R&D status
for in-situ plasma surface cleaning of SRF cavities at SNS

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Motivation for in-situ processing

• **Medium term**
  
  – Reach 1GeV + energy reserve
  
  – Increase high beta cavity gradients by about 2 MV/m in average

• **Long term**
  
  – 42-mA beam loading with 2\textsuperscript{nd} target station
  
  – Efficient utilization of RF power: ideally constant RF power/cavity is preferred → narrower performance scattering

• **Develop a cost effective method with minimal impact on machine operation**
SNS SRF cavity performance statistics

- Electron loadings (mainly field emission)
  - Collective effects
  - Thermal instability at the end group

![Graph showing performance statistics for medium and high beta cases.](image)
• Field emission
  – Not a fundamental limit in theory but the major limitation in multi-cell cavities in high-duty operational machines.
  – Performance scattering.

• Contamination
  – Contaminants entered during processing/assembly
  – Enhancement of field emission with condensed/absorbed gases and/or oxide layer/boundary layer
  – Locations of field emitters are random/statistical

• Field emitter processing characteristics
  – may change over time, possibly harder after conditioning/commissioning
  Ex. Clear improvement at an initial He-processed cavity in VTA
Helium vs. Plasma processing

• He-processing
  – high gradient, high energy electron (FE), no space plasma,
  – Few statistics on in-situ helium processing at $E_a > 10$ MV/m
  – No in-situ experience in pulsed mode w/ Couplers

• Plasma cleaning
  – low voltage glow discharge, low energy electron, space plasma & radical
  – Lack of experiences w/ SRF cavities
  – Routine & major cleaning method in semi-conductor industry, some of fusion devices and vacuum devices
Helium processing with H01

- **H01**: worst performing CM. Largest x-rays
  - Lowest operating gradients (~10 MV/m or less for operation) limited by field emission

- **Tried with cavity A in H01**

- **Helium processing is not adequate for SNS CM**
  - Initial Start-up; Showed about same behavior as baseline at ~9MV/m quench (end group)
  - Both Thermal Diodes (TDs) on HOMA and HOMB showed spikes up to 8K
  - Ended at ~8 MV/m after several hours of trials
  - Aggressive MP at HOM couplers → stop helium processing
Plasma cleaning

Ion, molecule (radical), electron

contaminants

Base material

wettability

before

after

- Cleaning
  - Soft
  - hard
- Activation
- Crosslinking
- Deposition
- Etching
Preliminary experiment

Complete removal of carbon/oxide layer
+Removal of absorbed/trapped (H₂, H₂O)
+Some effect similar with baking
Preliminary experiment for plasma generation in the SNS cavity

300W forward
200W reflected
1e-4 torr
Plasma processing with H01 test (First Attempt)

- Investigate possible in-situ processing
- The First attempt for the SNS cryomodules
  - No optimization studies
  - Explore the possibility
  - Comparisons of radiation before and after processing
- Very mild attempt
- Some unknowns
  - Copper damage (FPC, HOM feedthrough)?
  - Coupler window coating?
  - Unknown solid-state byproducts?
Radiation/electron activity diagnostics in the Test Cave

- Ionization Chamber
- Internal Ionization Chamber
- Phosphor Screen, Camera, Faraday Cup
H01 baseline test in the Test Cave

- All four cavities showed large amount radiations (onset ~6MV/m)
H01 baseline test in the Test Cave

- All four cavities showed large amount radiations (onset ~6MV/m)
Plasma Processing

- Very mild attempt; 10-20 W forward power, 60 Hz, 1-ms pulse at 4K, 1e-4 torr with helium gas
- Performed processing on 3 out of 4 cavities for < 5 min.
Partial warm history after processing

Much bigger amount of gases than normal warm-up
(lots of H₂, O₂ and hydro-carbons)
Continued until 150°C
Hydro carbon (44) and its fragments at around 150 C
Radiation (before and after processing)

Radiation reduced by factor of 100
Showed promising results for in-situ processing

Eacc=10

Before and after processing graphs showing radiation levels.
Radiation (before and after processing)

Radiation reduced by factor of 100
Showed promising results for in-situ processing

Before processing

After processing
R&D Main Objectives

• Apply plasma surface modification to decrease effect of field emission on superconducting niobium surfaces
  – Room temperature processing
  – Processing parameter optimization
    • Uniform processing
    • Repetitive processing
    • Understanding of processing
  – Systematic study
    • Figure out what we can do/can’t do
    • Find a statistically optimal procedure
Tools

In-situ Processing
Test Cavity

3.3 GHz, TM020 mode
Ep/Bp=1.12 (MV/m)/mT
Ex. Ep=50 MV/m, Bp=56 mT
P_{diss}=36 W at 4.2 K
OD: 150 mm

- Cold test
  w/ dual mode (CW or pulse)
- Plasma processing

Demountable witness plate
Witness Sample for Chemistry
FPC Flange
Microwave Plasma processor
Summary

• The first attempt of plasma processing w/ H01
  – Promising results

• R&D program
  – Hardware set-ups are in progress
  – Develop a procedure for statistical improvements
  – Expected gains (preliminary)
    • Removal of absorbed/trapped gases
    • Removal of oxide layer
    • Removal of small-size contaminants via physical bombardment or chemical reaction
    • Low temperature baking effect