Effects of Multiple Energy $^4He^+$ Bombardment on Cathode Materials Such As W at High Temperatures

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Introduction & Motivation

- Will the W cathode grid wires in IEC devices be eroded as atomic and molecular ions and neutrals of various energies bombard them?
- How much erosion by ion-impact sputtering of the W occurs?
- Mono-energetic $^4He^+$ ions cause subsurface damage to W surfaces, producing sharp points that can contribute to high voltage breakdown across IEC cathode grid wires, resulting in a lower maximum cathode voltage and lower fusion rates.

MITE-E

- MITE-E is used to simulate fusion reactor conditions by irradiating metal samples with He or D under specific conditions:
  - Temperature ranges from 500 to 1000°C.
  - Ion energies from 10 to 60 keV with ion currents of 200 ± 10 μA.
  - Fluence ranges of $1.0x10^{21}$ to $1.0x10^{23}$ ions/m^2.
- A variable power Nd:YAG laser provides the sample heating.
- Sample sizes are ~ 1cm x 1cm x 1mm.
- Physical changes in a sample are analyzed with the Focused-Ion Beam, Scanning Electron Microscope, Electron Backscatter Diffraction, and mass loss measurements.

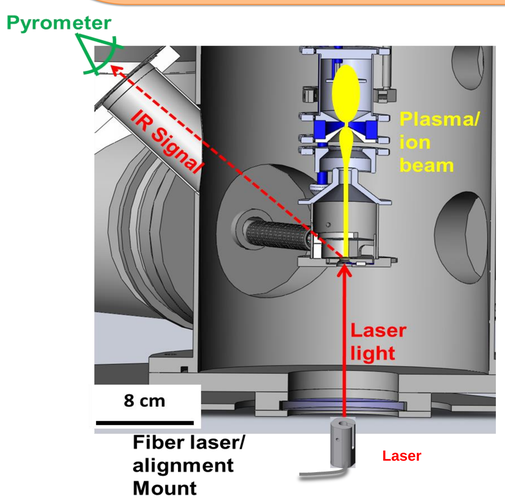


Figure 1: Solidworks™ model of the inside of the MITE-E vacuum vessel.

Ion Impact Damage to W

- Two PCW samples were irradiated with mono-energetic $^4He^+$ ions and suffered significant mass loss; some grains did not display severe damage.
- One PCW sample was irradiated with 10, 20, and 30 keV $^4He^+$ ions in sequence to a fluence of $1x10^{22}$ ions/m^2; all grains exhibit surface damage.
- Erosion of grains can be seen with increasing fluence. Grains of the [111] orientation appear to be less eroded than the surrounding grains.

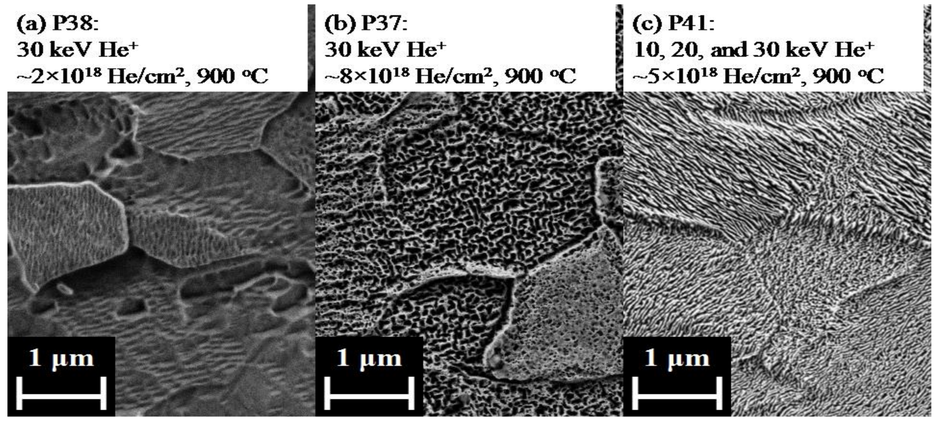


Figure 3: SEM images of eroded of W with increasing fluence using mono-energetic and multiple energy He^+ ion.[1]

