Plasma processing of Nb surfaces for SRF cavities

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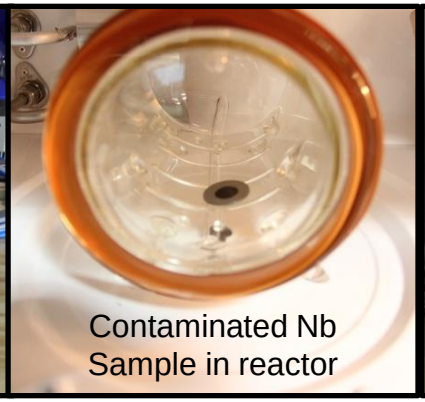
Overview

- **Context**
  - Most of the SNS cryomodules are limited by field emission
  - Plasma processing R&D aims to develop in-situ plasma processing and reduce field emission in SNS cryomodules*
  - So far, developed a room-temperature $Ne+O_2$ plasma processing technique to clean residual hydrocarbons in SNS High-beta cavities

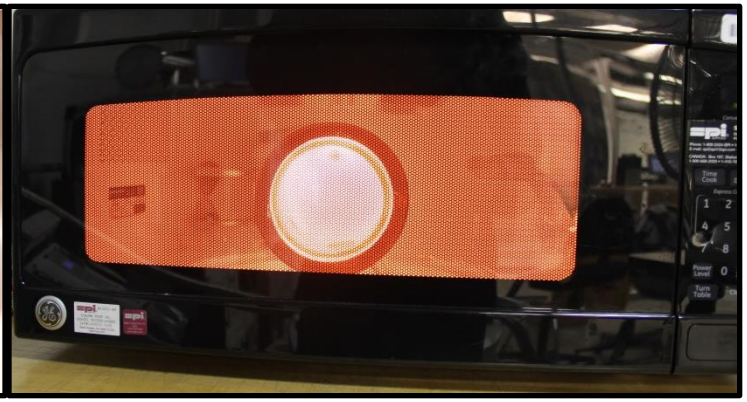
- **Studies of $Ne+O_2$ plasma processed Nb surfaces reveal**
  - O_2 oxidizes hydrocarbons and the volatile compounds are pumped out
  - Plasma cleaning increases the work function and reduces field emission

*M. Doleans et. al. "Plasma processing R&D for the SNS superconducting linac rf cavities", SRF2013

Microwave Plasma Processing of Nb Samples



Contaminated Nb Sample in reactor



- **$Ne+O_2$ plasma chemistry studies using a microwave plasma reactor**
- **Two types of Nb samples were used**
  - BCPed Nb samples for work function studies
  - Nb samples with added surface contamination for hydrocarbon removal rate studies
- **$Ne+O_2$ plasma chemistry for hydrocarbon removal is similar in SNS SRF cavities and in microwave plasma reactor**
  - Short cycles done in microwave to avoid heating effect

