Effects of High Temperature Pulsed Helium Implantation on Tungsten Surface Morphology

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Objective of UW Study of Tungsten Coatings

Determine the effect of helium and deuterium implantation on the surface morphology of tungsten at high temperatures for High Averaged Power Laser (HAPL) project

- **Why:** To evaluate whether tungsten will serve as a suitable material for ICF first wall application
- **How:** Use IEC device to irradiate materials with He^+ and D^+ ions. Then use Scanning Electron Microscopy and Focused Ion Beam to determine morphology changes

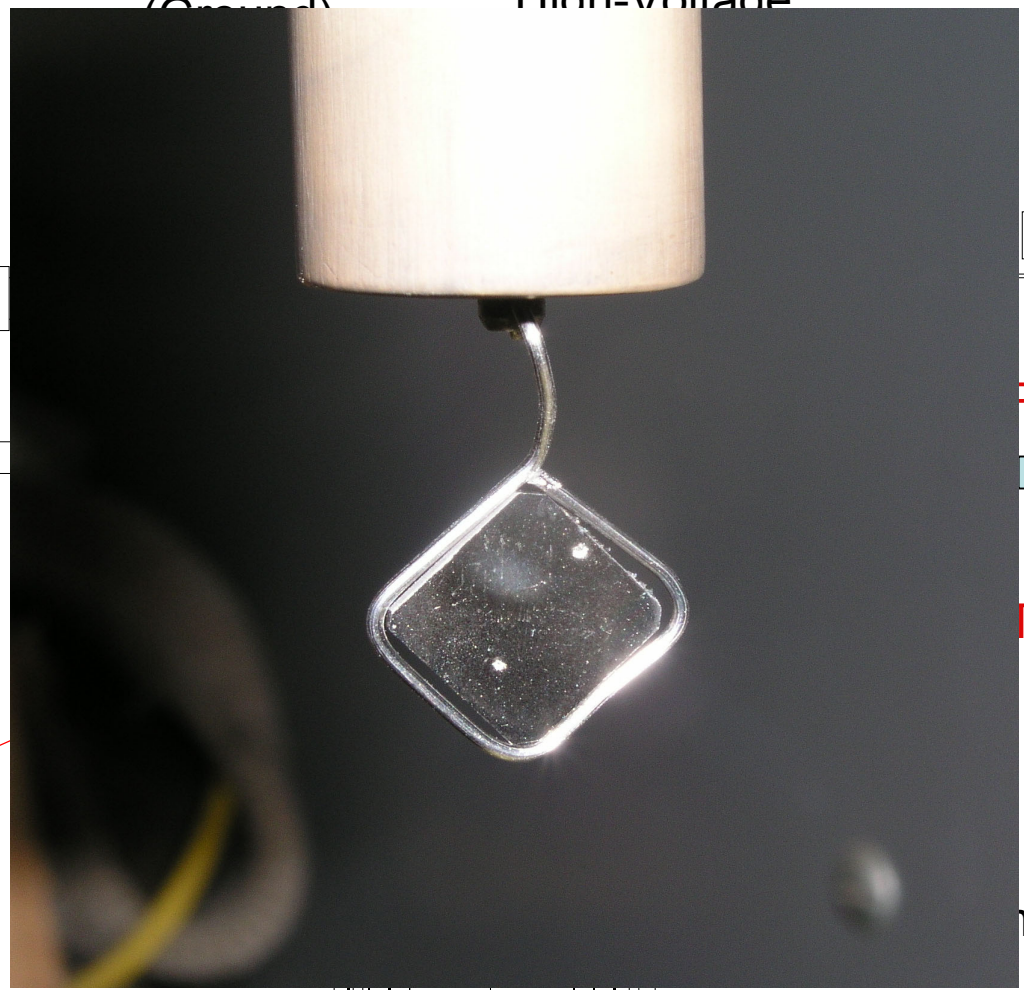
There has been an Extensive Campaign to Assess Ability of W Coatings to Operate in HAPL Environment