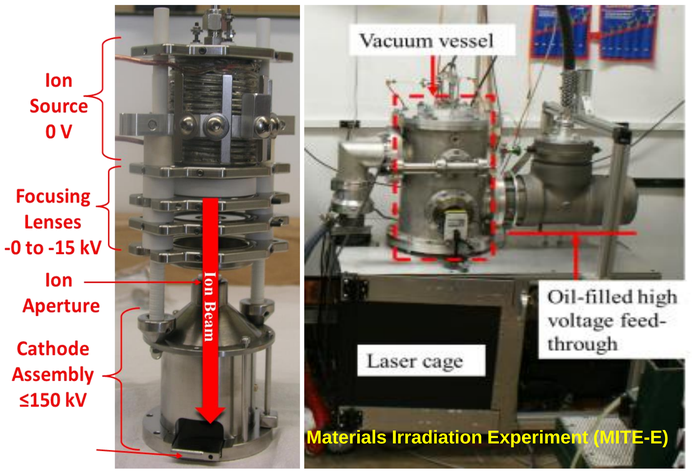
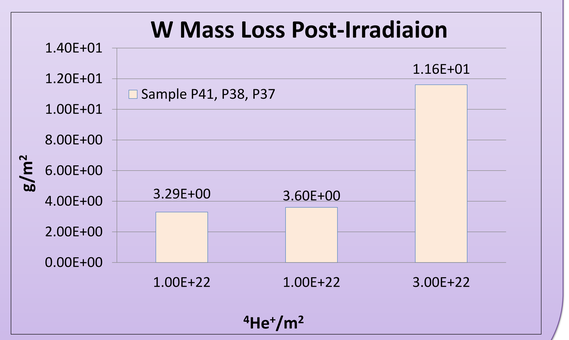


Figure 2: Ion gun (left) and the materials irradiation experiment (right)..

Mass Loss

- Sample areas are 5.03×10^{-5} m^2.
- $^4He^+$ ions eroded the multiple energy sample as much as the mono-energetic sample irradiated to the sample fluence.



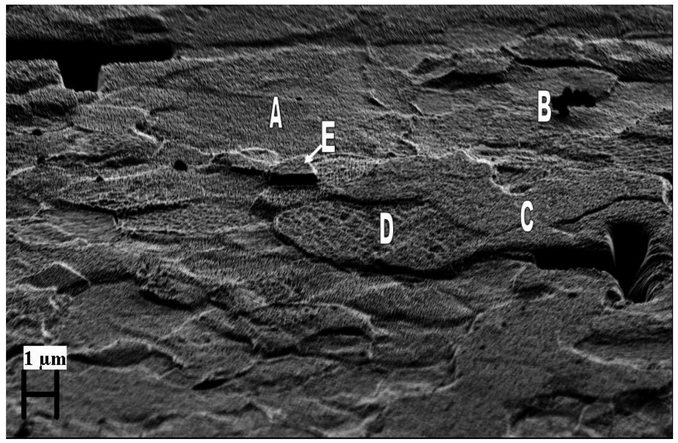


Figure 4: EBSD image showing grain E [-1, 1, 1] as the least eroded.[1]

Conclusions

- The multiple energy bombardment with $^4He^+$ ions causes more He to become trapped in the W lattice leading to greater erosion rates and more damage of the PCW on all grains.
- At high temperatures this trapped He is allowed to diffuse and escape through the surface leaving a “grass” structure behind.
- This surface structure has sharp points that can contribute to:
  - a high voltage breakdown across IEC cathode grid wires,
  - a lower maximum cathode voltage achievable,
  - and lower fusion rates.
- W grid wires are not highly resistant to particle damage as they suffer a mass loss with increasing fluence.
- Multiple energy bombardment creates highly eroded surfaces on all grains of PCW; due to this there is no orientation that is completely radiation resistant.

References

1.L. M. Garrison, “Improving the Materials Irradiation Experimental Facility and Increasing Understanding of Helium Irradiation of Tungsten,” PhD Thesis, University of Wisconsin - Madison, 2013.

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