Review of Thermal Treatments: Effects, Reliability, and Open Questions

Sam Posen
SRF Conference 2023
June 28, 2023

Sincere thanks for contributions from Dan Gonnella, Kensei Umemori, Marc Wenskat, Pashupati Dhakal, Matthias Liepe, Fabien Eozenou, Hayato Ito, Genfa Wu, Feisi He

Review of Bulk Niobium Heat Treatments: Timeline

Preparation and Characterization of Ultra-High-Purity Niobium

Klaus K. Schulze

JOM 33, 33–41 (1981) | Cite this article

Superconductor Science and Technology

FAST TRACK COMMUNICATION

Nitrogen and argon doping of niobium for superconducting radio frequency cavities: a pathway to highly efficient accelerating structures

A Grassellino[1], A Romanenko[1], D Sergatskov[1], O Melnychuk[1], Y Trenikhina[2], A Crawford[1], A Rowe[1], M Wong[1], T Khabiboulline[1] and F Barkov[1]

Published 22 August 2013 • © 2013 IOP Publishing Ltd

Superconductor Science and Technology, Volume 26, Number 10

Citation A Grassellino et al 2013 Supercond. Sci. Technol. 26 102001

DOI 10.1088/0953-2048/26/10/102001

PAPER • OPEN ACCESS

Unprecedented quality factors at accelerating gradients up to 45 MVm^{-1} in niobium superconducting resonators via low temperature nitrogen infusion

A Grassellino[1], A Romanenko[1], Y Trenikhina[1], M Checchin[1], M Martinello[1], O S Melnychuk[1], S Chandrasekaran[1], D A Sergatskov[1], S Posen[1], A C Crawford[1] + Show full author list

Published 8 August 2017 • © 2017 IOP Publishing Ltd

Superconductor Science and Technology, Volume 30, Number 9

Focus on The Jan Evetts SUST Award 2017

Citation A Grassellino et al 2017 Supercond. Sci. Technol. 30 094004

DOI 10.1088/1361-6668/aa7afe

PHYSICAL REVIEW APPLIED

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Open Access

Ultralow Surface Resistance via Vacuum Heat Treatment of Superconducting Radio-Frequency Cavities

S. Posen, A. Romanenko, A. Grassellino, O.S. Melnychuk, and D.A. Sergatskov

Phys. Rev. Applied 13, 014024 – Published 14 January 2020

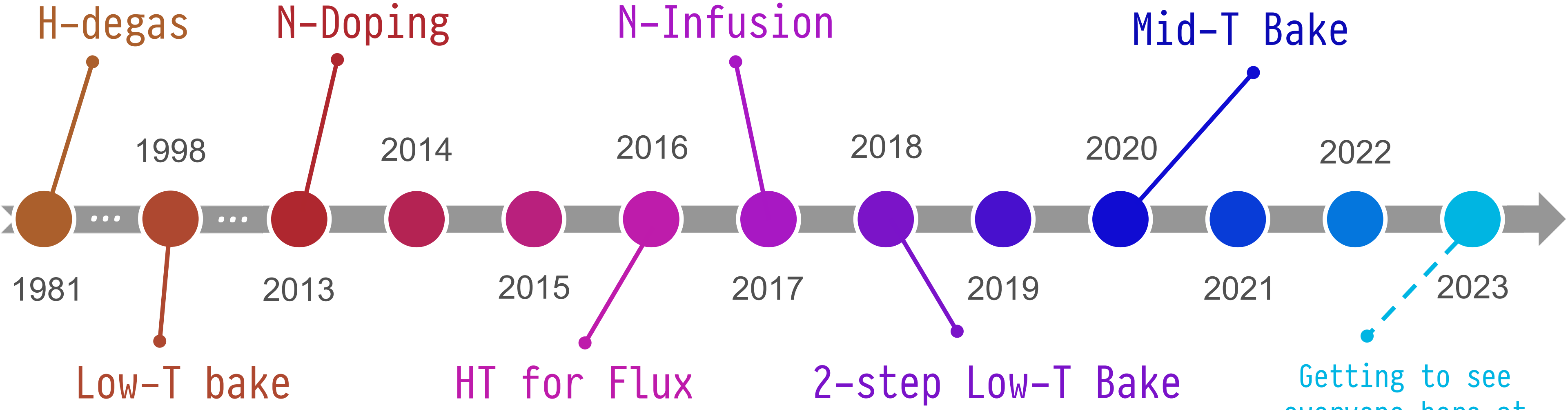
JOURNAL ARTICLE

Influence of furnace baking on Q–E behavior of superconducting accelerating cavities

H Ito, H Araki, K Takahashi, K Umemori

Progress of Theoretical and Experimental Physics, Volume 2021, Issue 7, July 2021, 071G01, https://doi.org/10.1093/ptep/ptab056

Published: 30 April 2021 Article history ▾



Getting to see everyone here at SRF'23! 😊😊

Proceedings of the 1997 Workshop on RF Superconductivity, Abano Terme (Padova), Italy

Superiority of Electropolishing over Chemical Polishing on High Gradients

Kenji SAITO, Hitoshi INOUE, Eiji KAKO, Takeo FUJINO, Shuichi NOGUCHI, Masaaki ONO and Toshio SHISHIDO

High Energy Accelerator Research Organization (KEK) 1-1, Oho, Tsukuba-shi, Ibaraki-ken, Japan, 305 - 0801

Proceedings of the 1999 Workshop on RF Superconductivity, La Fonda Hotel, Santa Fe, New Mexico, USA

Electropolishing and in-situ Baking of 1.3 GHz Niobium Cavities

L. Lilje*, D. Reschke, K. Twarowski, DESY, Notkestraße 85, 22607 Hamburg
P. Schmüser, Universität Hamburg
D. Bloess, E. Haebel, E. Chiaveri, J.-M. Tessier, H. Preis, H. Wenninger, CERN, Geneva
H. Safa, J.-P. Charrier, CEA, Saclay

RESEARCH ARTICLE | JUNE 03 2016

Efficient expulsion of magnetic flux in superconducting radiofrequency cavities for high Q applications

S. Posen; M. Checchin; A. C. Crawford; A. Grassellino; M. Martinello; O. S. Melnychuk; A. Romanenko; D. A. Sergatskov; Y. Trenikhina

Check for updates

+ Author & Article Information

Journal of Applied Physics 119, 213903 (2016)

https://doi.org/10.1063/1.4953087 Article history

CHORUS

arXiv > physics > arXiv:1806.09824

Physics > Accelerator Physics

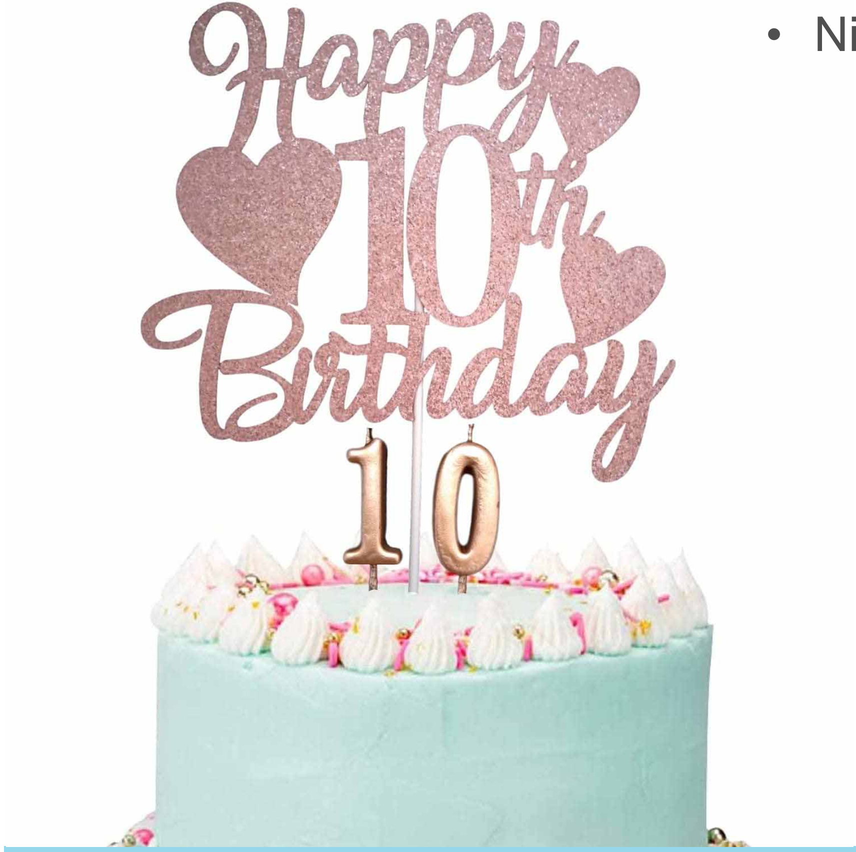
[Submitted on 26 Jun 2018]

Accelerating fields up to 49 MV/m in TESLA-shape superconducting RF niobium cavities via 75C vacuum bake

A. Grassellino, A. Romanenko, D. Bice, O. Melnychuk, A. C. Crawford, S. Chandrasekaran, Z. Sung, D.A. Sergatskov, M. Checchin, S. Posen, M. Martinello, G.Wu

Nitrogen Doping

2013

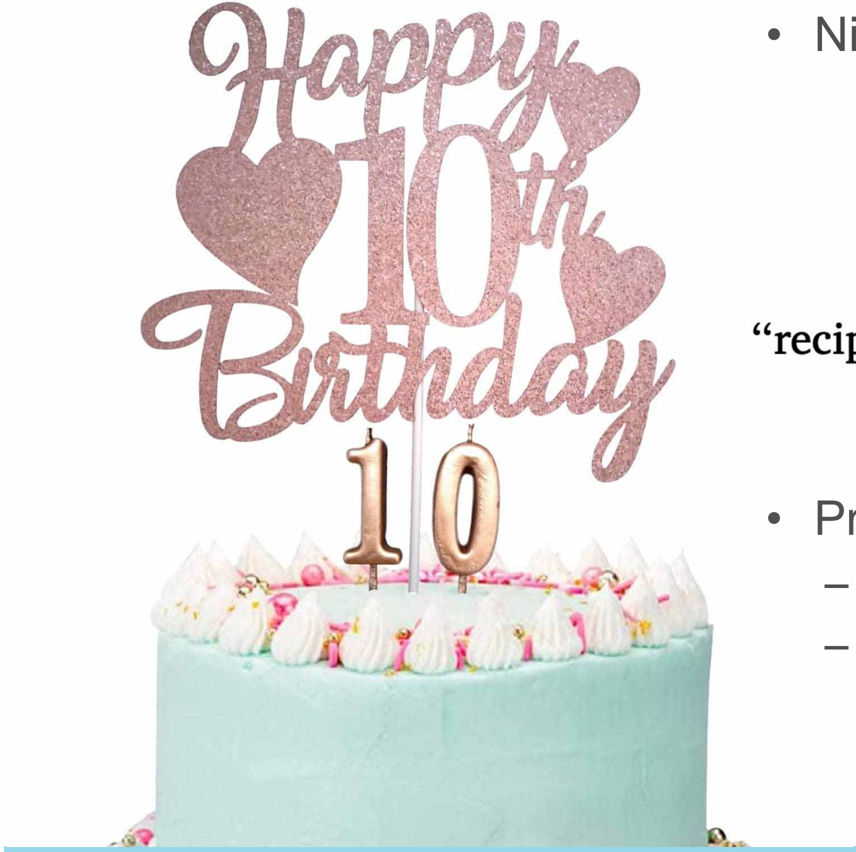


- Nitrogen doping turns 10 this year!