- Polycrystalline
  - He^+& D^+ Fluence Effect – 800-1200 ° C
  - Temperature and Voltage Effects
  - Simultaneous He^+ & D^+
  - Helium Retention
  - W-Re Alloy
  - Pulsed Irradiation
- Metallic Foams
  - Large, medium, & small grain size W on TaC – (He^+) 800-1200 °C
  - Large, medium, & small grain size W on TaC – (D^+) 800 °C
  - Medium grain size W on HfC (He^+ & D^+) – 800-1200 °C
- Single Crystal
  - He^+& D^+ Fluence Effect – 800 ° C
  - Simultaneous He^+ & D^+
  - Helium Retention

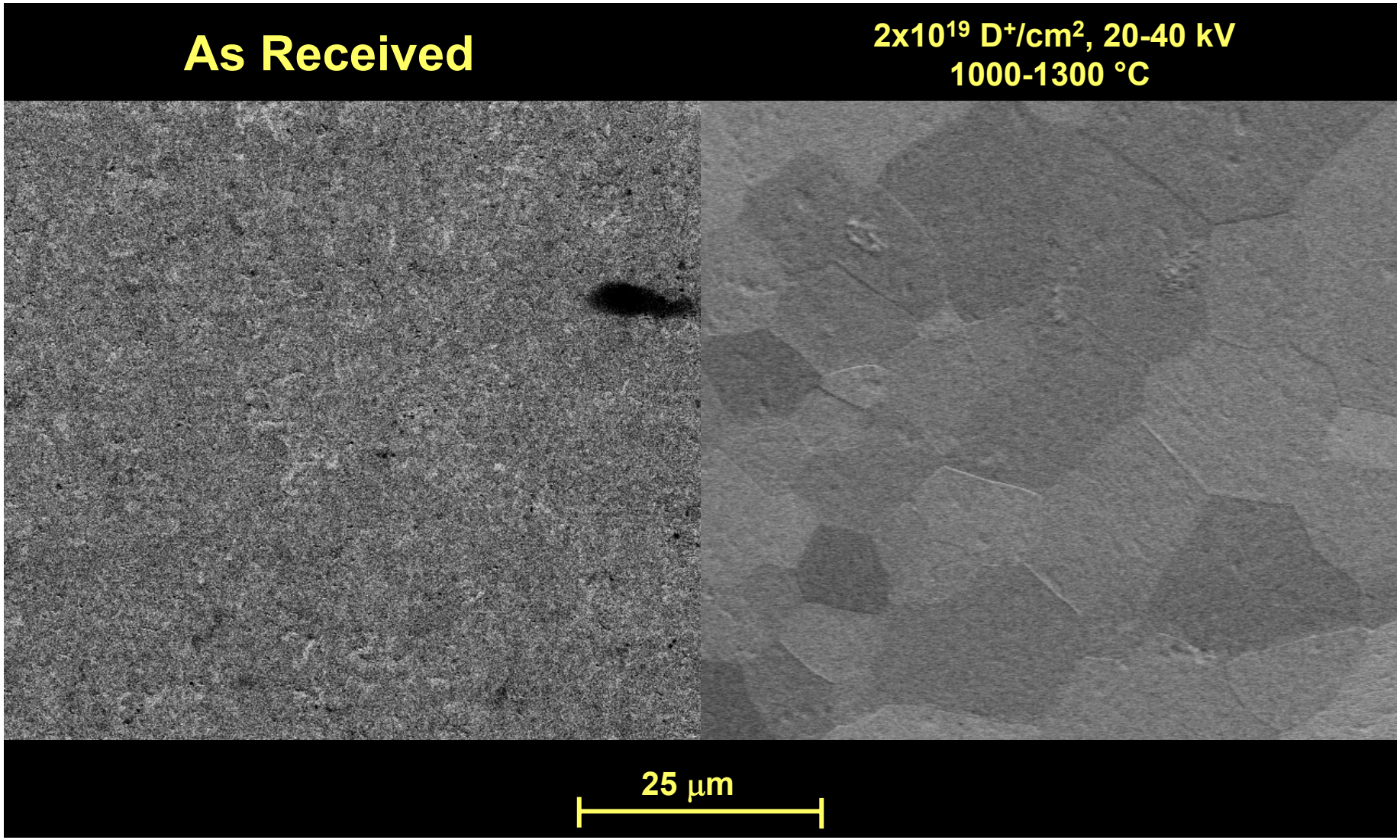
Previous Work

This Presentation

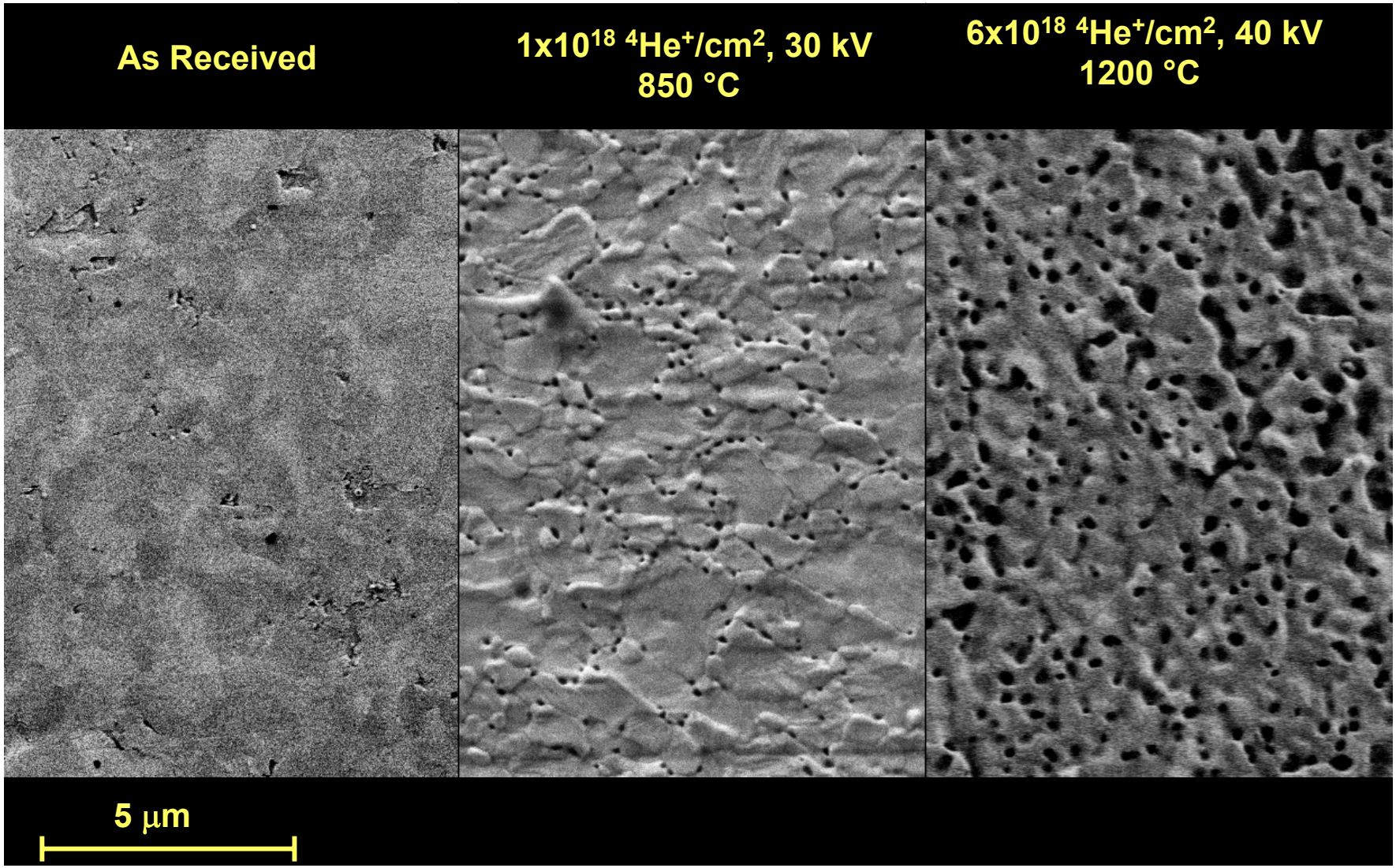
IEC Cathode was Replaced with W Sample for Implantation Studies



