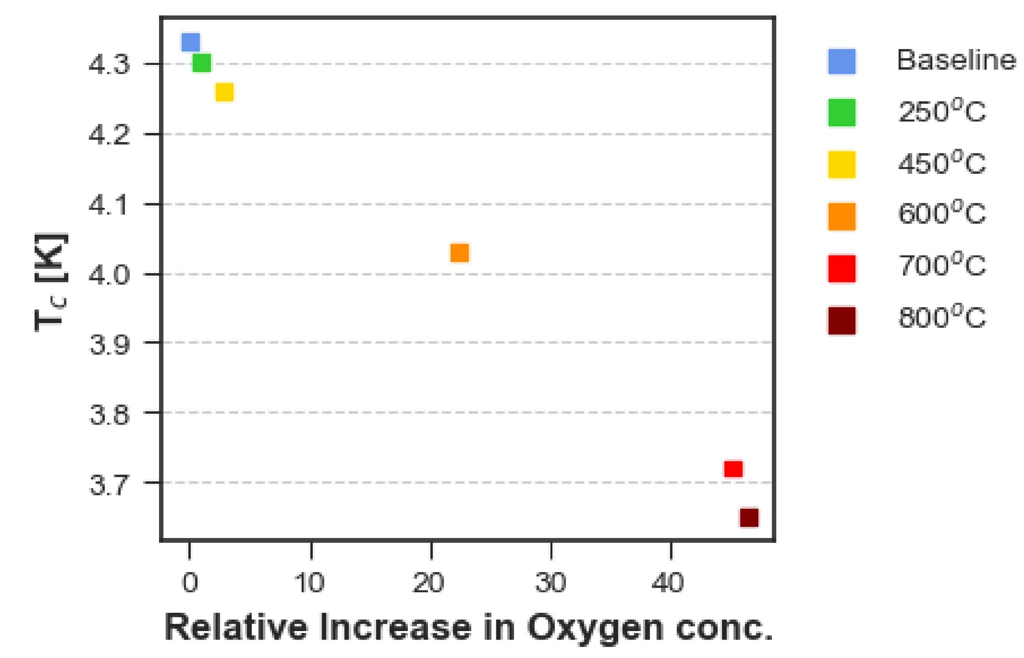


- ❑ Increases suboxide conc. relative to the native oxide
- ❑ Formation of TaC at temperatures 450˚C and above.



Superconducting properties

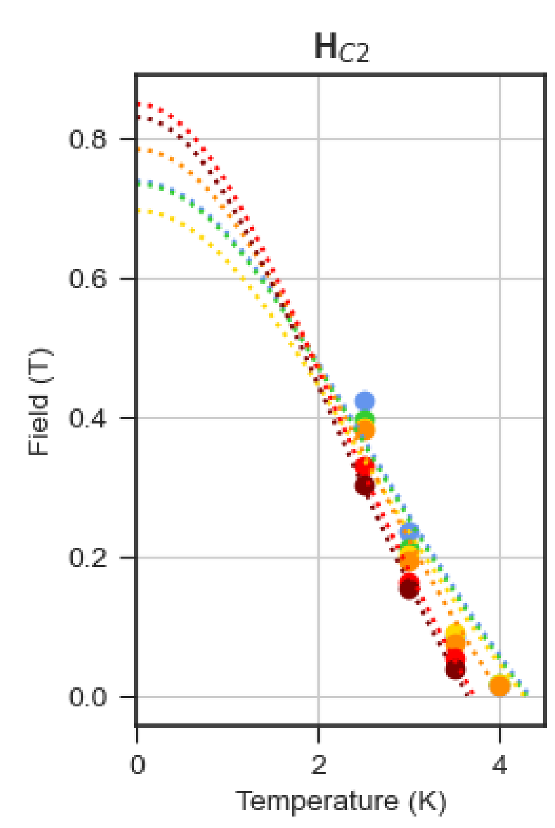




Sample	Tc	RRR
Baseline	4.33 K	19.47
250˚C	4.30 K	18.68
450˚C	4.27K	10.42
600˚C	4.03K	4.91
700˚C	3.72 K	3.11
800˚C	3.65K	2.76

Oxygen incorporation suppresses the critical temperature and raises the resistivity leading to a lower quality thin film.

$$H_{C2}(T) = H_{C2}(0)\left[\frac{1-\left({}^{T}/_{T_c}\right)^2}{1+\left({}^{T}/_{T_c}\right)^2}\right] \qquad H_{c2}(0) = \frac{\Phi_o}{2\pi\xi^2(0)}$$



Sample	Hc2(0) [T]	ξ (0) [nm]
Baseline	0.745	21.03
250˚C	0.733	21.20
450˚C	0.699	21.70
600˚C	0.783	20.51
700˚C	0.848	19.71
800˚C	0.829	19.94

While a decrease in coherence is seen with increasing annealing temperature, there is no strong correlation between the two.

Conclusion

1. Tantalum requires temperatures higher than 800˚C to dissolve its native oxide.
2. Annealing diffuses the oxygen into the film and results in the lowering of its T_c and RRR.
3. The impact of a layer of tantalum carbide on the surface of the film performance is still unknown.

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