Image from Amazon

Nitrogen Doping

2013



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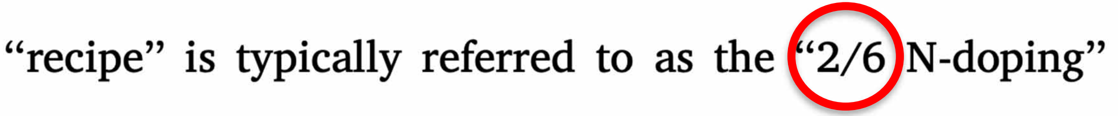

NIM-A, Vol. 883, pp. 143-150 (2018)

- Proposed birthday for N-doping:
  - February 6 (USA)
  - June 2 (everywhere else)

Image from Amazon

Fermilab

Nitrogen Doping

2013

- Nitrogen doping is now successfully implemented in production for LCLS-II, resulting in the highest Q_0 SRF linac to date
- Very high reliability is now achieved with industrial vendors, but it took substantial efforts
- Impetus and investments from LCLS-II efforts helped to drive progress in these challenges

Open question: Cause of lower quench field

Open question: Cause of anti-Q-slope – but there are theories (e.g. non-equilibrium)

However, materials studies helped achieve a mature understanding of the ***impact*** *of N-impurity profiles*

Superconductor Science and Technology

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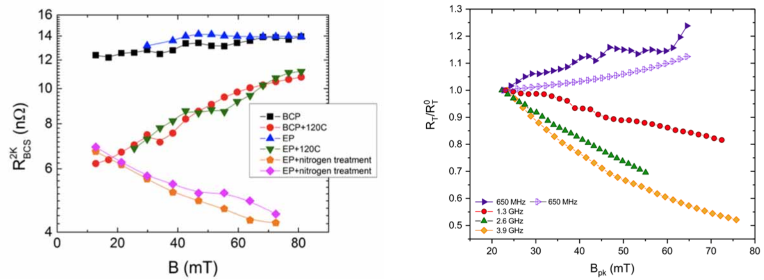
Citation A Grassellino *et al* 2013 *Supercond. Sci. Technol.* **26** 102001

DOI 10.1088/0953-2048/26/10/102001



PHYSICAL REVIEW LETTERS **121,** 224801 (2018)

Field-Enhanced Superconductivity in High-Frequency Niobium Accelerating Cavities

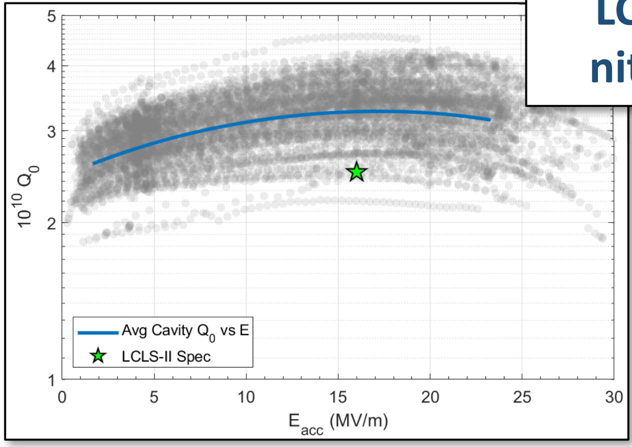
M. Martinello,* M. Checchin, A. Romanenko, A. Grassellino, S. Aderhold, S. K. Chandrasekeran, O. Melnychuk, S. Posen, and D. A. Sergatskov
Fermi National Accelerator Laboratory, Batavia, Illinois 60510, USA

Based on the experimental data, our hypothesis is that the frequency dependence of the temperature-dependent surface resistance may be a consequence of the quasiparticle distribution being out of equilibrium, with the extent of the nonequilibrium behavior depending on the resonant frequency and on the types and concentration of impurities.

Nitrogen-Doped Cavity Experience in LCLS-II

LCLS-II constructed 373 nitrogen-doped cavities

Vertical Test



VT Performance

$\langle E_{max} \rangle$ = 23 MV/m

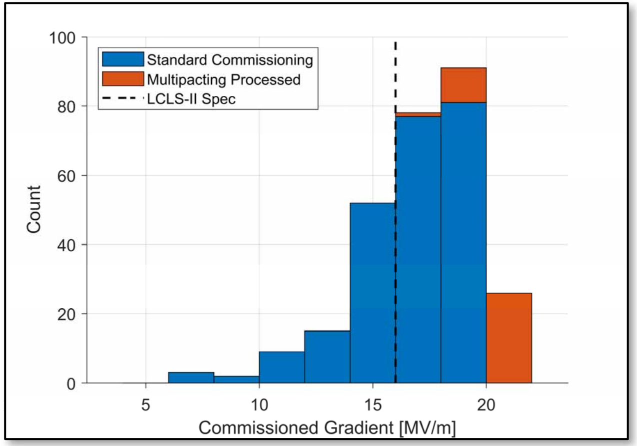
$\langle Q_0 \rangle = 3.3 \times 10^{10}$

Linac Performance

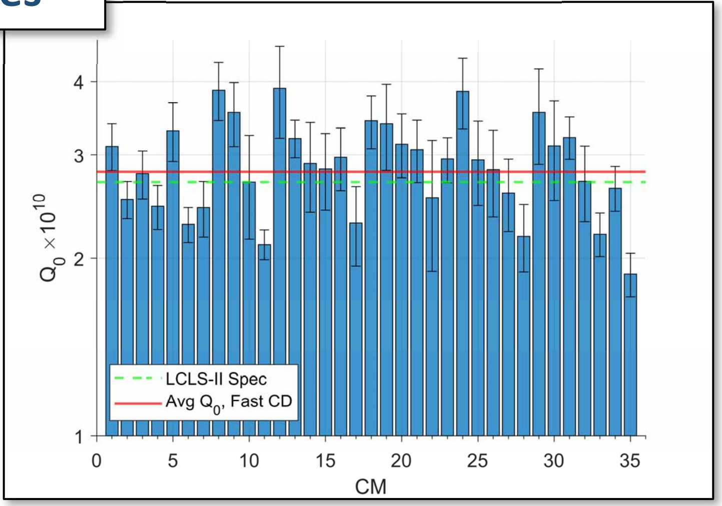
Gradient preserved

$\langle Q_0 \rangle = 2.8 \times 10^{10}$

Linac Gradient Performance



Q_0 in the Linac



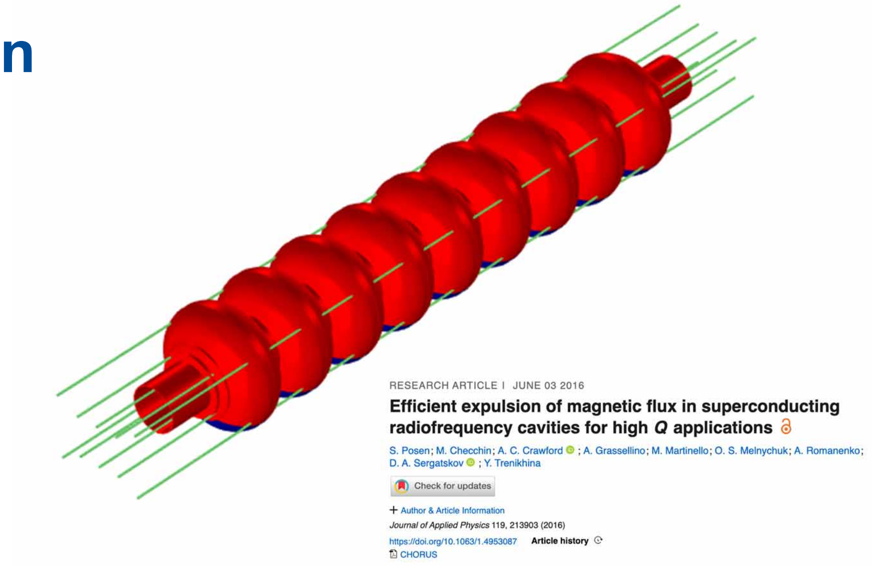
- *High Q_0 from nitrogen-doping has been preserved in the linac*
- *Expect further improvement over time from improved cool downs, degauss, etc*

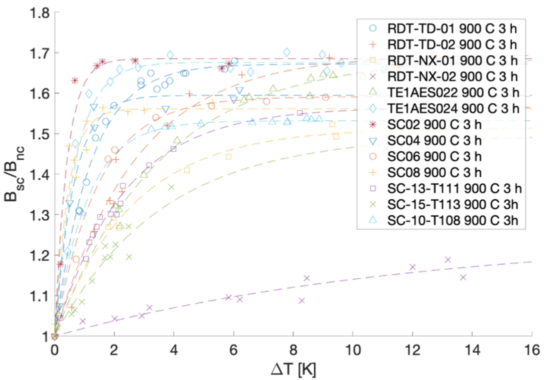
Slide from Dan Gonnella – more in his talk on Monday

2016

Heat Treatment for Flux Expulsion

- ~900 C heat treatment to reduce flux pinning, improve expulsion of ambient magnetic fields during cooldown
- Implemented successfully in LCLS-II production
- Improve Q by changing **bulk**, not surface
- Still challenging to find the right temperature to balance expulsion and mechanical properties, variations from one niobium production lot to another





Open question: specification to ensure strong flux expulsion without making material too soft

Fermilab

Nitrogen Infusion

2017

- Motivation for N-infusion: knew N-doping helped Q: try to combine with low T bake to get both high Q and high gradient
- Procedure: 1) 800 C+ to remove oxide, 2) plateau at 120 C for 48 hours with nitrogen injection
- Has led to very high cavity gradients
- Reproducibility in other labs has been challenging, likely due to no EP after 800 C in furnace -> even small contamination from furnace is a challenge
- To avoid degradation from contamination, great care is needed: clean furnace, caps

PAPER • OPEN ACCESS

Unprecedented quality factors at accelerating gradients up to 45 MVm^{-1} in niobium superconducting resonators via low temperature nitrogen infusion

