Helium Ion Damage to IEC Cathode Materials Inspiring a Dual-Beam Irradiation Experiment

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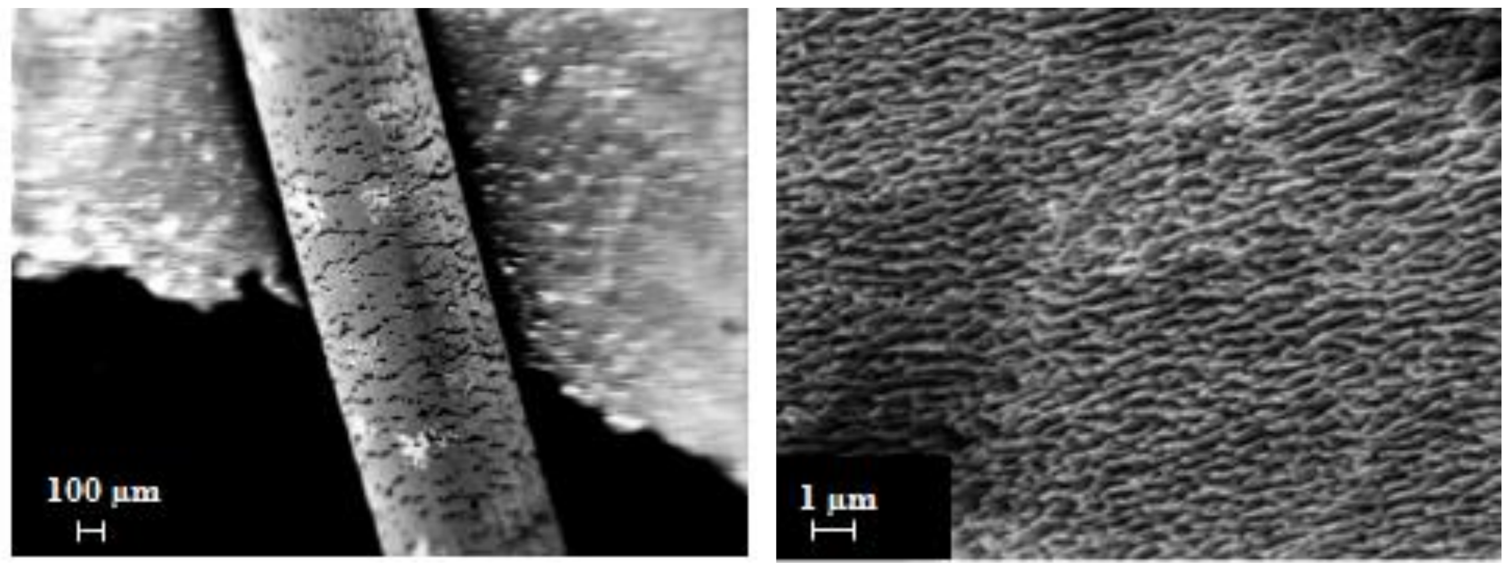
Background

- Helium ions are known to cause extensive microstructural surface modifications to metal cathode grids. These ions can be a fusion product (D-D, D-T fusion) or a fuel (D-^{3}He).
- Damage to IEC cathodes by He^+ at high temperature (>800 °C) can decrease device performance by early plasma breakdown.

