WG1 TTC: Impact of Baking on the Performance of Low-beta, Low-frequency QWRs at 4 K

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Introduction

- FRIB linac contains 94 quarter-wave resonators with $\beta = 0.085$ (QWR, $f = 80.5$ MHz, $T = 2$ K, 4.3 K); prep: buffered chemical polishing (BCP)

- BCP + in-situ low-temperature bake (LTB, 120 C, 48hrs) improves medium field Q-slope (MFQS) at 4.3 K

- Cause for reduction in MFQS? How to utilize it?

- Examine the BCS resistance in three different baking scenarios
  - In-situ LTB: 120 C 48hr
  - Furnace LTB: 120 C 48hr
  - Furnace medium temp. bake (MTB): 350 C 3hr
Goal and Methodology

- **Goal:** isolate BCS resistance and the effect of baking

- **Note:** FRIB QWRs use indium gasket as RF seal
  - Seating of gasket has impact on residual resistance
    - Residual resistance is dominant component for FRIB QWR at 2 K

- In rough approximation, ignore BCS contribution at 2K
  - \( R_s(2K, B_{pk}) \approx R_{res}(B_{pk}) \)
  - \( R_{BCS} \approx R_s(4.3K, B_{pk}) - R_{res}(2K, B_{pk}) \)
Hypothesis: improvement in MFQS is due to improved thermal impedance
- Shown anodized cavity has increased performance ~4 K [1]

First case to look at: S85-990
- Baseline
- BCP + 120C in-situ bake
- Post-test BCP, then retest. Performance within variation for un-baked cavities
- BCP + 120C in-situ again

Effect of first bake reset by BCP
- Then recovered by second bake

Conclusion: improved MFQS not necessarily due to improved thermal impedance
Test furnace LTB and compare the result with in-situ LTB
• Resulting Q-curve is in red

Can see that furnace configuration yields similar MFQS improvement
• Bottom flange (Ti) and tuning plate (Nb) are not baked in furnace baking
Furnace MTB

- Test for our first furnace MTB (350 C, 3hr)
- Isolate BCS resistance at 4.3 K, compare with other bake tests
  - Included are baseline tests, dots
- Performance is more in-line with unbaked cavity at 4.3 K
  - Trend agrees with findings of mid-T bake at 4 K by TRIUMF [2]
    » Results shown from 220 MHz multimode QWR and HWR
- Cannot preform in-situ MTB due to indium seal for bottom flange

Rs v. Field and T

- Previously: had testing availability to take CW data at multiple temperatures for furnace LTB
  - Cryogenic stability: ±0.01 K on average
  - Interested in transition in trend from quadratic and linear as T decreases
    » Expected sharp transition in curve through $T_\lambda$, as seen in other geometries/freq. [3]

- Next steps: use simple fitting model at first
  \[c_0 + c_1 b + c_2 b^2\]
  - $c_1$ is associated with hysteresis losses, $c_2$ carries thermal feedback and pair-breaking losses information [5]

- Redo this measurement when available
  - Measure another LTB cavity with more data sets below $T_\lambda$
  - Measure an un-baked cavity to compare with; reduction of $c_1$ would suggest diffusion of oxygen away from surface [6, 7] as explanation of MFQS reduction

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Summary

* Found that LTB improves MFQS for FRIB $\beta = 0.085$, 80.5 MHz QWRs at 4.3 K
  - See from decomposition of $R_s$ that improvement comes from change in BCS
  - Furnace LTB has similar improvement to in-situ LTB

* MTB doesn’t offer improved MFQS for FRIB QWRs
  - Difference in frequency, much lower
  - Difference in surface treatment: EP v. BCP

* When available, continue examination of trend of MFQS with temperature

* Developed a new recipe for spare FRIB QWRs production
  - Bulk BCP, 600 C H degas, light BCP, 120 C 48hr furnace LTB, and high pressure rinse
Thank you! Questions?
Full Citations


Extra Slides: Partial Pressure Readouts for LTBs (Furnace left, in-situ right)

Partial Pressures for Furnace LTB Duration

Partial Pressures for In-situ LTB

J. Brown, WG1 TTC 2023, Slide 11
Case of EP+In-situ LTB FRIB $\beta = 0.65$ 644 MHz upgrade cavity
- Simple model of normalized resistance using a constant residual resistance
- CW data over MF region, see two distinct bands for Q-slope as function of field
  » $T > T_\lambda$ and $T < T_\lambda$

See shift in slope as LHe transitions to superfluid
- Suggests MFQS can be improved by further improving thermal impedance

Plethora of QWR LTB and baselines for FRIB
- Reproduce and refine analysis with more updated model
Previously: taking residual resistance to be a constant
• In reality, residual resistance changes with cool down sensitivity and that $R_{res} = R_{res}(B_{pk})$

Want: isolate the BCS resistance at 4.3K to examine change in MFQS
• How: From idealized model: $R_{BCS}(2K, 80.5MHz) \approx 0.04 \, n\Omega$

For 11 baked cavities: $R_{BCS,avg} = 0.199 \, n\Omega$ at 2K-1.8K

For 13 baked cavities: $R_{BCS,avg} = 0.506 \, n\Omega$ at 2K

First order approx: ignore BCS at 2K for QWR
• $R_s(2K, B_{pk}) \approx R_{res}(B_{pk})$
Extra Slides: Unbaked Cooldown

Surface Resistance vs. $\sqrt{\gamma}$ for Cooldown of Unbaked Cavities

- $R_{\text{unbaked}} = 2.74 \times R_{\text{calc}}(2K) = 0.912$
- $R_{\text{unbaked}} = 2.77 \times R_{\text{calc}}(2K) = 0.501$
- $R_{\text{unbaked}} = 2.29 \times R_{\text{calc}}(2K) = 0.338$
- $R_{\text{unbaked}} = 3.56 \times R_{\text{calc}}(2K) = 0.373$
- $R_{\text{unbaked}} = 3.04 \times R_{\text{calc}}(2K) = 0.739$
- $R_{\text{unbaked}} = 3.90 \times R_{\text{calc}}(2K) = 0.494$
- $R_{\text{unbaked}} = 1.69 \times R_{\text{calc}}(2K) = 0.656$
- $R_{\text{unbaked}} = 2.94 \times R_{\text{calc}}(2K) = 0.625$
- $R_{\text{unbaked}} = 2.11 \times R_{\text{calc}}(2K) = 0.415$
- $R_{\text{unbaked}} = 5.54 \times R_{\text{calc}}(2K) = 0.142$
- $R_{\text{unbaked}} = 3.79 \times R_{\text{calc}}(2K) = 0.463$
- $R_{\text{unbaked}} = 2.89 \times R_{\text{calc}}(2K) = 0.457$
- $R_{\text{unbaked}} = 4.15 \times R_{\text{calc}}(2K) = 0.214$
Extra Slide: 2 K Q-curves

Surface Resistance $R_s$ vs. Peak Magnetic Field for Baked and Unbaked Cavities @ 2 K

- Unbaked Cavities
- In-situ LTB
- Furnace LTB
- Furnace MTB

- Surface Resistance $R_s$ (nΩ)
- Peak Magnetic Field $B_{pk}$ (mT)