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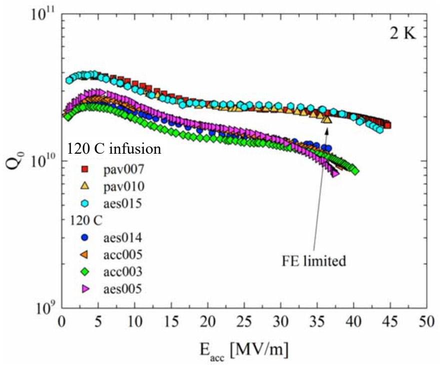
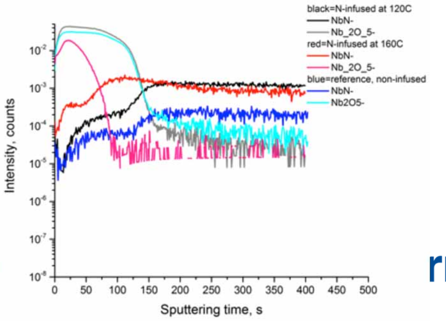
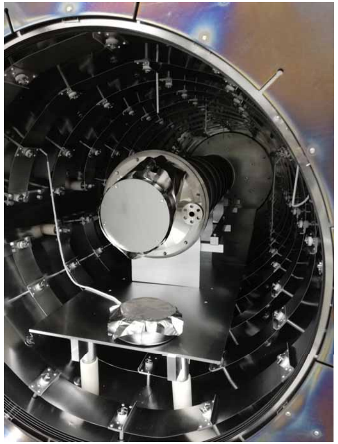
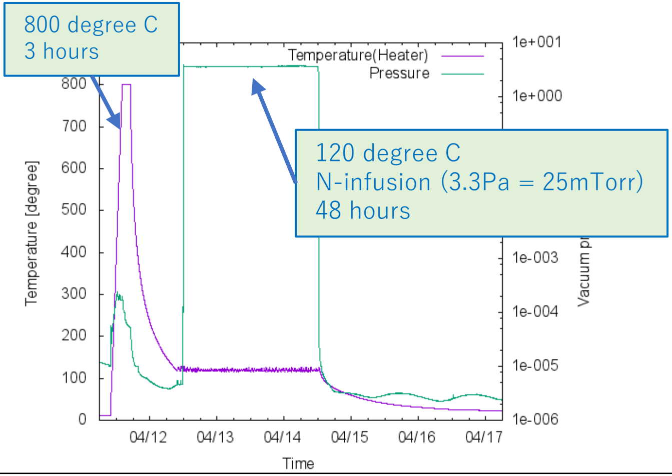
Published 8 August 2017 • © 2017 IOP Publishing Ltd
Superconductor Science and Technology, Volume 30, Number 9
Focus on The Jan Evetts SUST Award 2017
Citation A Grassellino *et al* 2017 *Supercond. Sci. Technol.* **30** 094004
DOI 10.1088/1361-6668/aa7afe



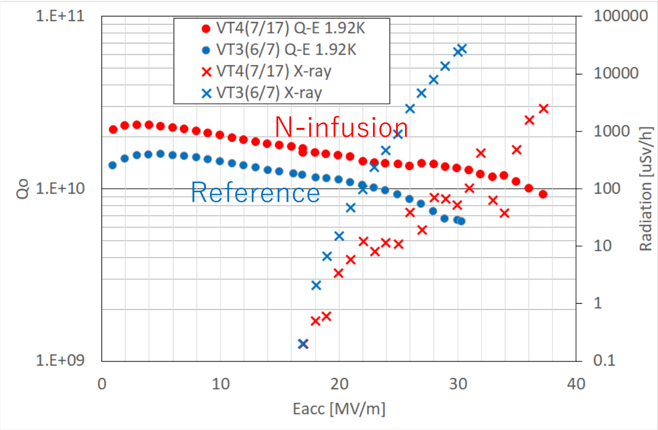


Results of Nitrogen-infusion at KEK

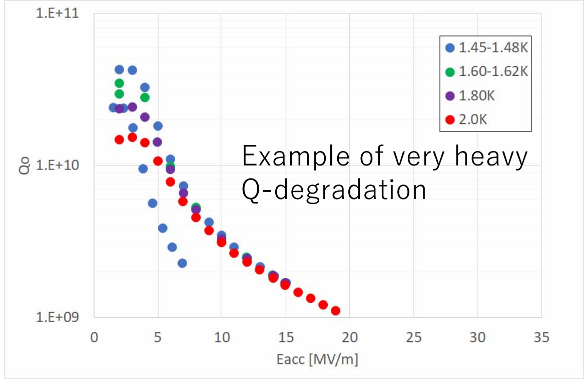


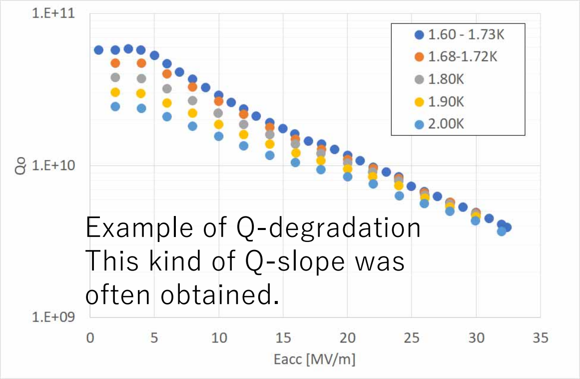


Example of good results



Example of bad results





- N-infusion at KEK showed improvement of Q-value, but not for gradient.
- Reproducibility of N-infusion was very poor.
- Very often, Q-degradation was observed. → Contamination from the furnace??
- Quality control was difficult.

Slide from Kensei Umemori

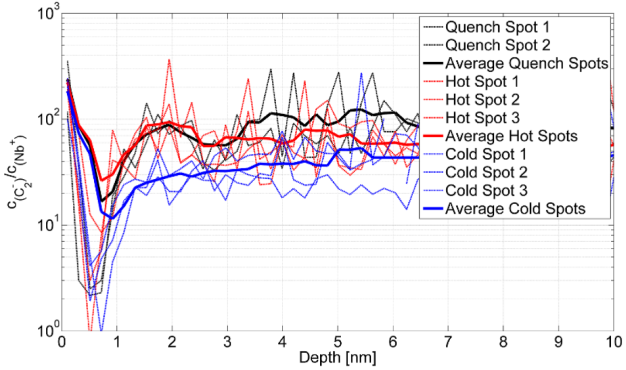
Lessons learned on furnace infrastructure

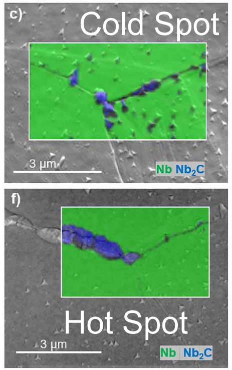
”Forensic“ study to identify key process parameters

- Studies show a correlation between furnace pressure and/or partial pressure of CO/CO_2 to surface resistance

  → **lower pressures resulted in higher Q_0**

- Clear **excess of carbon** in hot spots vs. cold spots shown by SIMS, SEM and EBSD/EDX studies
- **No nitrogen** observed in any samples from infusion runs
- Conclusions:
  - RGA analysis is mandatory - low partial pressure of CO and CO_2 is crucial.
  - Extreme cases of carbon contamination cause grain decoupling.
  - Minor carbon contamination will prevent N adsorption and limit performance improvement



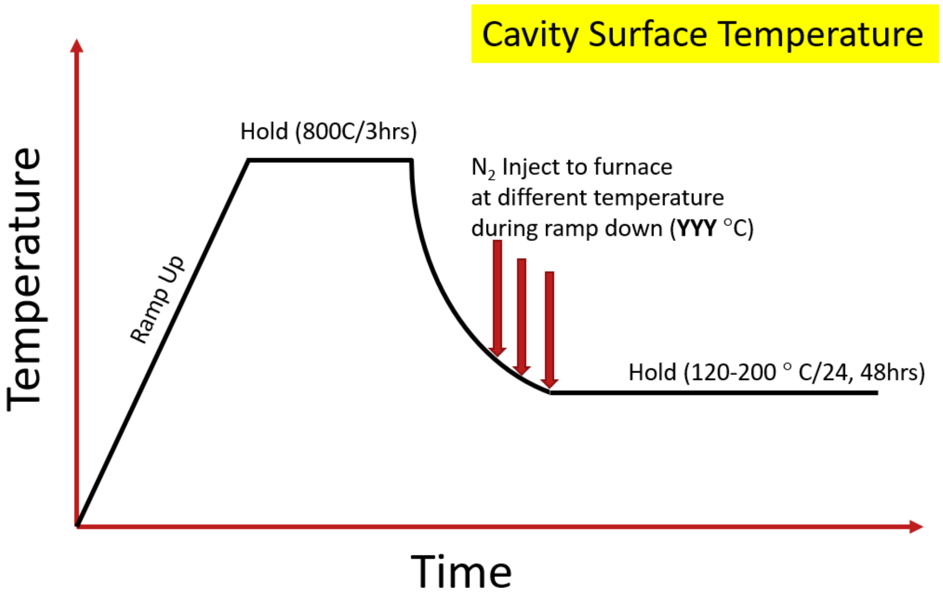


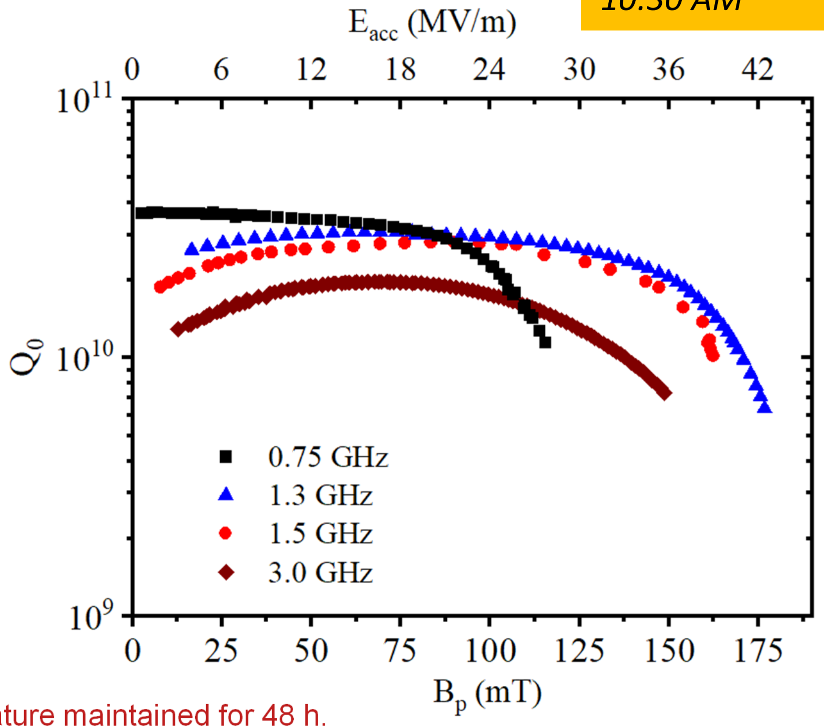
Related publications:
Marc Wenskat *et al* 2020 *Supercond. Sci. Technol.* 33 115017
Arti Dangwal Pandey *et al* 2021 *Appl. Phys. Lett.* 119 194102
C. Bate, PhD Thesis 2021

Slide from Marc Wenskat

JLAB Infusion Recipe and Results

P. Dhakal
Talk: 06/27/2023
10:30 AM





- 0.75 – 3.0 GHz single-cell fine-grain Nb cavities (RRR>300)
- **N-infusion**: 800 °C/3h, N_2 at ~25 mTorr ~300°C, cooling to hold temperature maintained for 48 h.
- R&D to understand the mechanism and depth of the N2 diffusion (in any) on going (SIMS and XPS)
- Multi-cell are being prepared to valid the recipe.

