The Role of Oxygen Concentration in Enabling High Gradients in Niobium SRF Cavities

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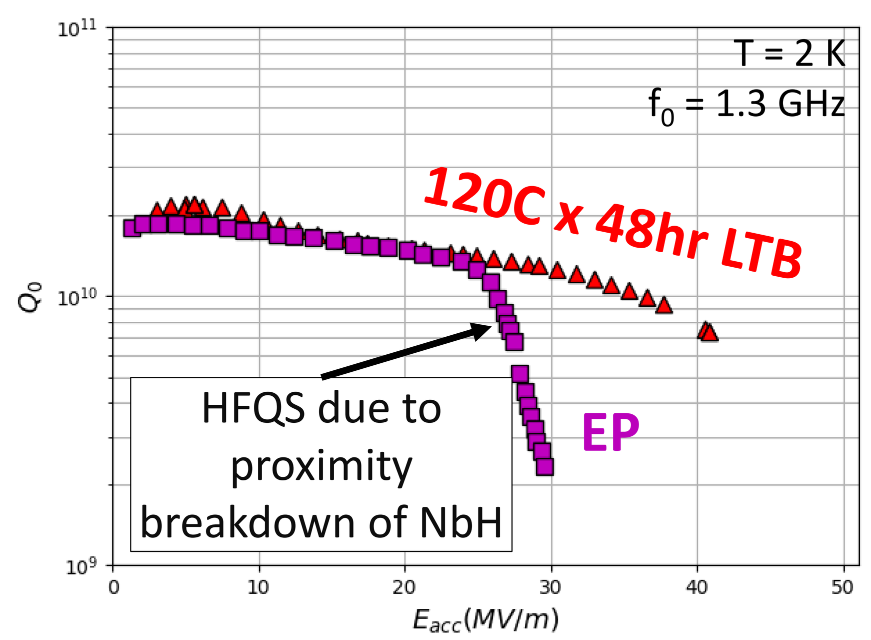
1. Introduction

We studied the role of *O concentration with depth* in the *performance of Nb SRF cavities*. An ensemble of electropolished 1.3 GHz single-cell cavities, all of which initially showed high field Q-slope (HFQS), was subjected to sequential testing and treatment with *in-situ low temperature baking at various temperatures*. We find that gradually *increasing the integrated bake duration causes* (i) an *increase in the onset of HFQS* until it is absent up to quench (ii) a *non-monotonic relationship with the quench field* with a peak near ~90 nm (iii) an *evolution of the R_{BCS} toward a non-equilibrium behavior that drives anti-Q slope*. One possible driver for the observed phenomena stems from the diffusion of O from the oxide. Our findings support the hypothesis that the *mitigation of HFQS* that arises from 120 C *in-situ* LTB is *mediated by the diffusion of O* from the native oxide which prevents the precipitation of proximity-coupled nano-hydrides, in turn enabling higher quench fields. The observed decrease in quench field for cavities in which O has been diffused >90 nm from the RF surface may be due to a reduction of the field limit in the SS bilayer structure. We also suggest that the *observed evolution of R_{BCS} occurs due to the absence of proximity coupled inclusions, bringing about non-equilibrium effects.*