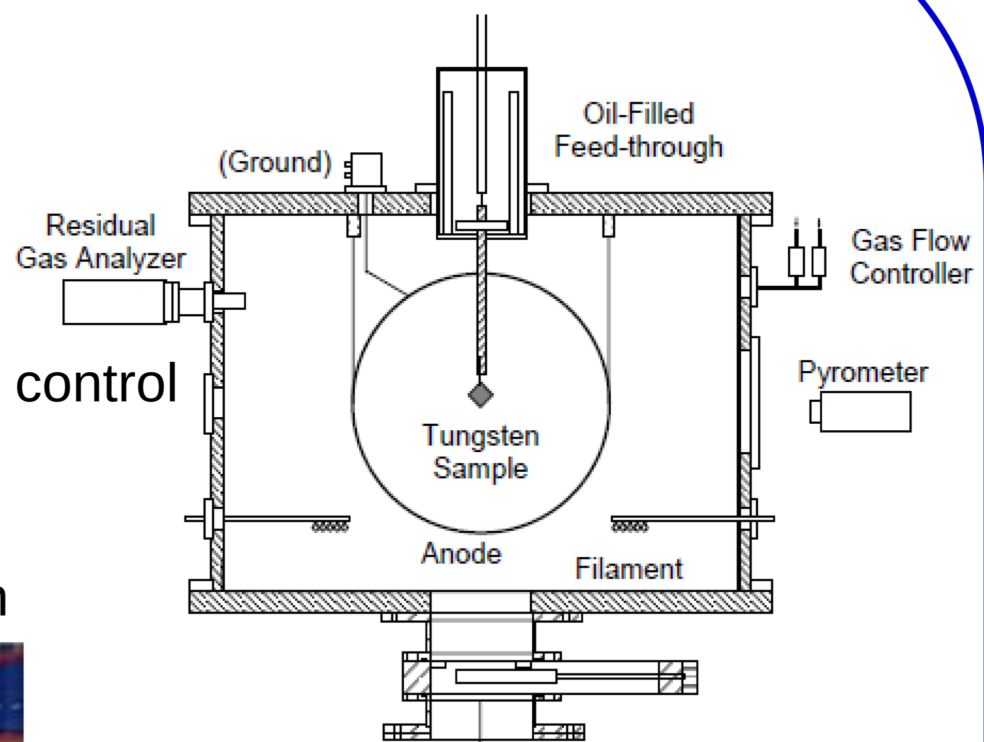


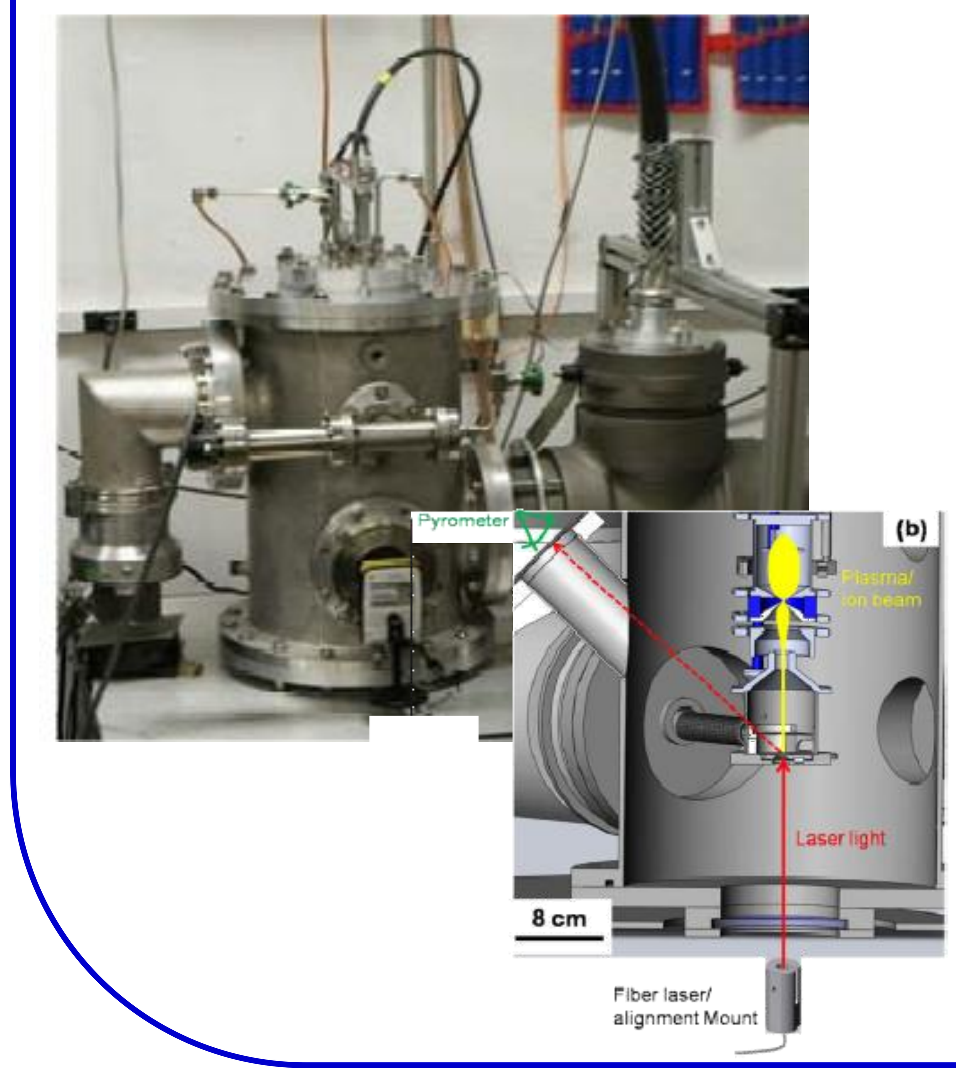
Images taken from G.R. Piefer, *PhD Thesis* **University of Wisconsin, Madison** (2006)