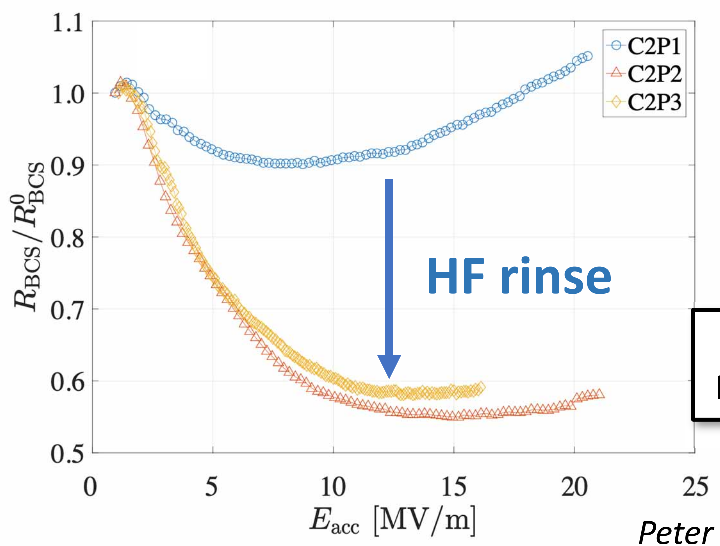
11 12

Slide from Pashupati Dhakal

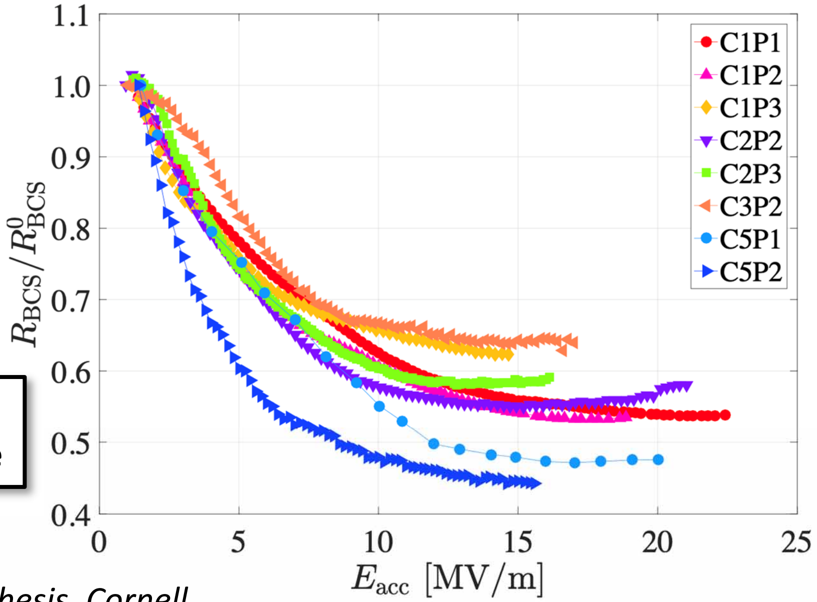
Low-T Doping at Cornell

Treatment	Anneal #1	Anneal #2	Infusion	Gas	Anneal #3	Chemical Etching[1,2,3]
C1P1	800 °C (3 hr)	—	160 °C (48 hr)	Ar + CO_2	—	HF
C1P2	800 °C (3 hr)	—	160 °C (48 hr)	Ar + CO_2	—	HF + OP (27 nm)
C1P3	800 °C (3 hr)	160 °C (3 hr)	160 °C (24 hr)	N_2	—	—
C1P4	800 °C (3 hr)	160 °C (3 hr)	160 °C (24 hr)	N_2	—	OP (54 nm)
C2P1	900 °C (3 hr)	160 °C (3 hr)	160 °C (4.5 dy)	N_2	—	—
C2P2	900 °C (3 hr)	160 °C (3 hr)	160 °C (4.5 dy)	N_2	—	HF
C2P3	900 °C (3 hr)	160 °C (3 hr)	160 °C (4.5 dy)	N_2	—	HF (×2)
C3P1	800 °C (3 hr)	160 °C (3 hr)	160 °C (48 hr)	N_2	—	—
C3P2	800 °C (3 hr)	160 °C (3 hr)	160 °C (48 hr)	N_2	—	HF (×2)
C3P3	800 °C (3 hr)	160 °C (3 hr)	160 °C (48 hr)	N_2	—	HF (×2) + EP (100 nm)
C4P1	800 °C (5 hr)	—	160 °C (48 hr)	Ar + CO_2	—	OP (54 nm)
C5P1	800 °C (12 hr)	—	160 °C (48 hr)	N_2	160 °C (168 hr)	—
C5P2	800 °C (12 hr)	—	160 °C (48 hr)	N_2	160 °C (168 hr) + 75 °C (6 hr)	—

- *Performed various 160C bakes in N_2 and Ar+CO_2*
- ***All** cavities showed strong reduction in BCS resistance with field*
  - *HF rinsing required in some cases to remove surface contamination (Ti)*



Slide from Matthias Liepe



Peter Koufalis, PhD Thesis, Cornell

2018

2-Step Low-T Bake

arXiv > physics > arXiv:1806.09824

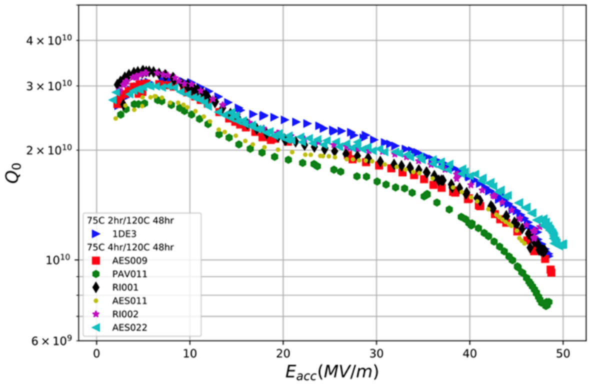
Physics > Accelerator Physics

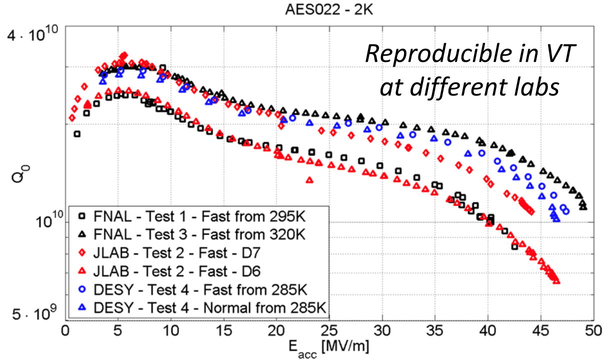
[Submitted on 26 Jun 2018]

Accelerating fields up to 49 MV/m in TESLA-shape superconducting RF niobium cavities via 75C vacuum bake

A. Grassellino, A. Romanenko, D. Bice, O. Melnychuk, A. C. Crawford, S. Chandrasekaran, Z. Sung, D.A. Sergatskov, M. Checchin, S. Posen, M. Martinello, G.Wu

- Accidental oven setting, adding 4 hours at 75 C before 48-hour 120 C bake, led to improved performance
- Unprecedented gradients in 1.3 GHz single cell TESLA cavities, up to 50 MV/m
- Consistently high gradients in single cells observed at Fermilab (always combined with cold EP) – reproduced in vertical tests at other labs



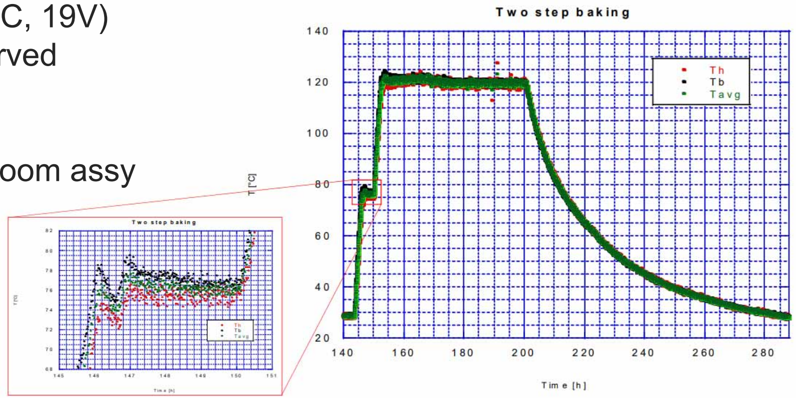


Open questions: cause of improvement still unclear - needs to be studied; also bifurcation

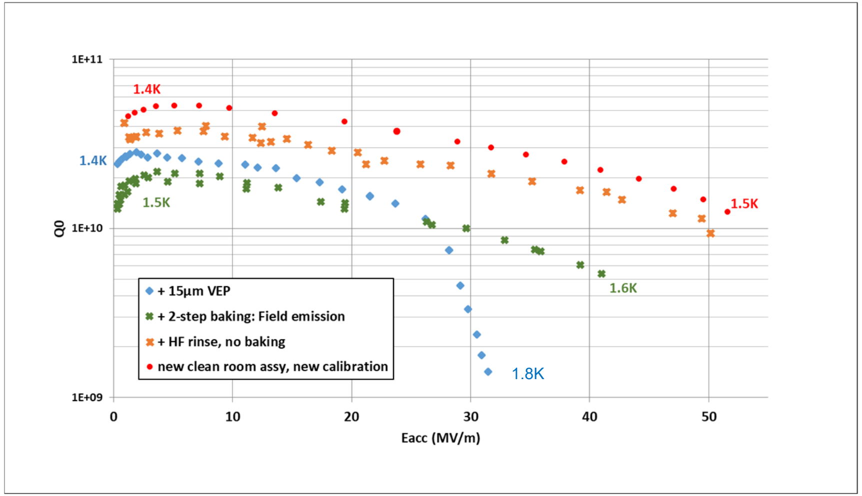
2-Step Baking results on 1AC3 1300MHz 1Cell

- Cavity used for different R&D experiments (alternative acid concentration, doping…)
- Best gradient: 37MV/m after standard baking (48h @120°C)
- Last treatment: + VEP 15µm (T<15°C, 19V)
- 2-step baking : Field Emission observed
- + HF rinse: significant improvement:
  <u>Gradient > 50 MV/m</u> achieved
- Cavity tested again after new cleanroom assy and modified calibration

