High Fluence Implantation of Helium in Tungsten

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Progress Since the Last Meeting

- Tungsten sample has been irradiated to 10 times previous levels with energetic helium ions.
- Characterization of high fluence (\(10^{20}\ \text{He}^+/\text{cm}^2\)) irradiated sample has begun.
- Work has begun on the development of pulsed IEC operation.
- The \(\text{He}^+\) energy spectra on the first wall and the IEC sample temperatures were re-evaluated.
The IEC Voltage Capability Covers Nearly 25% of the Ions at the First Wall
Tungsten Samples Have Been Irradiated in the IEC Device

- Powder metallurgy samples
- Obtained from Lance Snead, Oak Ridge
- Polished finish
- Spot-welded on to a W-Re wire loop
IEC Run Extended He\(^+\) Implantation Database to 10\(^{20}\) Ions/cm\(^2\)

- Previous maximum fluence was 10\(^{19}\) He\(^+\)/cm\(^2\)
- Irradiation was performed at 30 kV, 6 mA, 0.5 mTorr, and 1150 °C
- This is equivalent to 20 effective full power days in the reference HAPL design (all helium energies)
- It is also equivalent to ~ 100 effective full power days in the reference HAPL design (10 keV < He\(^+\) < 100 keV)
Higher Fluence Yielded Additional Pore Formation and Degradation of Surface

$\sim 1150 \, ^{\circ}C$

1x$10^{19}$ He$^+/cm^2$, 30 kV, 6mA

1x$10^{20}$ He$^+/cm^2$, 30 kV, 6mA
High Temperature Irradiation of Tungsten Produced Drastic Changes in the Surface Morphology

1150 °C
Measured Mass Loss was Observed at 5x the Calculated Physical Sputtering Rate

- Experimental sputtering yield is $\sim$0.038 atoms/ion at 30 keV for $\perp$ incidence (Roth, et. al.-1980)

- Based on these results, $2\times10^{20}$ He$^+$ on a 2 cm$^2$ sample would physically sputter a maximum of $\sim$2.1 mg (without redeposit)

- Measured mass loss was $10.2\pm0.1$ mg

- The mass difference may be due to flaking or other discrete particle loss mechanisms
Implications of Material Loss

- Reference HAPL chamber could lose 48 µm/FPY due to low energy He alone
- Physical sputtering from other light ions (H⁺, D⁺, T⁺) could contribute another 6 µm/FPY
- Additional damage from carbon and heavier ions could further increase this loss
- These processes could result in the formation of a minimum of ~80 kg/FPY of radioactive dust in the chamber
Systematic Pyrometer Malfunction Discovered

- Implication – Past quoted temperature of W samples were too low by 100 to 300 °C.
- Pyrometer repair brought measured temperatures closer to theoretically calculated temperatures
- Current corrections now result in secondary electron emission coefficients of $\approx 2-3$ (more in line with measurements on other materials).
- These changes slightly affect temperatures quoted at PPPL (Fall ’04), NRL (Spring ’05), and LLNL (Summer ’05)
Work has Begun on Pulsed IEC Operation

- Steady-state experiments have limited ability to simulate pulsed HAPL operation
- A new campaign has begun to develop pulsed IEC operation
- Initial experiments have shown promising results
Pulsed Experiments Will Provide More Realistic Tungsten Damage

Pulse Frequency (Hz)

Pulse Width (sec)

Reference

HAPL

RHEPP (Ions)

ORNL (Infrared)

XAPPER (X-rays)

Dragonfire (Laser)
Initial Pulsed IEC Operation has Shown Promising Results

- High voltage pulsing circuit has been constructed and tested to 50 kV
- Pulses have been run as low as \(~100\ \mu s\) pulse width, 1-100 Hz frequency, and up to 300 mA peak current
- Video shows 30 kV operation at \(~1\) Hz
Conclusions

- Increasing the helium fluence from $10^{19}$ He$^+/\text{cm}^2$ to $10^{20}$ He$^+/\text{cm}^2$ resulted in an increased surface roughening.

- Large fluences cause erosion of the tungsten first wall at 1150 °C beyond calculated physical sputtering values.

- Pulsed IEC operation will allow irradiation at conditions closer to the reference HAPL design than previous experiments.
Future Work

- Evaluate deuterium retention rates and profiles using Elastic Recoil Detection analysis

- Repeat D\(^+\) and He\(^+\) Irradiations to 10\(^{19}\) ions/cm\(^2\) with pulsed operation
Questions?
IEC Device Provides Steady-State and Pulsed Operation

- High-Voltage Feedthrough
- Neutron Detector
- (Ground)
- D$_2$ and He Gas Flow Controllers
- Pyrometer
- Tungsten Sample
- 65 cm Filaments
- 91 cm Neutron Detector
- 50 cm Outer Grid
- RGA
- Proton Detector
- D$_2$ and D$_3$ Gas Flow
- D$_2$ and He Gas Flow Controllers
- Pyrometer
- Tungsten Sample
- 65 cm Filaments
- 91 cm Neutron Detector
- 50 cm Outer Grid
Secondary Election Coefficient on Tungsten

8 mTorr Xenon Background Lowers Energy Spectrum

Helium-4 Ion Spectrum at Wall

- Ions stopped in gas

**Graph Details:**
- **X-axis:** Ion Energy [keV]
- **Y-axis:** Number of Ions
- **Legend:**
  - Blue line: 8 mTorr Xe
  - Red line: Vacuum

**Data Points:**
- Ion Energy values range from $10^0$ to $10^5$ keV.
- Number of Ions range from $10^{13}$ to $10^{20}$.

**Graph Observations:**
- The graph compares the ion spectrum in 8 mTorr Xenon and Vacuum conditions.
- There is a significant decrease in the number of ions at higher energy levels in the Xenon condition.
- The Vacuum condition shows a more consistent distribution of ions across energy levels.