Irradiation Facilities

HOMER

- Actual IEC plasma species exposure
- Isotropic ion flux
- Limited temperature, energy control
- Must back out fluence using measured ion currents and secondary electron emission



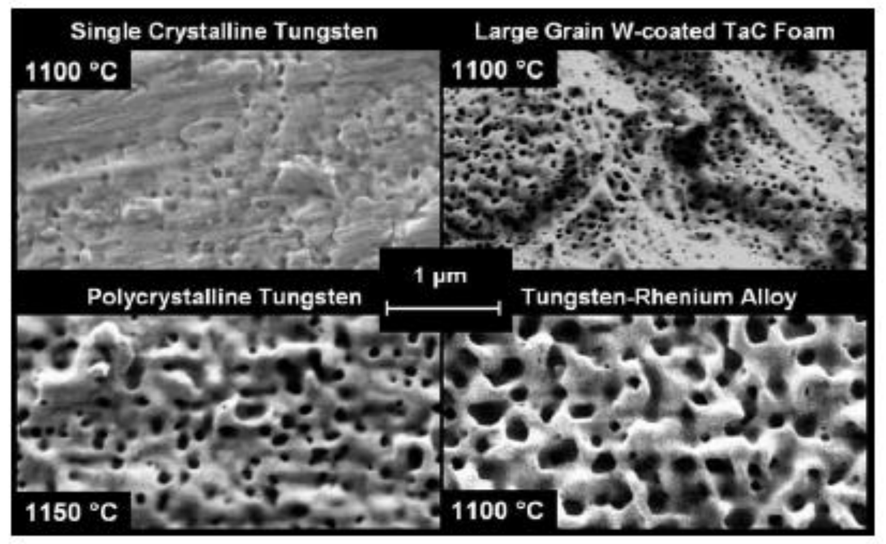


MITE-E

- Helium ion exposure only
- Beam incident to sample normal
- High degree of ion fluence control using fiber optic signal from sample
- Controlled temperature with Nd:YAG laser, allowing independent control of ion energy and sample temperature

Materials Study

- Materials irradiated in HOMER include:
  - Polycrystalline tungsten (PCW),
  - Single-crystalline tungsten (SCW),
  - Tungsten-25% rhenium alloy (W-25%Re),
  - Tungsten-coated tantalum carbide foam (TaC)



- Damage characterized by pore growth and pore density.
- SCW is most resistant, but not a realistic cathode material.
- W-25%Re is more susceptible than pure W, but is preferable as a cathode material due to superior ductility.