4h @ 75°C + 48h @120 °C



1C cavity on VEP set-up



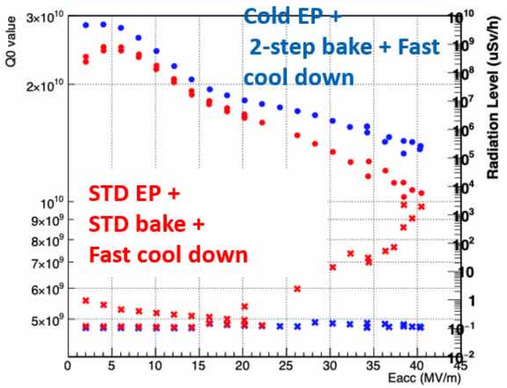
Slide from Fabien Eozenou

Result of cold-EP + 2-step bake (70 ℃ 4 h) at KEK

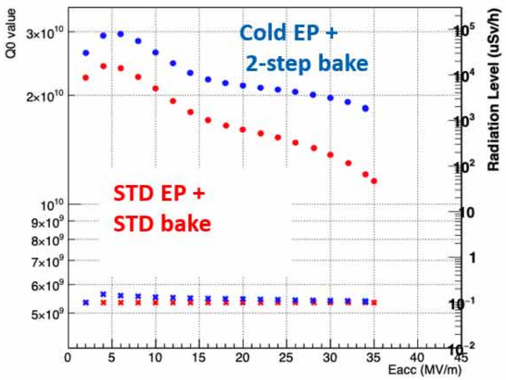
- Comparison of Q-E between "STD EP + bake" and "cold EP + 2-step bake" is shown below.
  - Red: KEK STD EP (25-30 ℃) + STD bake (120 ℃ 48 h bake).
  - Blue: Cold EP(～14℃) + 2-step bake (70 ℃ 4 h bake + 120 ℃ 48 h bake).

Cavity temperature during measurement
- R8 STD ... at 2.07K
- Other cases ... at 2.0 K (2.00~2.01 K)

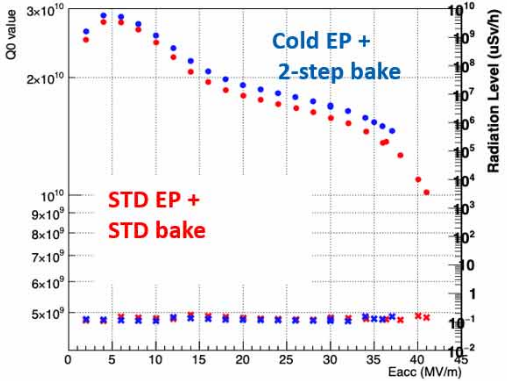
VT results for MT6 (9cell, Fine Grain Nb)



VT results for R8 (1-cell, Fine Grain Nb)



VT results for R17b (3-cell, Large Grain Nb)



- Higher Q tends to be obtained for 2-step baked cavity.
- On the other hand, improvement of gradient can not be obtained.
  - ⇒ Why higher gradient for high-Q/high-G recipe is difficult at KEK? Cavity? EP? Furnace? Baking procedure? Cooling procedure at VT?

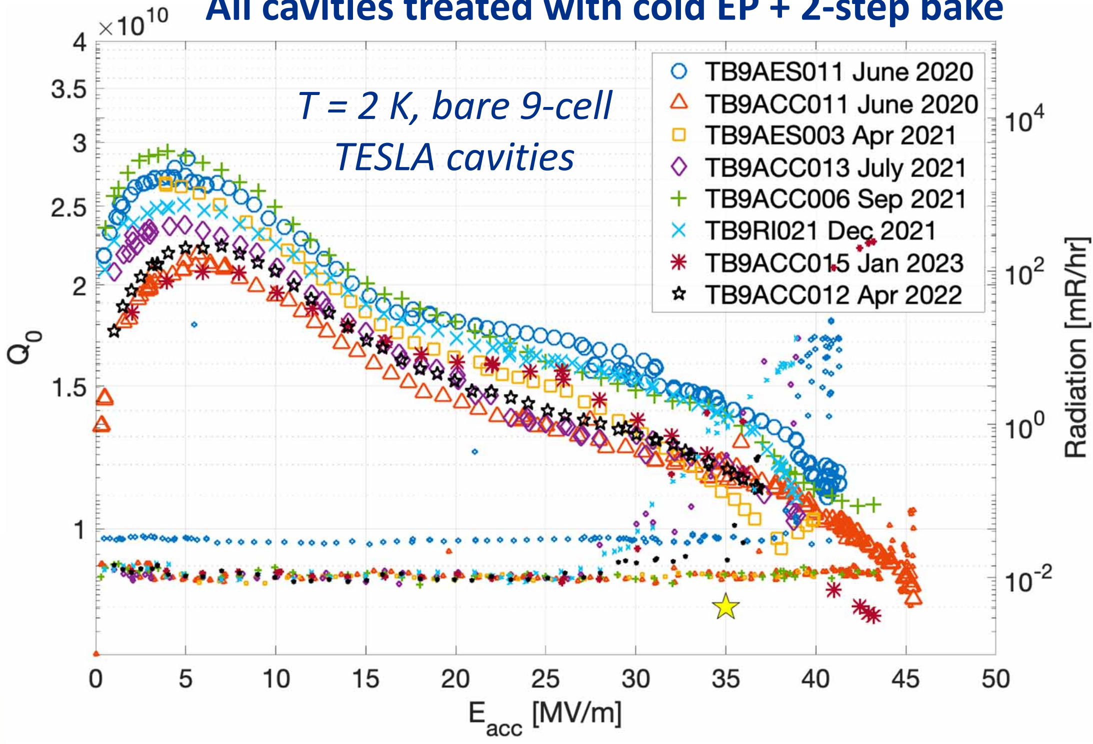
Slide from Kensei Umemori

High Gradient Cryomodule Collaborative Effort

- Eight 9-cell cavities under consideration for HGC reached an average of 41.0 MV/m, several now tanked

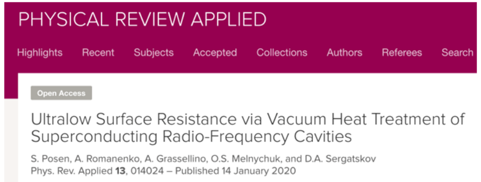
Fermilab · Jefferson Lab · DESY · cea · Cornell University · KEK-JAPAN · Argonne National Laboratory · TRIUMF

All cavities treated with cold EP + 2-step bake



2020

Mid-T Bake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Ultralow Surface Resistance via Vacuum Heat Treatment of Superconducting Radio-Frequency Cavities

S. Posen, A. Romanenko, A. Grassellino, O.S. Melnychuk, and D.A. Sergatskov

Phys. Rev. Applied 13, 014024 – Published 14 January 2020


PHYSICAL REVIEW APPLIED

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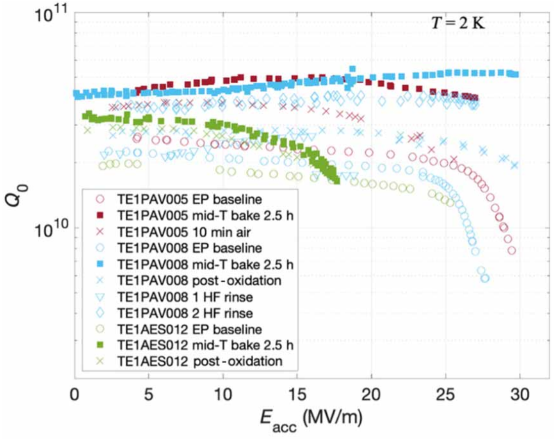
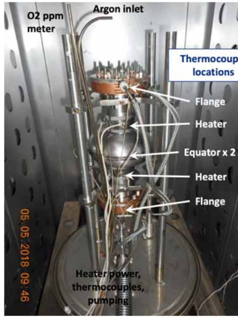
Three-Dimensional Superconducting Resonators at $T < 20$ mK with Photon Lifetimes up to $\tau = 2$ s

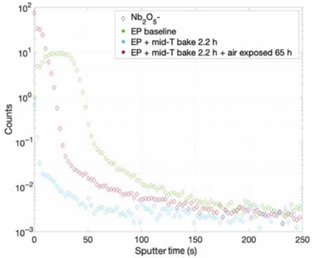
A. Romanenko, R. Pilipenko, S. Zorzetti, D. Frolov, M. Awida, S. Belomestnykh, S. Posen, and A. Grassellino

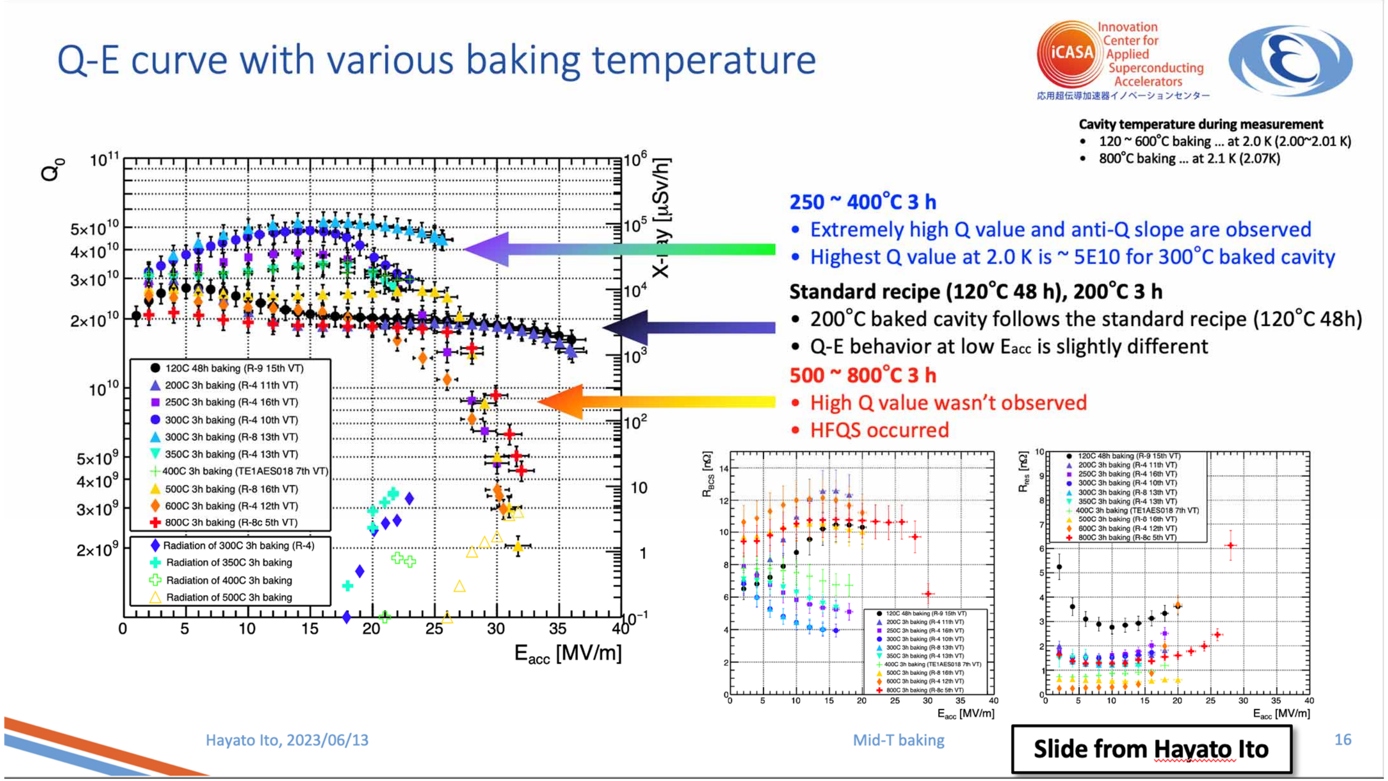
Phys. Rev. Applied 13, 034032 – Published 12 March 2020