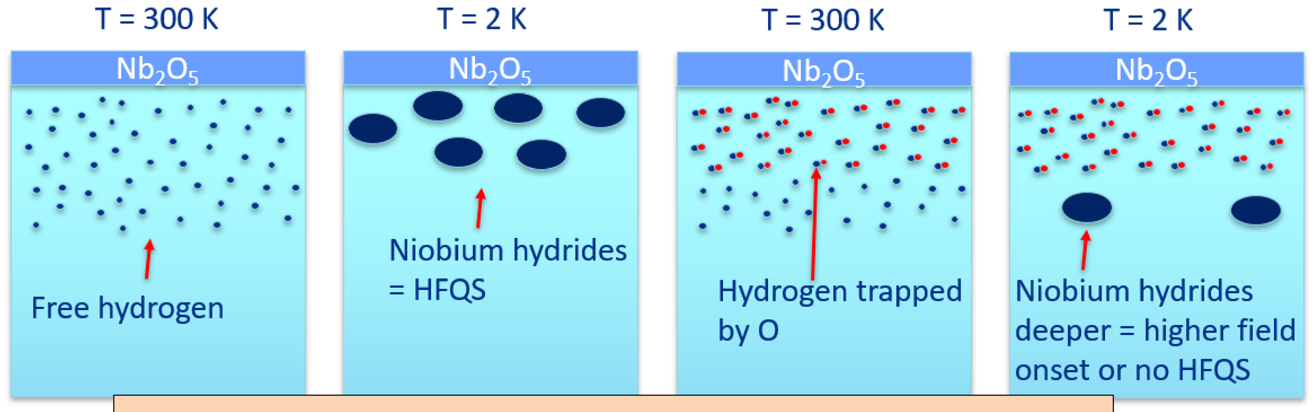
2. Model for Low T Baking

The standard 120C x 48 hr *in-situ* low temperature bake is well known to mitigate high field Q slope

Standard 120C LTB
800C x 3 hr in UHV
40 um EP
120C x 48hr *in-situ*



Recent work by Romanenko[1] suggests that *in-situ* LTB diffuses O from native oxide according to Fick's law, captures H, and prevents NbH precipitation ➔ *mitigates HFQS*

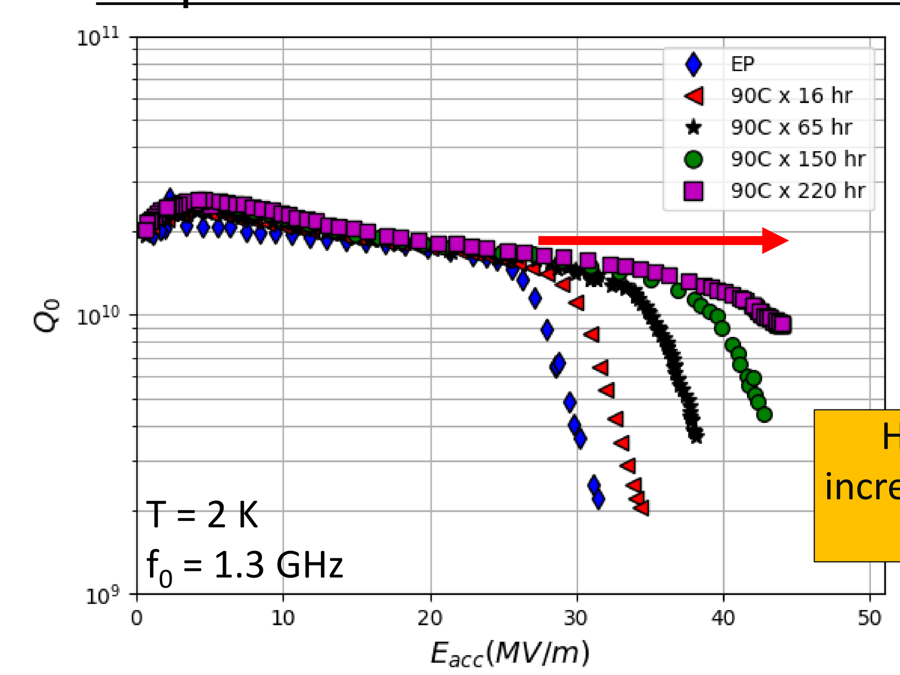


What effect does O concentration in the RF layer have on SRF cavity performance?