Mass Loss

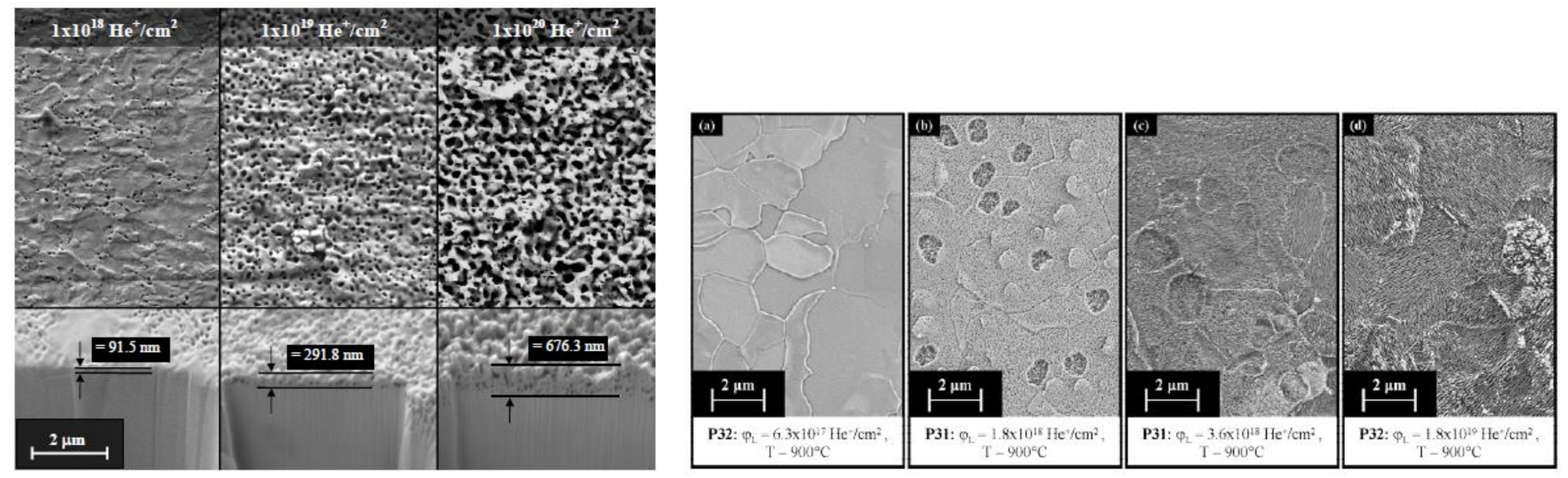
- Mass losses of samples in HOMER and MITE-E were substantially higher than predicted by sputtering alone.

Sample data from HOMER at 30 keV and 1150°C:

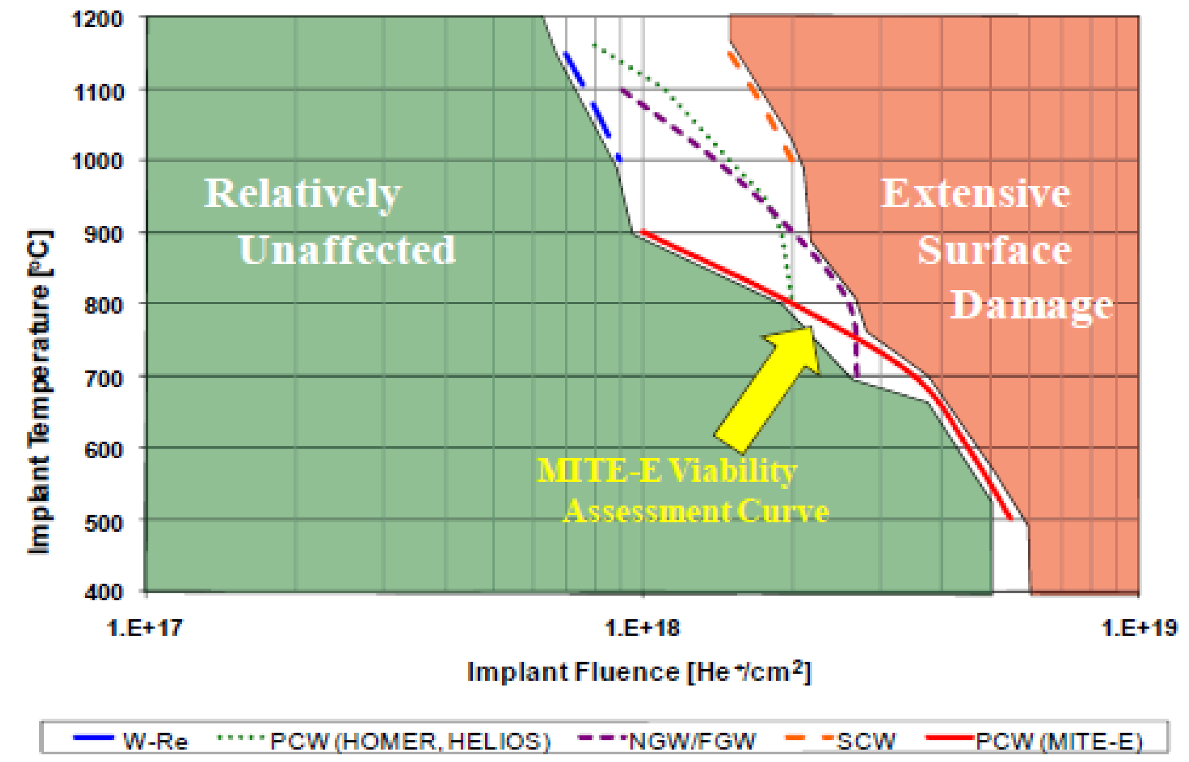
Fluence (He^+/cm^2)	Expected Sputtering Loss (mg)	Actual Loss (mg)	Thickness Loss (µm)
1.00E+20	2.1	10.2	2.6
1.00E+19	0.2	4.2	1.1