- In-situ mid-T bake: cavity assembled
- Developed initially for quantum applications to remove Nb_2O_5 layer, enabling high Q at mK and low photon counts
- SIMS studies determined 300-450 C temperature
- Accelerator regime: anti-Q-slope similar to N-doping; high Q even after oxide regrows
- Currently understood mechanism is adding impurities like N-doping, but in this case oxygen
- Advantages compared to N-doping:
  - No post-doping light EP: key for complex geometries where uniform EP is challenging; removes step
  - Lower temp reduces risk of contamination









JOURNAL ARTICLE

Influence of furnace baking on Q–E behavior of superconducting accelerating cavities

H Ito, H Araki, K Takahashi, K Umemori

Progress of Theoretical and Experimental Physics, Volume 2021, Issue 7, July 2021, 071G01, https://doi.org/10.1093/ptep/ptab056

Published: 30 April 2021 **Article history** ▾

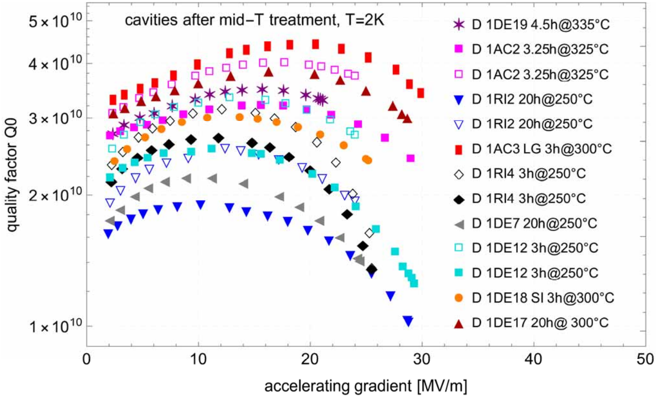
KEK: Furnace Mid-T Bake

- Under US/Japan collaboration, process was shared with KEK and they adjusted it to their facility
- Furnace mid-T bake: unassembled cavity in furnace
- More accessible than in-situ mid-T bake, just use normal furnace!

Heat treatment R&D is ongoing and reproducible

Furnace upgrades improve research capabilities

- **Two very good furnaces at DESY and U Hamburg**
  - New single-cell furnace & refurbished niobium retort furnace for 9-cell cavities.
- **2-step bake**
  - 4h@75°C/24@130°C as standard treatment in the last 4 years.
  - Thorough analysis not done yet - no obvious improvement compared to regular 120°C bake.
- **Mid-T heat treatment**
  - Reproducible and stable process.
  - RF tests of 14 single-cell cavities, treated in three furnaces.
  - All succeeded in improving R_{BCS} (anti-Q-slope) and resulted in varying maximum accelerating field.
  - Partially enhanced R_{res} is under investigation.



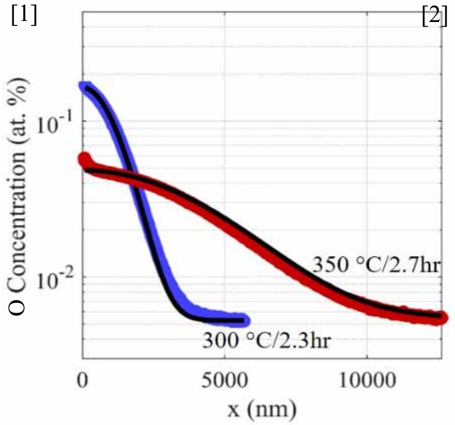
All in DESY Niobium retort furnace medium temperature treated cavities. Open markers depict curves which were intentionally stopped to avoid quenching.

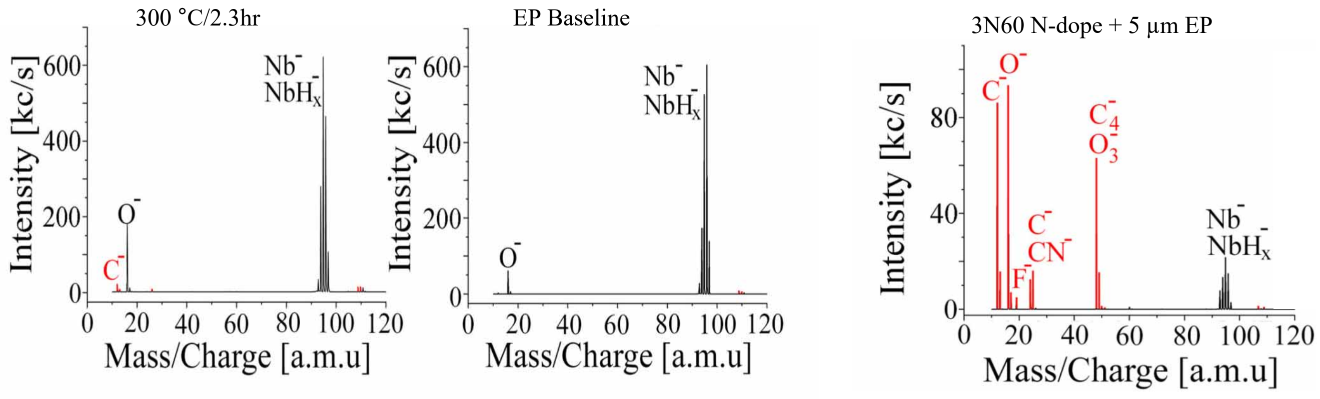
Related contributions at SRF:
C. Bate – Poster ID 2030
R. Ghanbari – Poster ID 2101
A. Zaidman – Poster ID 2421
M. Wenskat – Poster ID 2054 & Talk 2901

Baking 300 °C – 400 °C at JLab

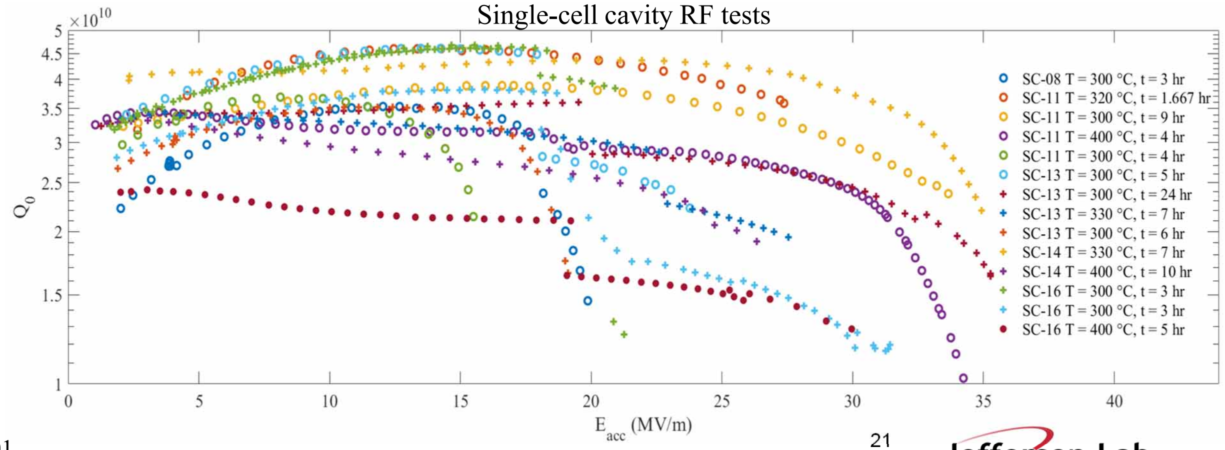
Slide from Pashupati Dhakal

For More info:
See Poster by E. Lechner





- *SIMS measurements show that O in the main impurity for mid-T baked cavities [1]*
- *SIMS measurements show fewer impurities introduced during vacuum annealing vs N doping*
- *Baking too long or too high in temperature shows EP-like performance (O absorbed into bulk)*
- *Sensitive to multipacting at ~20 MV/m*
- *High Q_0 but low E_{max} observed in multi-cell cavities*

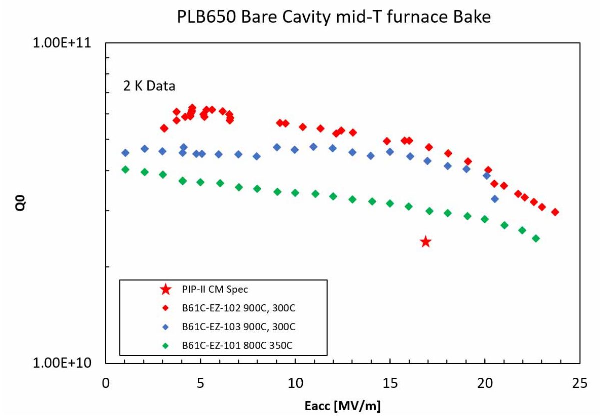


[1] Lechner, E. M., et al. *Applied Physics Letters* 119.8 (2021): 082601.
[2] Angle, Jonathan W., et al. *Journal of Vacuum Science & Technology B* 41.3 (2023).