Deuterium Implantation Caused Substantial Grain Growth

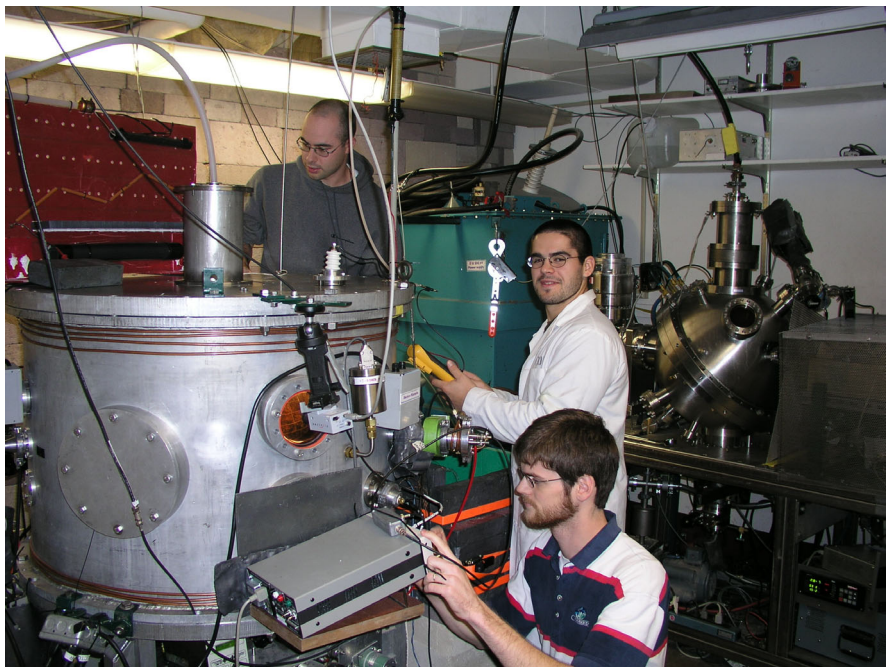


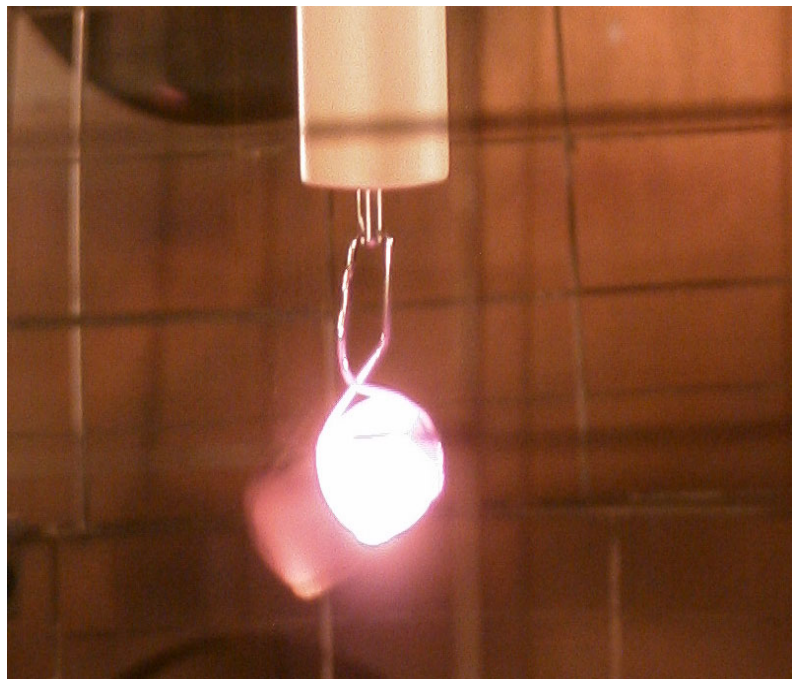
High Temp. He Implantation Above $1x10^{18}$ He^+/cm^2 Created a Porous Surface Structure