6 cell HB cavity on plasma processing station

Workfunction (WF) Measurement

Field emission is directly related to WF of surface via Fowler-Nordheim law

$$j \propto \frac{\beta E}{\Phi} e^{-\frac{a\Phi^{3/2}}{\beta E}}$$

j : current density
Φ : work function
βE : enhanced surface electric field

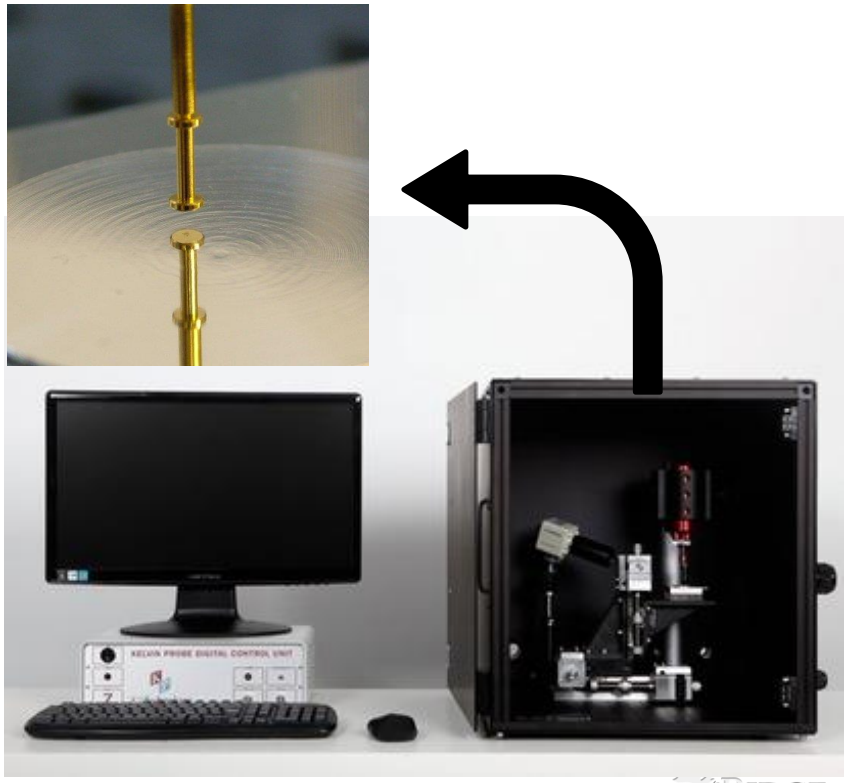
Higher WF ⟹ Lower field emission

WF measured by Scanning Kelvin probe

- **Based on Lord Kelvin's principle**
  - Potential difference between surfaces with different WF
- **Measures contact potential difference (CPD) between sample surface and measuring tip**
  - WF is calculated by using following equation

$$\Phi = WF_{tip} + CPD_{sample}$$

- **Measured WF of Nb samples before and after Ne+O_2 plasma processing**



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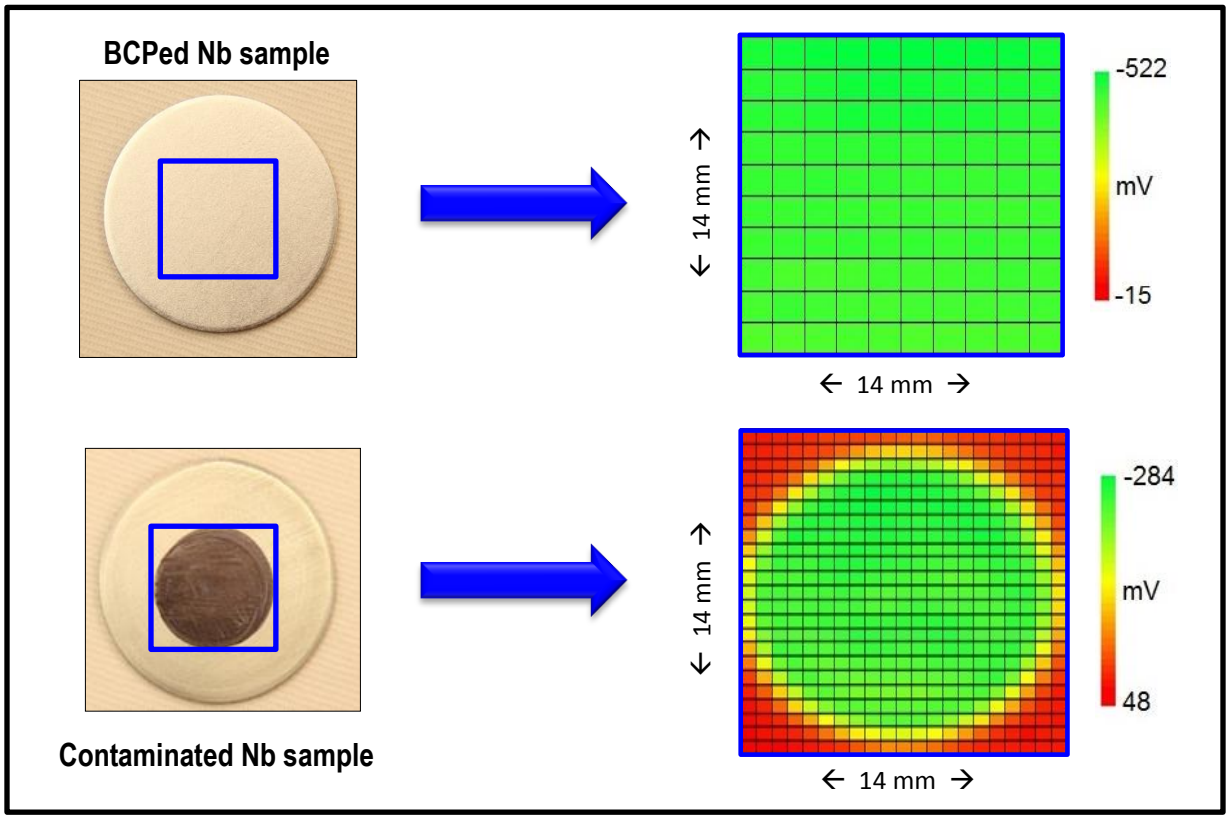
WF Measurement (cont.)