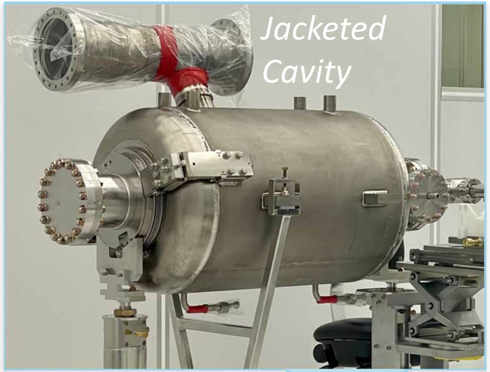
Jefferson Lab

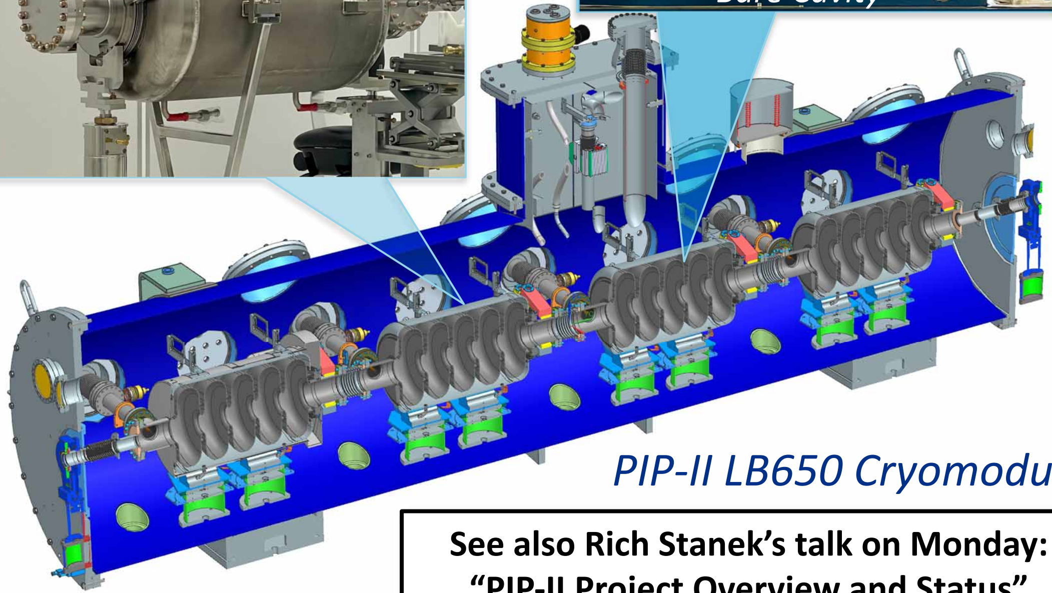
Mid-T Bake for Fermilab PIP-II LB650 Cryomodule

- High Q recipe using Mid-T furnace baking was endorsed by a review committee and adopted for LB650 cryomodules
- Uniform few-micron EP proved challenging on LB650 geometry, but mid-T bake doesn't need it!



LB650 Cavity Processing Final Design Review Report, April 4, 2023





PIP-II LB650 Cryomodule

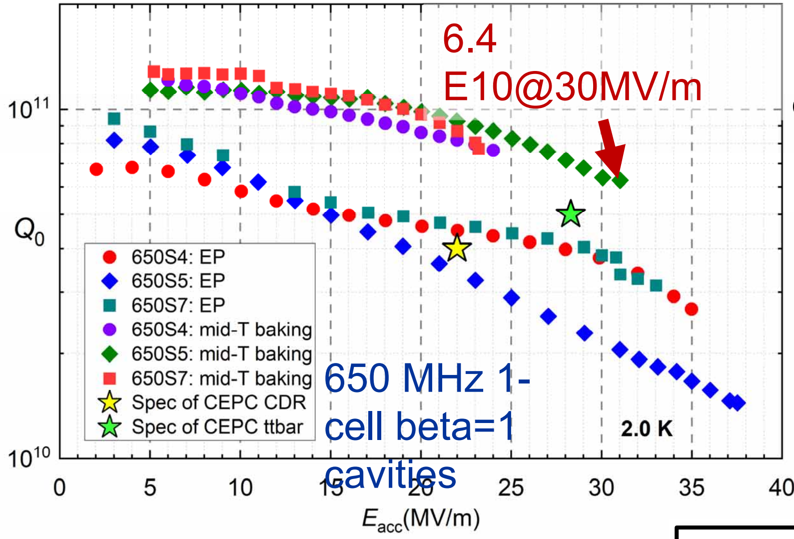
See also Rich Stanek's talk on Monday: "PIP-II Project Overview and Status"

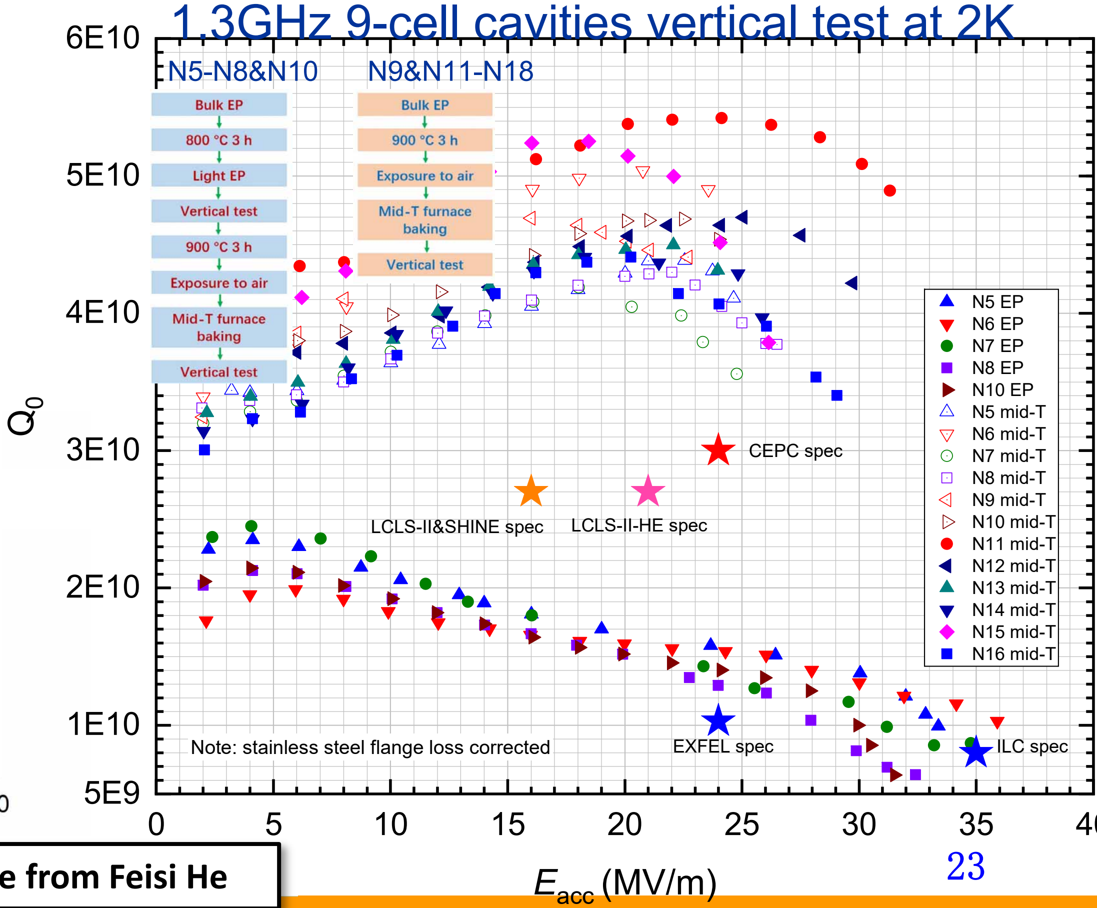
Slide from Genfa Wu

PIP-II

Mid-T furnace baking of 1.3GHz 9-cell & 650MHz cavities

- 14 1.3GHz-9cell cavities was mid-T baked at 300C for 3hrs upto now. Average Q0~4.5e10 at 16&21MV/m (ss flange loss corrected), average Eacc ~ 26MV/m
- After mid-T baking (300 C for 3 h), 650 MHz 1-cell cavities achieved state-of-the-art Q0, which reached 6.4E10 @ 30 MV/m (at 2.0 K).



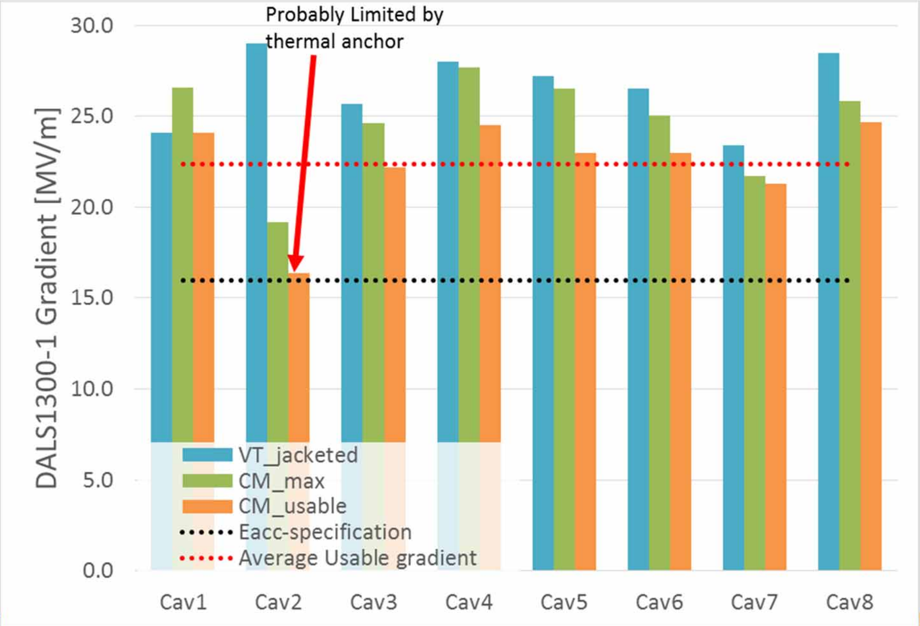


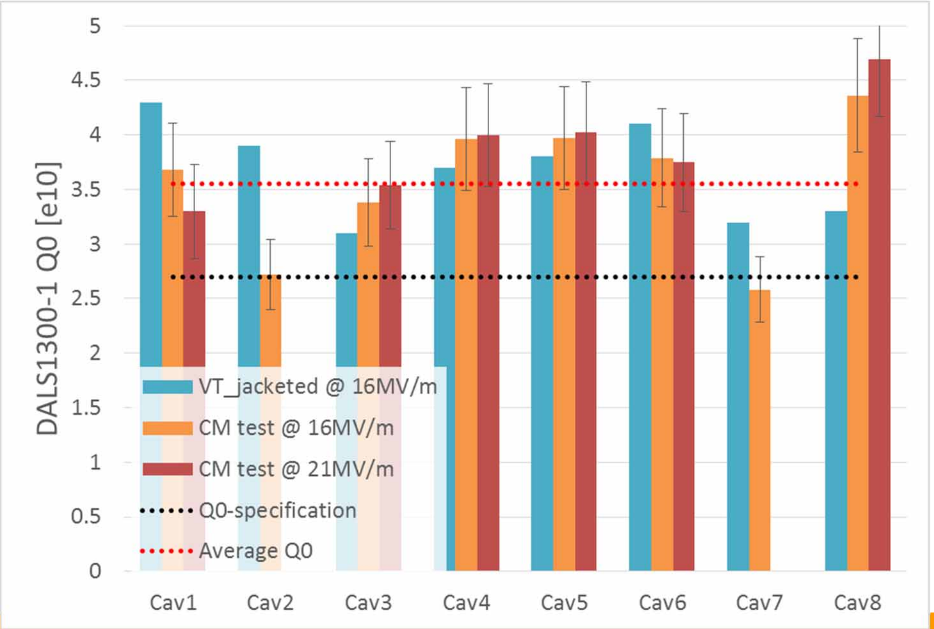
Slide from Feisi He

First cryomodule of 8 mid-T cavities tested at IHEP

Slide from Feisi He

- IHEP is developing the cryomodule for the DALS project
- Dynamic heat load at 133MV is 61W (Q0~3.6±0.5e10 at 16MV/m)
- Dynamic heat load at 174MV is 104W (Q0~3.6±0.4e10 at 21MV/m)
- Usable voltage up to now (stable>1hr, <1mSv/h) is 185MV (~22MV/m), which is limited by 5.2kW power source.
- More details will be published later, after all measures are finished.





