Status of 650MHz Cavities for PIP-II

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PIP-II $\beta=0.90$ & 0.92 Jacketed Cavity FDR

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In partnership with:
India/DAE
Italy/INFN
UK/STFC
France/CEA/Irfu, CNRS/IN2P3
Outline

• High Q optimization:
  – Intro on N-doping treatment
  – Early tests on 650 MHz
  – 5-cells cavity results
  – Processing optimization for higher Q in cryomodule
  – Trapped flux sensitivity measurements

• Instrumentation for prototype cavities

• Summary
N-doping treatment: how is done

Example of a N-doping process (2/6 recipe):

- Nb bulk EP cavity annealed for 3 hours in vacuum (UHV furnace) at 800°C
- Nitrogen injected (25 mTorr) at 800°C for 2 minutes
- Cavity stays for another 6 minutes at 800°C in vacuum
- Cooling in vacuum
- 5 µm electro-polishing (EP)
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N-doping treatment: interstitial N in Nb

Only Nb from TEM/NED spectra: N must be interstitial

Y. Trenikhina et al, Proc. of SRF 2015
N-doping treatment: performance improvement with field

\[ R_S \left( 2K, B_{Trap} \right) = R_{BCS} \left( 2K \right) + R_0 + R_{Fl} \left( B_{Trap}, l \right) \]

Anti-Q-slope emerges from the BCS surface resistance decreasing with field

A. Romanenko and A. Grassellino, Appl. Phys. Lett. 102, 252603 (2013)

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HB650 Single-cell Early Test Results

- 120C baked cavities not always meet specs
- N-doping capable to double the Q-factor at medium field, sometimes affected by early quench
- **World record Q-factor** of 7e10 at 2K, 17 MV/m and 650 MHz with N-doping
HB650 Single-cell Early Test Results

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• N-doping capable to double the Q-factor at medium field, sometimes affected by early quench

• World record Q-factor of $7 \times 10^{10}$ at 2K, 17 MV/m with N-doping

Results were very promising with N-doping, however:

1. Large variability was observed with both processing (N-doping and 120C baking)
2. No anti-Q-slope observed with N-doped cavities
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HB650 5-cells Tests Results (all N-doped + 20um EP)

- Light N-doping applied to 650 MHz cavities: **2/6 N-doping + 20um EP**

- 3 N-doped 5-cells 650 MHz cavities meet PIP-II specification

- B9A-AES-010 **will be dressed with He vessel**, the others will be re-processed to improve performance
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**HB650 5-cells Tests Results (all N-doped + 20um EP)**

- Very light N-doping treatment was chosen
  - **Pro:** no early quench observed
  - **Cons:** very little doping effect remains
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Frequency dependence of $R_{\text{BCS}}(E_{\text{acc}})$

- N-doped cavities at 650 MHz do not show the $R_T$ reversal (anti-Q-slope) typically observed at 1.3 GHz

- The physical mechanism underneath the reversal of $R_{\text{BCS}}$ (here called $R_T$) has a stronger effect at high frequencies

- Also for 120C baked cavities, the field dependence of $R_T$ is unfavorable at low frequencies

- Optimization of processing specifically for 650 MHz is needed!!

HB650 Single-cell R&D program

• **Intensive processing optimization** is being pursued starting from 2018:
  • **GOAL**: reach the highest possible Q at medium/high field for 650 MHz cavities
  • **Flux expulsion** and **trapped flux sensitivity** will be also optimized for Q preservation in cryomodule

• Surface treatments under studies: EP, BCP for baseline and modified 120C (75-120C baking), N-doping for Q improvement

• Trapped flux sensitivity will be acquired for each treatment to understand magnetic flux shielding requisition in cryomodule
All data acquired in 2018
EP vs N-doping (B9AS-RRCAT-301)

N-doping (2/6 + 5um EP)

EP

\[ \sigma \] vs \[ E_{\text{acc}} \] (MV/m)

10^{11}

10^{10}

10^{9}

0 5 10 15 20 25 30 35

E_{\text{acc}} (MV/m)
EP vs N-doping and 75-120C baking (B9AS-PAV-104)

N-doping (3/60 + 5um EP)

75-120C baking

Eacc (MV/m)

Q

10^9

10^10

10^11
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Trapped Flux Sensitivity Measurements

N-doped cavities show significant larger sensitivity that other treatments
Minimizing Losses in Cryomodules due to Trapped Flux

• Even though final processing of 5-cells 650 MHz cavities is not finalized yet, it is necessary to minimize as much as possible flux trapping, especially knowing that N-doped cavities show larger sensitivity

• In order to do that, we are:
  • **Maximizing flux expelling efficiency**: all our 5-cells are being treated at 900C for 3 hours, this treatment is known to relief stress and dislocations and cause flux trapping during cooldown
  • **Minimizing remnant magnetic field in cryomodule**: design of magnetic shielding is in process and will take into account sensitivity of production processing
  • **Instrumenting cavities with thermometers and fluxgates** in order to monitor the magnetic field in-situ and the cooldown properties
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**Flux-gates location**

In order to understand flux expulsion efficiency during cooldowns, simulations suggested that the flux-gates need to be placed as follow:

- Longitudinally between irises ($B_{sc} / B_{nc} = 0.18$)
- Vertically between irises ($B_{sc} / B_{nc} = 0.85$)

In this way the variation of the field ($B_{sc}/B_{nc}$) during the SC transition, after complete Meissner effect, is maximized and the fraction of field trapped/expelled can be estimated.

The simulations, courtesy of Iouri Terechkine, take into account REAL magnetic field environment in cryomodule and integrate the results within the active length of the fluxgate.
Flux-gates location

In order to detect $B$ generated by thermo-currents a **transverse** fluxgate is needed.

Example of magnetic field generated by thermo-current during a fast cooldown of an LCLS-II cryomodule.
Thermometers location

Thermometers will be placed in different locations on cell #1, 3, 5 to monitor both vertical and longitudinal thermal-gradient during cooldown.
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• The production processing for 650 MHz cavities is still under investigation, the treatment with the best compromise between BCS, residual and trapped flux surface resistance at ~20 MV/m will be chosen;

• A very light N-doping treatment was applied to 5-cell cavities giving mostly good results. The best 5-cell cavity will be dressed within next days, the other have been reset and treated with 900C baking to maximize flux expulsion. They will be soon re-processed and will be dressed once specs are met;

• Magnetic shielding design will be finalized after the production processing is chosen since that will set the maximum magnetic field allowed in cryomodule;

• Some of the 5-cell cavities will be instrumented, before being dressed, with fluxgates and thermometers to monitor: remnant magnetic field, flux expulsion efficiency, magnetic field due to thermo-currents and cooldowns dynamic directly in the cryomodule.