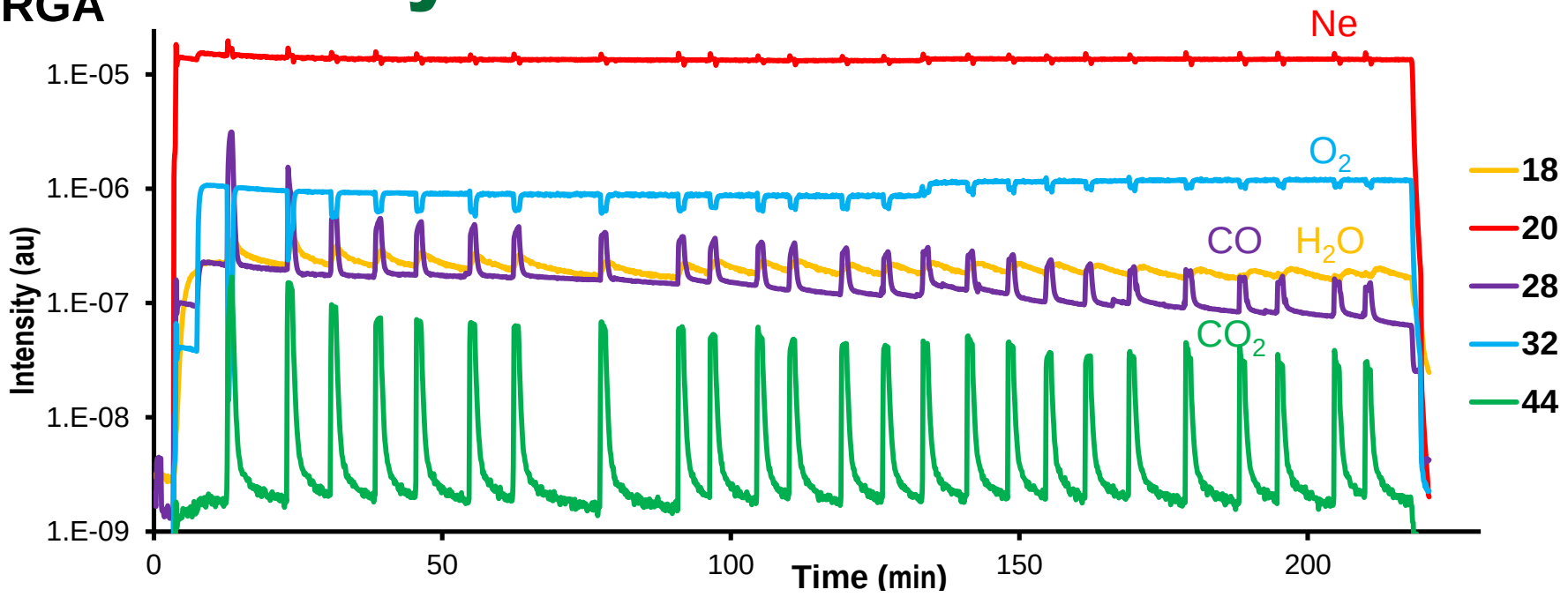
CPD MAPPING - BEFORE PLASMA PROCESSING



- **WF of BCPed sample was increased after Ne+O_2 plasma processing**
  - Removed hydrocarbons from sample surface measured in RGA
- **Increased WF of surface can help lowering field emission in SRF cavities**