Slide from Daniel Bafia's talk on Tuesday: "The role of nitrogen and other impurities in SRF cavity performance"

Summary of Surface Treatments

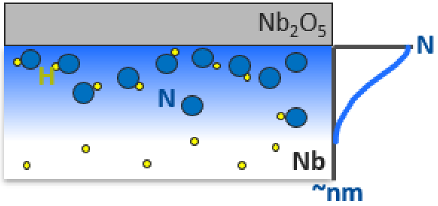
are important here!

N Based Treatments

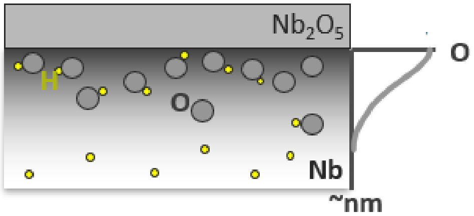
Vacuum/O Based Treatments

Low Temperature (90 C – 200 C)

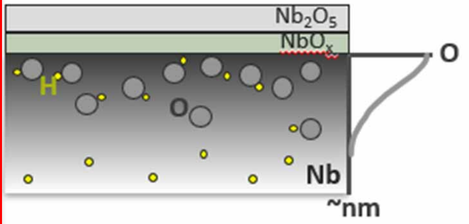
N-Infusion



Furnace LTB



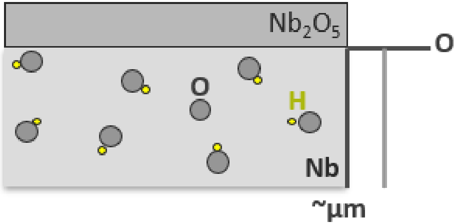
In Situ LTB



Mid Temperature (300 C < T < 450 C)

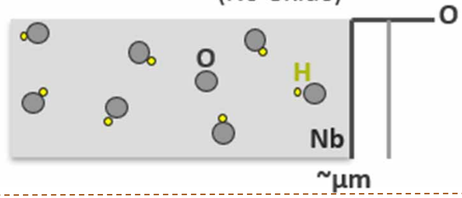
Under exploration

Furnace Mid-T Bake



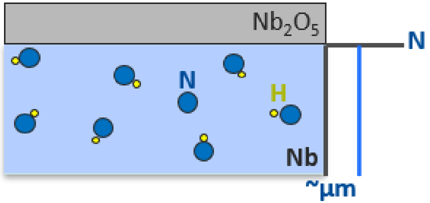
In situ Mid-T Bake

(No Oxide)

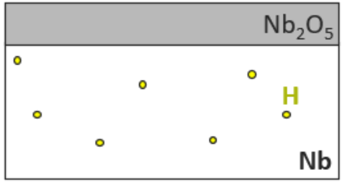


High Temperature (+700 C)

N-Doping



800C HT Baked



No extrinsic impurities

Review of Bulk Niobium Heat Treatments: Timeline

Preparation and Characterization of Ultra-High-Purity Niobium
Klaus K. Schulze
JOM **33**, 33–41 (1981) | Cite this article

Superconductor Science and Technology
FAST TRACK COMMUNICATION
Nitrogen and argon doping of niobium for superconducting radio frequency cavities: a pathway to highly efficient accelerating structures
A Grassellino[1], A Romanenko[1], D Sergatskov[1], O Melnychuk[1], Y Trenikhina[2], A Crawford[1], A Rowe[1], M Wong[1], T Khabiboulline[1] and F Barkov[1]
Published 22 August 2013 • © 2013 IOP Publishing Ltd
Superconductor Science and Technology, Volume 26, Number 10
Citation A Grassellino *et al* 2013 *Supercond. Sci. Technol.* **26** 102001
DOI 10.1088/0953-2048/26/10/102001

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Unprecedented quality factors at accelerating gradients up to 45 MVm^{-1} in niobium superconducting resonators via low temperature nitrogen infusion
A Grassellino[1], A Romanenko[1], Y Trenikhina[1], M Checchin[1], M Martinello[1], O S Melnychuk[1], S Chandrasekaran[1], D A Sergatskov[1], S Posen[1], A C Crawford[1] + Show full author list
Published 8 August 2017 • © 2017 IOP Publishing Ltd
Superconductor Science and Technology, Volume 30, Number 9
Focus on The Jan Evetts SUST Award 2017
Citation A Grassellino *et al* 2017 *Supercond. Sci. Technol.* **30** 094004
DOI 10.1088/1361-6668/aa7afe

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Ultralow Surface Resistance via Vacuum Heat Treatment of Superconducting Radio-Frequency Cavities
S. Posen, A. Romanenko, A. Grassellino, O.S. Melnychuk, and D.A. Sergatskov
Phys. Rev. Applied **13**, 014024 – Published 14 January 2020

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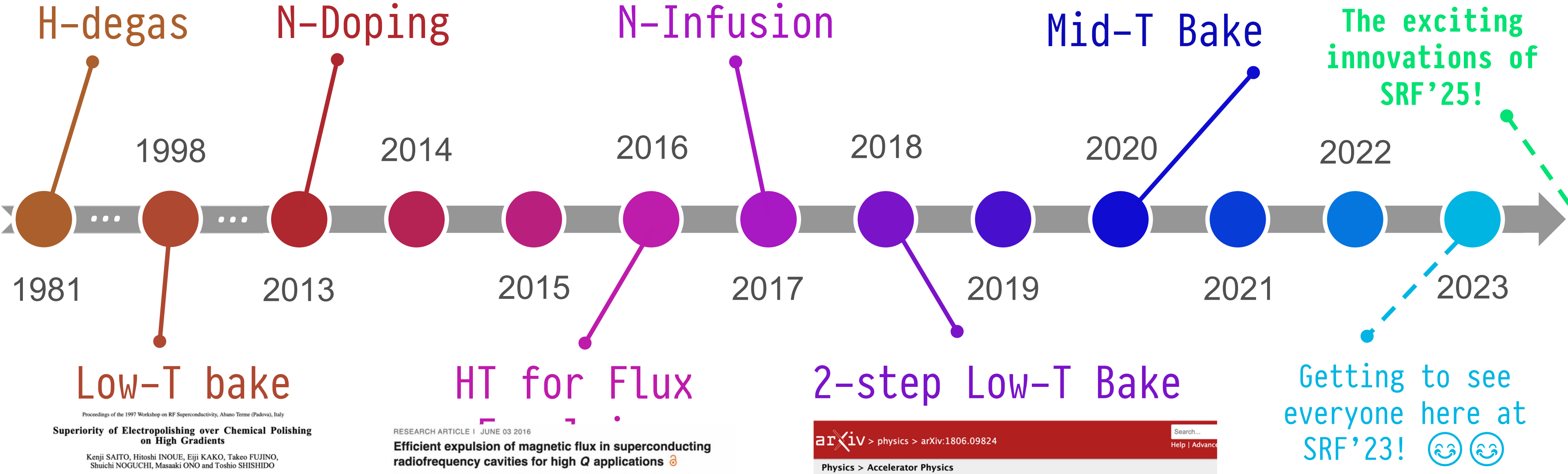
Influence of furnace baking on Q–E behavior of superconducting accelerating cavities
H Ito, H Araki, K Takahashi, K Umemori
Progress of Theoretical and Experimental Physics, Volume 2021, Issue 7, July 2021, 071G01, https://doi.org/10.1093/ptep/ptab056
Published: 30 April 2021 **Article history**



Proceedings of the 1997 Workshop on RF Superconductivity, Abano Terme (Padova), Italy
Superiority of Electropolishing over Chemical Polishing on High Gradients
Kenji SAITO, Hitoshi INOUE, Eiji KAKO, Takeo FUJINO, Shuichi NOGUCHI, Masaaki ONO and Toshio SHISHIDO
High Energy Accelerator Research Organization (KEK)
1-1, Oho, Tsukuba-shi, Ibaraki-ken, Japan, 305 - 0801

Proceedings of the 1999 Workshop on RF Superconductivity, La Fonda Hotel, Santa Fe, New Mexico, USA
Electropolishing and in-situ Baking of 1.3 GHz Niobium Cavities
L. Lilje*, D. Reschke, K. Twarowski, DESY, Notkestraße 85, 22607 Hamburg
P. Schmüser, Universität Hamburg
D. Bloess, E. Haebel, E. Chiaveri, J.-M. Tessier, H. Preis, H.Wenninger, CERN, Geneva
H. Safa, J.-P. Charrier, CEA, Saclay

RESEARCH ARTICLE | JUNE 03 2016
Efficient expulsion of magnetic flux in superconducting radiofrequency cavities for high *Q* applications
S. Posen; M. Checchin; A. C. Crawford; A. Grassellino; M. Martinello; O. S. Melnychuk; A. Romanenko; D. A. Sergatskov; Y. Trenikhina
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Journal of Applied Physics 119, 213903 (2016)
https://doi.org/10.1063/1.4953087 Article history
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arXiv > physics > arXiv:1806.09824
Physics > Accelerator Physics
[Submitted on 26 Jun 2018]
Accelerating fields up to 49 MV/m in TESLA-shape superconducting RF niobium cavities via 75C vacuum bake
A. Grassellino, A. Romanenko, D. Bice, O. Melnychuk, A. C. Crawford, S. Chandrasekaran, Z. Sung, D.A. Sergatskov, M. Checchin, S. Posen, M. Martinello, G.Wu

Fermilab

Summary

- In the last decade, several thermal treatments were developed, leading to unprecedented Q and gradient
- Not all are reproduceable everywhere – high gradient heat treatments N-infusion & 2-step bake have shown ~50 MV/m in some cases, others not
- N-doping took a lot of development to make reproducible but is now industrialized. Still more development was needed for LCLS-II-HE
- Furnace Mid-T bake has shown to be comparatively straightforward to reproduce successfully, even when scaling up to multicells or to complex geometries
- Mid-T bake benefits a lot from the R&D done on N-doped cavities for reducing trapped flux dissipation