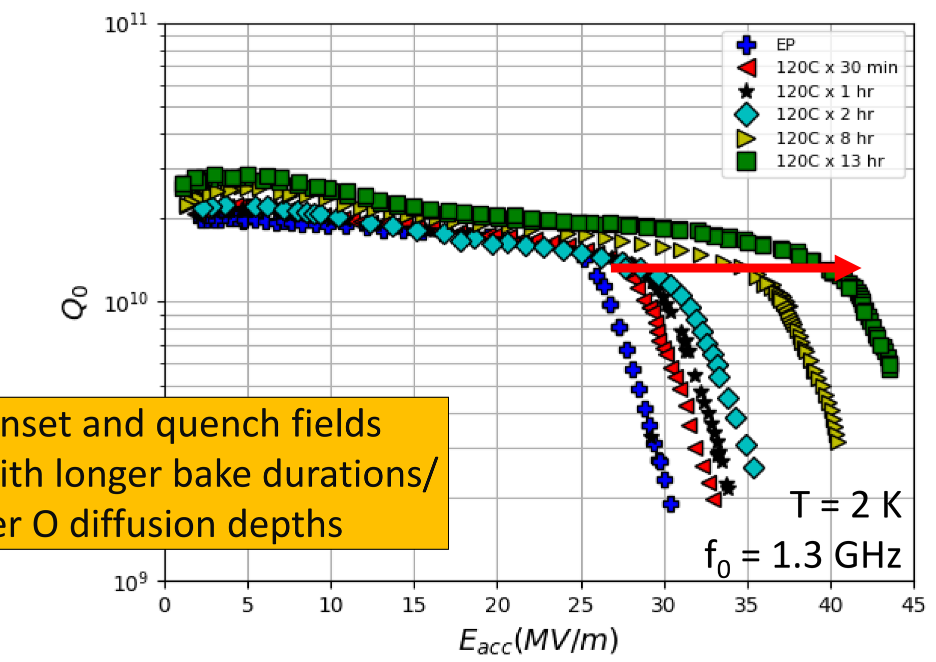
3. Experimental

An ensemble of 1.3 GHz TESLA Nb cavities were subjected to *sequential in-situ low temperature baking* at 90C, 120C, 150C, 160C, or 200C and tested after each step.

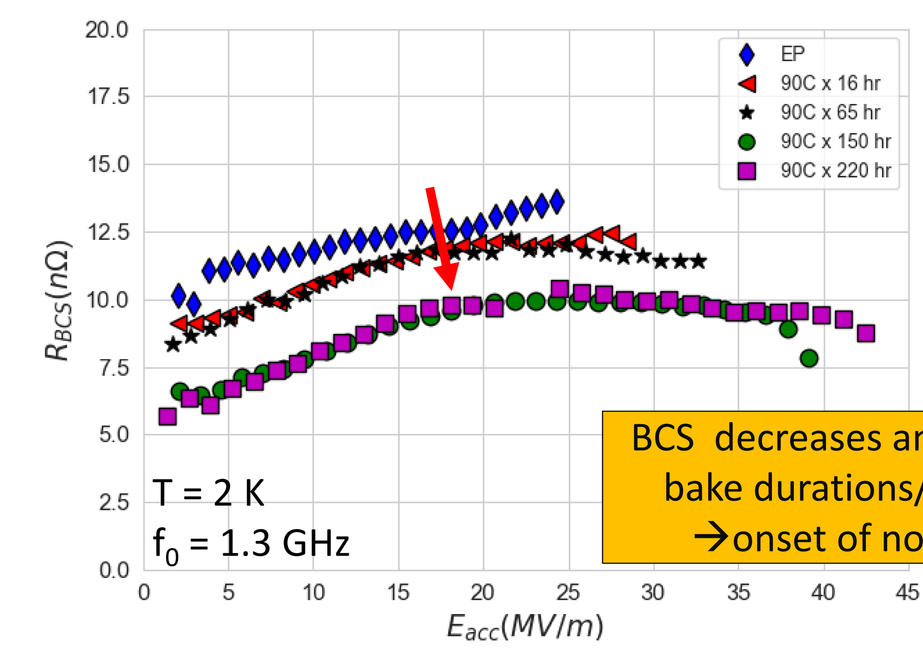
Cavity TE1AES014 After Sequential Rounds of LTB at 90 C