Sample	Increase in WF $\Delta\Phi$(eV)
BCPed Nb sample	0.2

Hydrocarbon removal



- **Ne+O_2 plasma (140 mTorr, 2% O_2)**
  - 225 min RGA recording, 25 min plasma processing (1 min cycles)
- **O_2 is consumed in the plasma to oxidize hydrocarbons**
- **Basic plasma chemistry**

$$C_xH_y + O_2 \rightarrow CO + CO_2 + H_2O$$

- **Volatile compounds H_2O, CO, CO_2 are pumped out and measured in RGA**
- **From weight measurement: Removal rate ~ 8.4 µg/min**

Before After

Conclusions

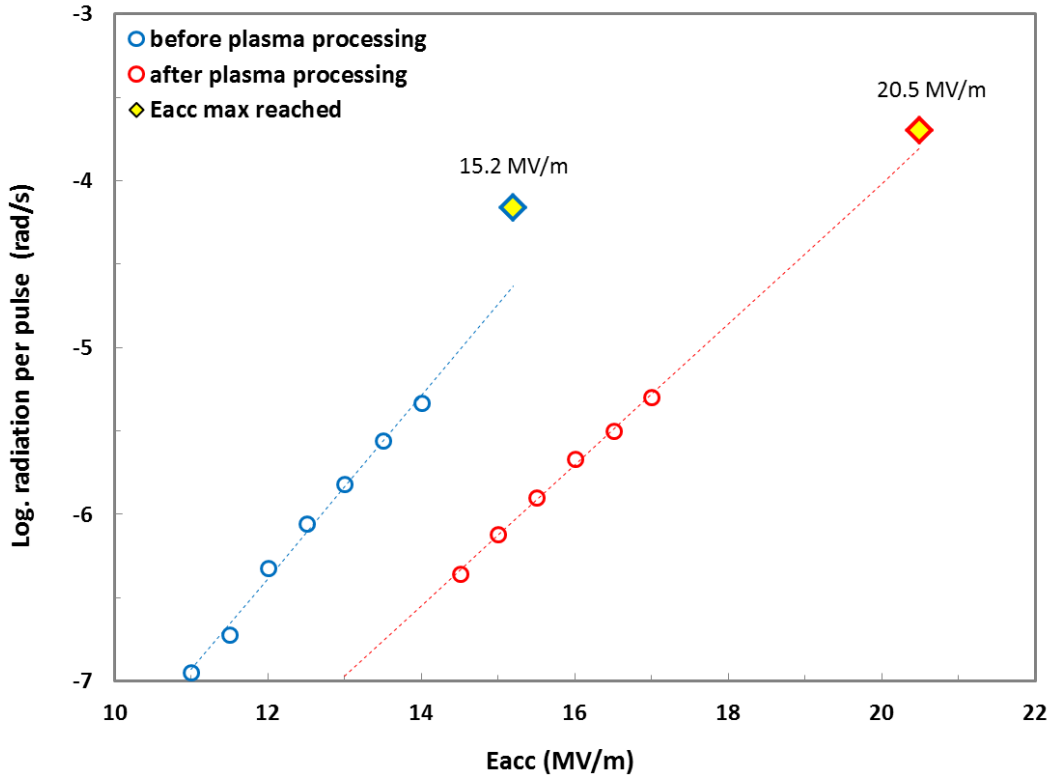
- $Ne+O_2$ plasma is very effective to remove hydrocarbons
- Hydrocarbons are removed as CO, CO_2 and H_2O volatile by-products
- Surface WF is increased after the $Ne+O_2$ plasma processing
- Other surface studies related to plasma processing, e.g. surface oxidation, are on-going

It Works

For more discussions please visit MOPP115

Thank You

Cold Test Results of Plasma Processed SNS HB cavity*



- **Maximum gradient increase -** From 15.2 MV/m to 20.5 MV/m
- **Field emission onset increased -** From 11 MV/m to 13 MV/m
- **Radiation level at given gradient reduced -** Radiation lowered by an order of magnitude

***M. Doleans (doleansmm@ornl.gov)**
SNS talk on "First cold-test results of plasma processed SNS High-beta SRF cavities", Aug 14, 2014