SURFACE STUDIES OF PLASMA PROCESSED Nb SAMPLES

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SNS is managed by UT-Battelle, LLC, under contract DE-AC05-00OR22725 for the U.S. Department of Energy

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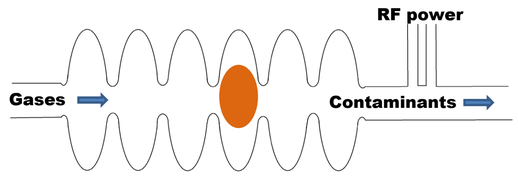
Overview of the Plasma Processing at SNS

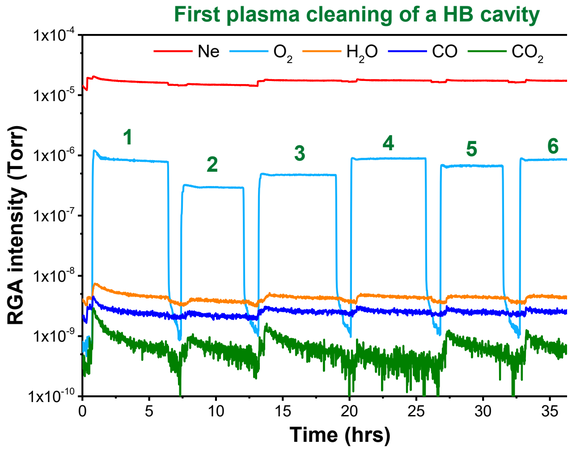
- Most of the SNS HB cavities are presently limited by the field emissions and operating below their design gradient
- Recently, a room temperature in-situ plasma processing technology for SNS HB cavities aiming to remove hydrocarbon contaminants has been developed at SNS
- Plasma processed cavities have shown significant improvement in the accelerating gradient with much reduced electron activities during cold test in HTA
- In-situ plasma processing of an offline cryomodule is progressing
- Surface studies on Nb samples confirmed the cleaning of the surface hydrocarbons and improvement of the workfunction of Nb surface after plasma processing with the standard mixture for SRF cavities



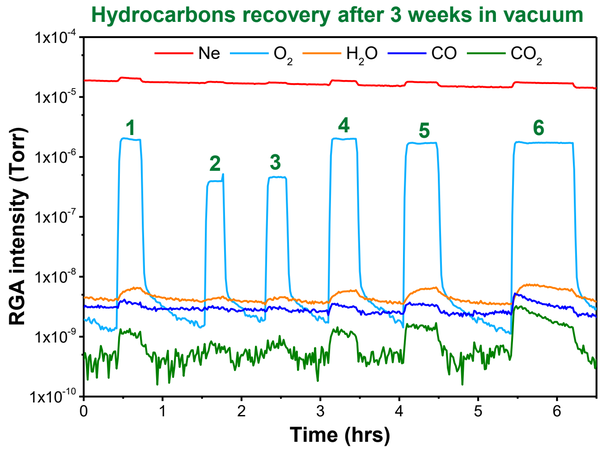
Plasma Processing of SRF Cavities at SNS

- Plasma in each cell of the multi-cell cavities can be generated utilizing the different cavity modes (more details in the talk by M. Doleans on Thursday)
- Ne is used as a primary gas to ignite and tune plasma in a desired cell and O_2 is introduced to clean hydrocarbons from cavity surface
- RGA spectrum obtained during plasma processing shows H_2O, CO and CO_2 as a by-products of the plasma chemistry of hydrocarbons on cavity surface
- CO and CO_2 signals were depleted during plasma processing indicating the cleaning of cavity surface
- Hydrocarbons recovery on cavity surface was observed when a cavity was subjected to plasma processing again after 3 weeks. Cavity was kept under vacuum during the waiting time of 3 weeks (RGA spectra are shown below)

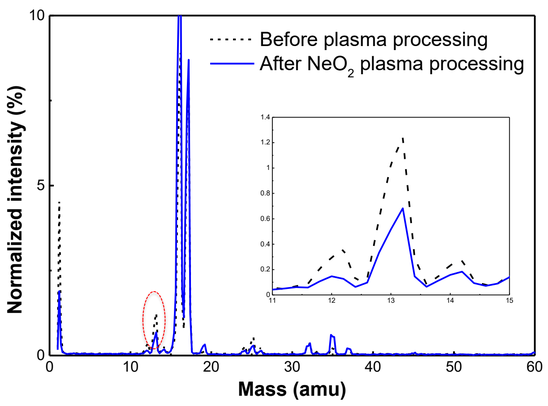
First plasma cleaning of a HB cavity



Hydrocarbons recovery after 3 weeks in vacuum



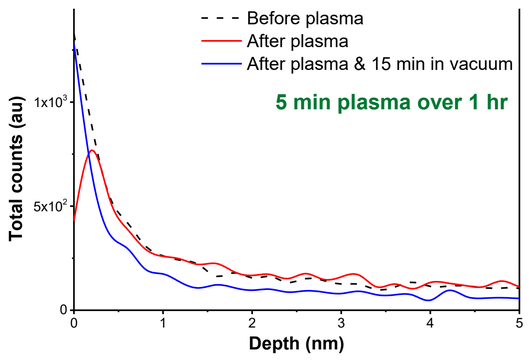
Secondary Ion Mass Spectrometry (SIMS)