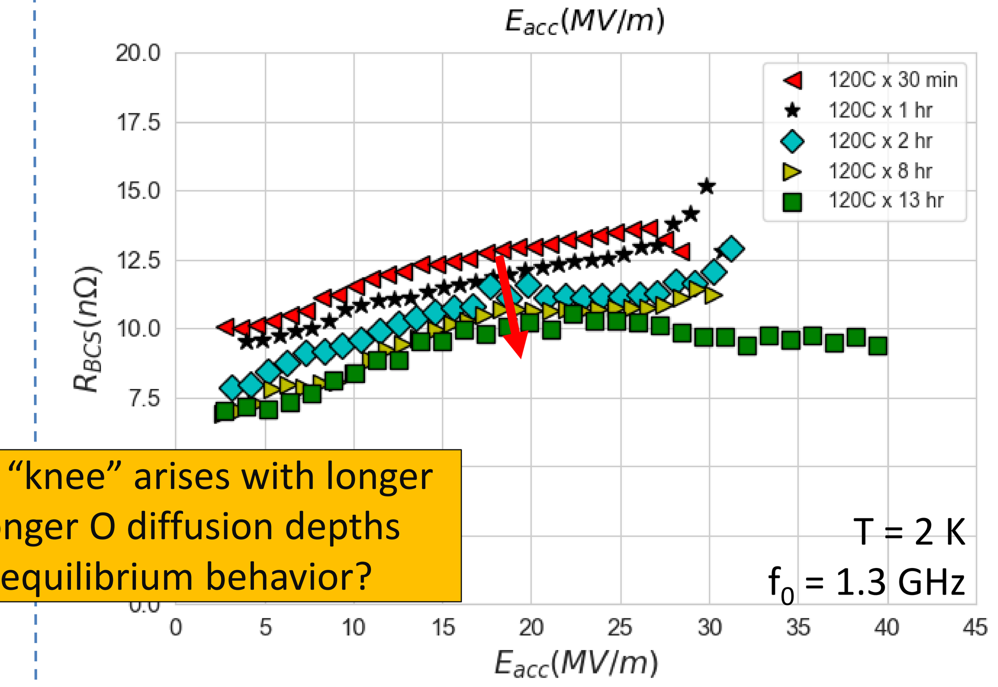


Cavity TE1RI003 After Sequential Rounds of LTB at 120 C



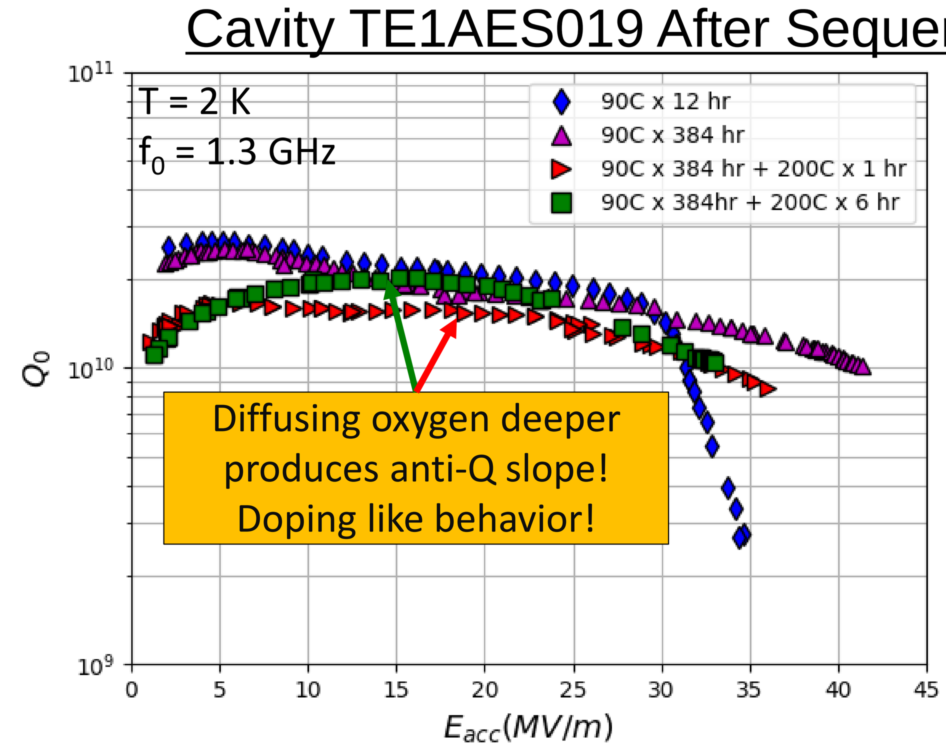
HFQS onset and quench fields increase with longer bake durations/ longer O diffusion depths