- Additional mass loss may be from the erosion of entire microstructure features (blisters, needles, etc). These feature erosions may impact local electric fields, leading to cathode performance degradation.

Helium Fluence and Temperature



(left): Fluence scan of PCW irradiated in HOMER at 30 keV, 1150°C
(right): Fluence scan of PCW irradiated in MITE-E at 30 keV, 900°C

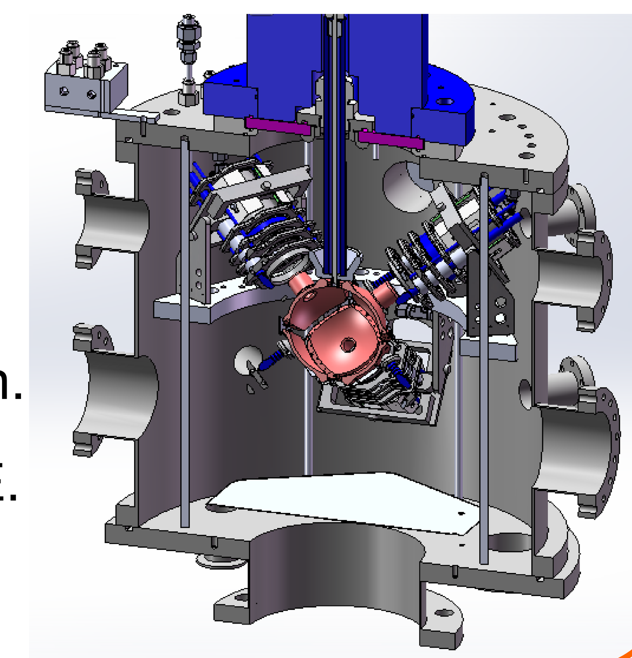


Onset of helium damage observed in MITE-E by He^+ fluence and temperature

- Operation in HOMER at 30 keV, 7 mA yields T~1150°C
- 1E19 He^+/m^2 corresponds to 30 min of HOMER runtime at cathode conditions of 30 keV, 7 mA using helium fuel at 0.5 mTorr.
- Operation of D-D plasma unlikely to cause significant helium damage in IEC devices. Regular IEC operation with helium fuel will incur surface damage.

What's Next: Dual-Beam Irradiation

- Present UW-IEC materials investigative capabilities only allow either *in-situ* plasma irradiation with limited control or are limited to helium-only single-beam irradiation.
- I propose modifying UW's current Six Ion Gun Fusion Experiment (pictured right) to allow the simultaneous dual-beam irradiation of a cathode sample using infrastructure based on MITE-E's design.
- This experiment will retain the independent sample temperature and ion energy control seen in MITE-E. Simultaneous irradiation with both deuterium and helium ions will simulate the damage to a cathode caused by the presences of both these species as expected in D-D, D-T, and D-^{3}He fusion.



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