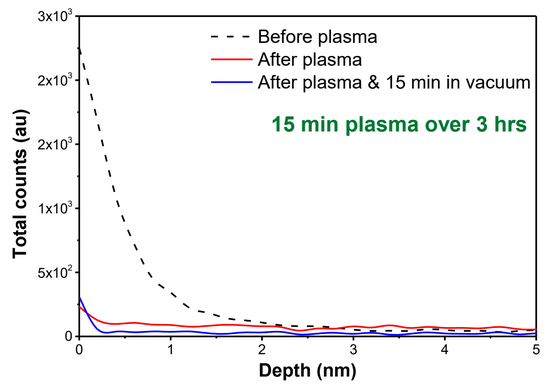


IMS negative spectrum found eduction in the CH^- at top surface fter NeO_2 plasma processing

H^- recovery at top surface from nderneath surface was observed after aiting in vacuum for 15 minutes

onger plasma processing was found eneficial to mitigate hydrocarbons ecovery through diffusion mechanism





Plasma Processing of Nb Samples

- A barrel plasma reactor located inside microwave housing (2.4 GHz) was used for plasma chemistry studies on Nb samples
- Nb samples were first mechanical polished and ~200 µm thickness was removed
- Gas feed system was designed to provide adequate gas mixture at required pressure in the plasma reactor
- Ne base pressure ~ 130 mtorr with 2% of O_2 was used for plasma processing (similar to cavity plasma processing)

- An RGA, mounted on pumping system was used for the analyses of the gases coming out of the plasma reactor during plasma processing
- Similar plasma chemistry to cavity plasma processing was observed in the microwave plasma processing
- Ne plasma is shown in the picture

Workfunction (WF) Measurements

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

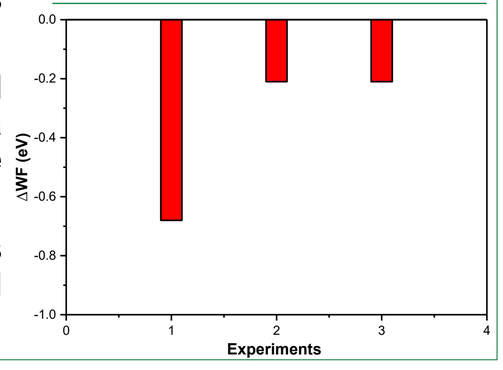
$$j \propto \frac{\beta E}{\phi} e^{-\frac{a\phi^{3/2}}{\beta E}}$$

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

Higher WF ⟶ Lower field emission

- WF measurements were performed using scanning kelvin probe (SKP) system
- An improvement in the WF up to 0.6±0.1 eV was found after NeO_2 plasma processing
- WF degradation due to hydrocarbons recovery from underneath surface in vacuum was observed
- WF measurement of Nb sample with artificial hydrocarbons generated by $NeCH_4$ plasma confirmed that hydrocarbons can degrade surface WF (more than 1 eV was measured)
- Multiple plasma processing was advantageous to sustain higher WF for longer time and mitigate hydrocarbons diffusion process

Experiments	Experimental conditions	Δ WF (eV)
1	Total 1.5 hrs. of active plasma and 15 hrs waiting in vacuum	-0.6±0.1
2	Total 5 hrs. of active plasma and 15 hrs waiting in vacuum	-0.21±0.1
3	Total 6.5 hrs. of active plasma and 24 hrs waiting in vacuum	-0.21±0.1



Conclusions

- NeO_2 plasma is very effective to remove organic contaminants from cavity surface
- Hydrocarbons recovery at top surface from underneath surface was observed both on cavity and sample surface
- Surface WF was improved by 0.5 to 1.0 eV after NeO_2 plasma processing
- Multiple plasma processing is beneficial to mitigate hydrocarbons recovery at room temperature
- Cavity performance degradation due to mechanical imperfections can't be recovered using O_2 plasma processing

Future Scope of Work

- Further surface studies are planned to evaluate the effect of plasma processing on different Nb surface e.g. after BCP, EP etc.
- Studies on Nb samples after light plasma etching for surface cleaning will be performed

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