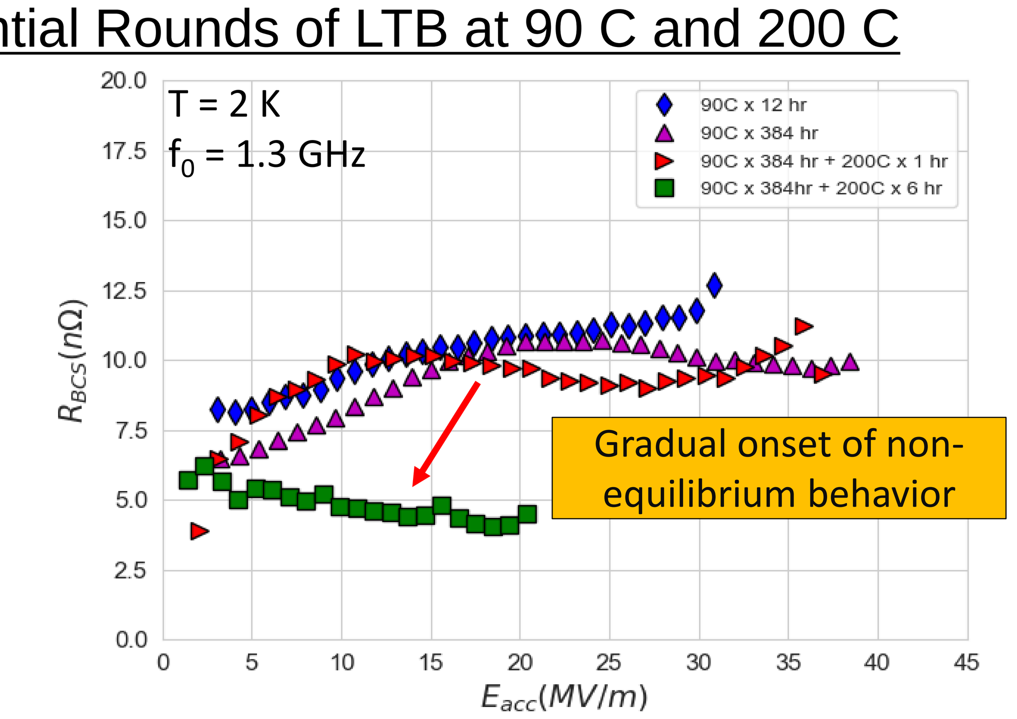


BCS decreases and "knee" arises with longer bake durations/longer O diffusion depths →onset of non-equilibrium behavior?

Cavity TE1AES019 After Sequential Rounds of LTB at 90 C and 200 C

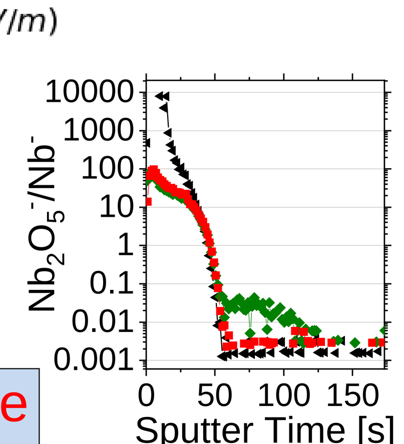


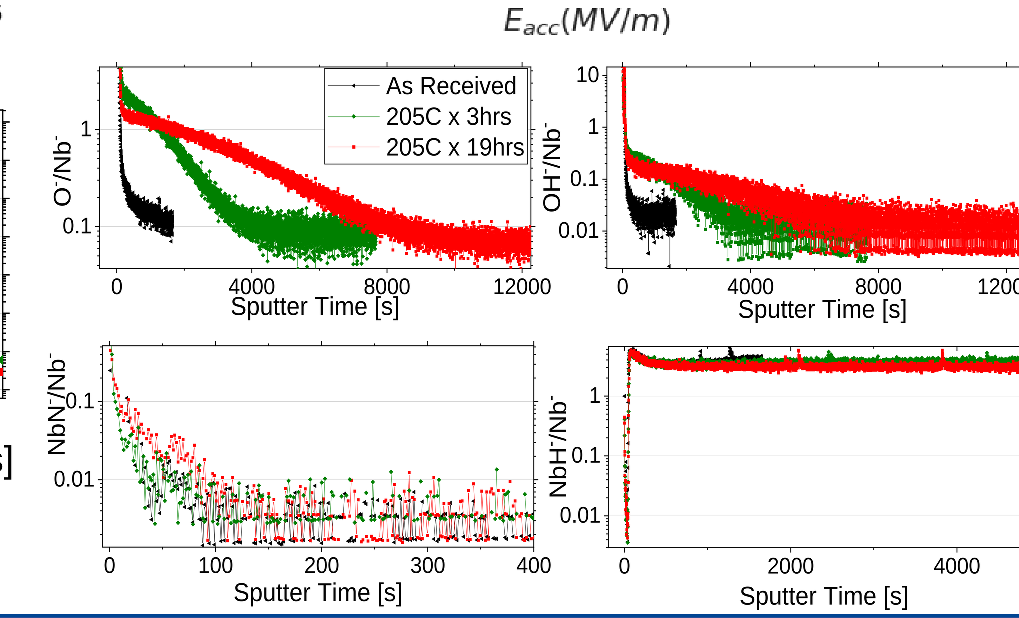
Diffusing oxygen deeper produces anti-Q slope! Doping like behavior!



Gradual onset of non-equilibrium behavior

SIMS studies on cavity cutouts suggest O drives the doping behavior, *no N!*

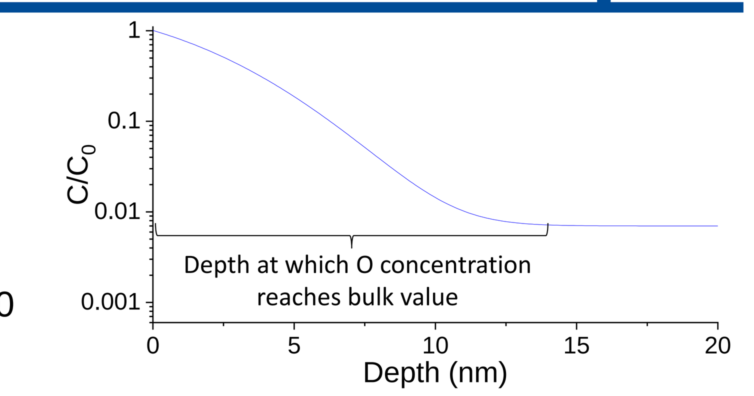




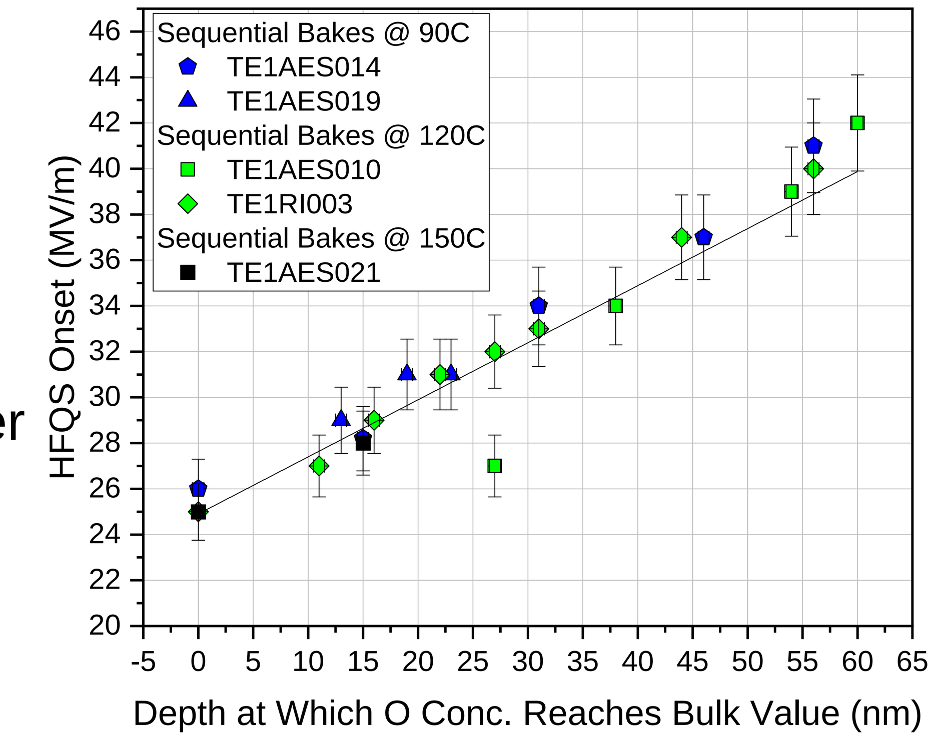
Do non-eq. effects arise due to less proximity coupling to NbH?

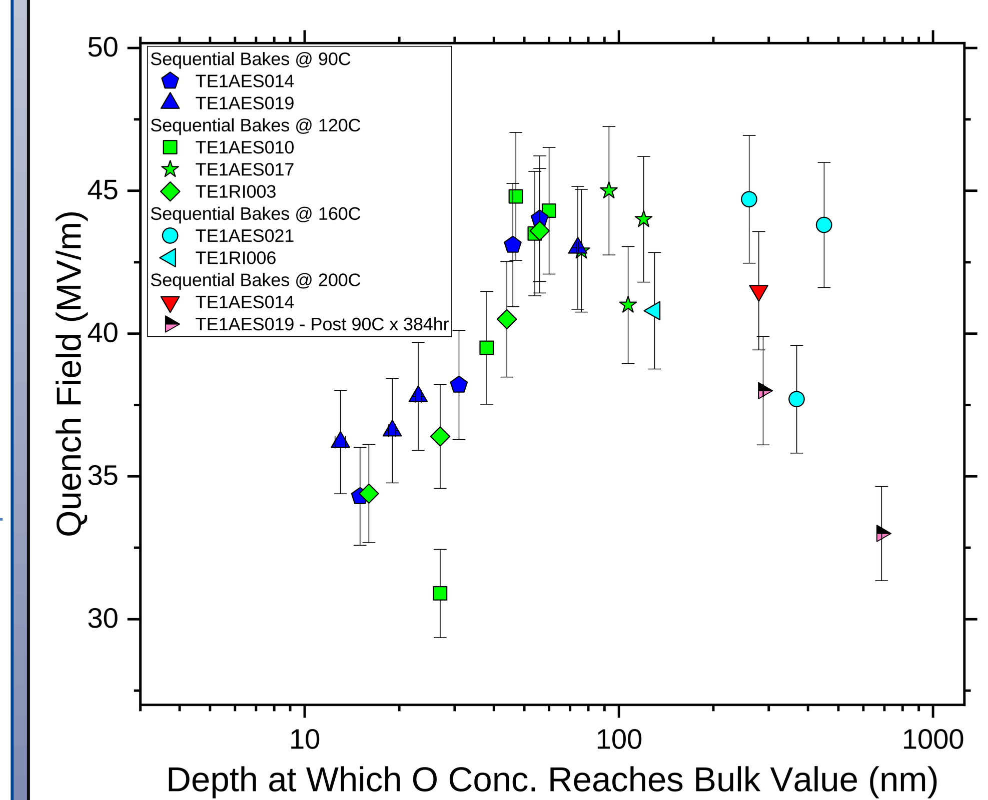
4. Trends w/ O Diffusion Depth

- O diffusion in Nb well modelled by Fick's law with concentration at surface constant at solubility limit C_0



- *HFQS onset varies linearly with depth to which O diffuses*
- Supports Romanenko model → smaller/fewer hydrides yield higher onset





- HFQS mitigation by *O diffusion enables larger quench fields*
- *Quench field decreases when O diffuses >90 nm*, may be due to decrease of field limit of SS bilayer[2]
- *Interplay of thermo-magnetic and magnetic quench*?

5. Conclusions

- *O diffusion* plays a key role in the *mitigation of HFQS* and in enabling *high quench fields* in SRF cavities
- Peak *quench fields* achieved when diffused *O extends ~90 nm from RF surface*
- *Diffusing O deep toward bulk may bring about non-equilibrium behavior in R_{BCS}* and suggests "Oxygen doping" → anti-Q slope behavior *may occur* when *proximity coupling* and *inelastic scattering are low*

6. References

[1] A. Romanenko *et al.*, Proc. of SRF'19, THP014
[2] T. Kubo, SUST **30,** 023001 (2017)

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