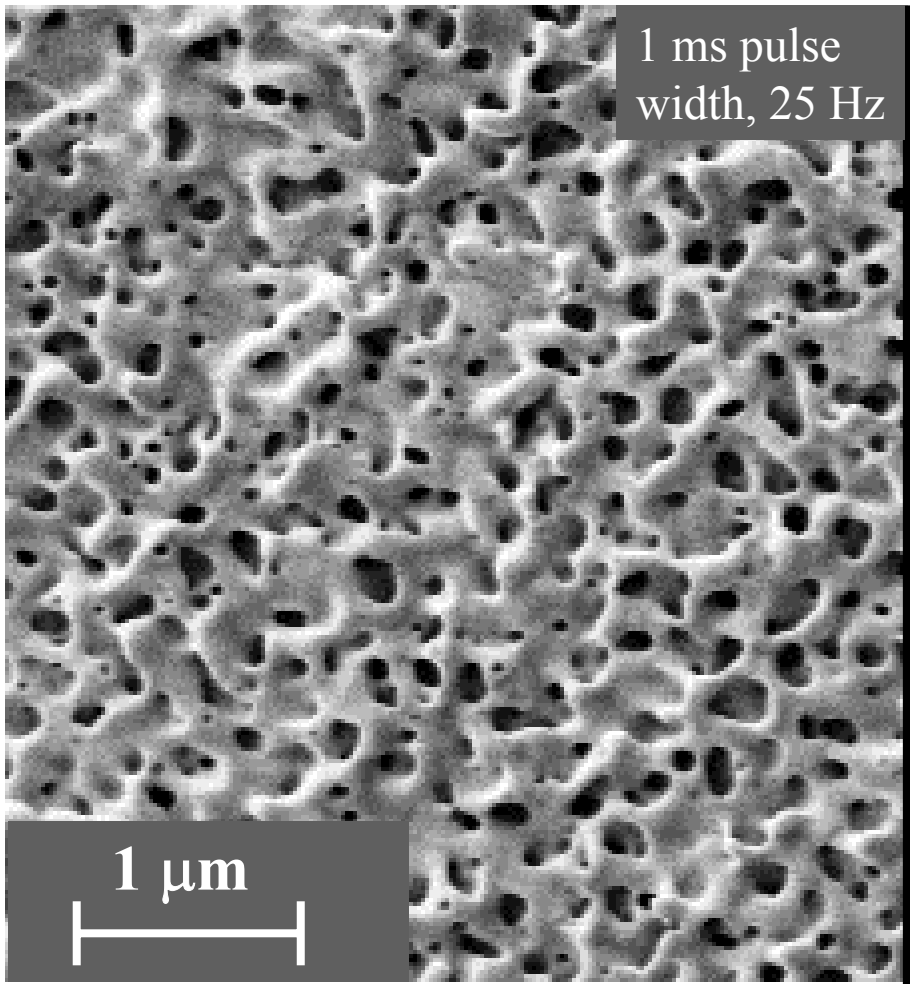
New Design Allows Pulsed IEC Operation

- Currently able to pulse up to 115 kV
- Operation has been performed with pulses as short as 100 μs
- Capable of running D_2 and/or He fuel gas

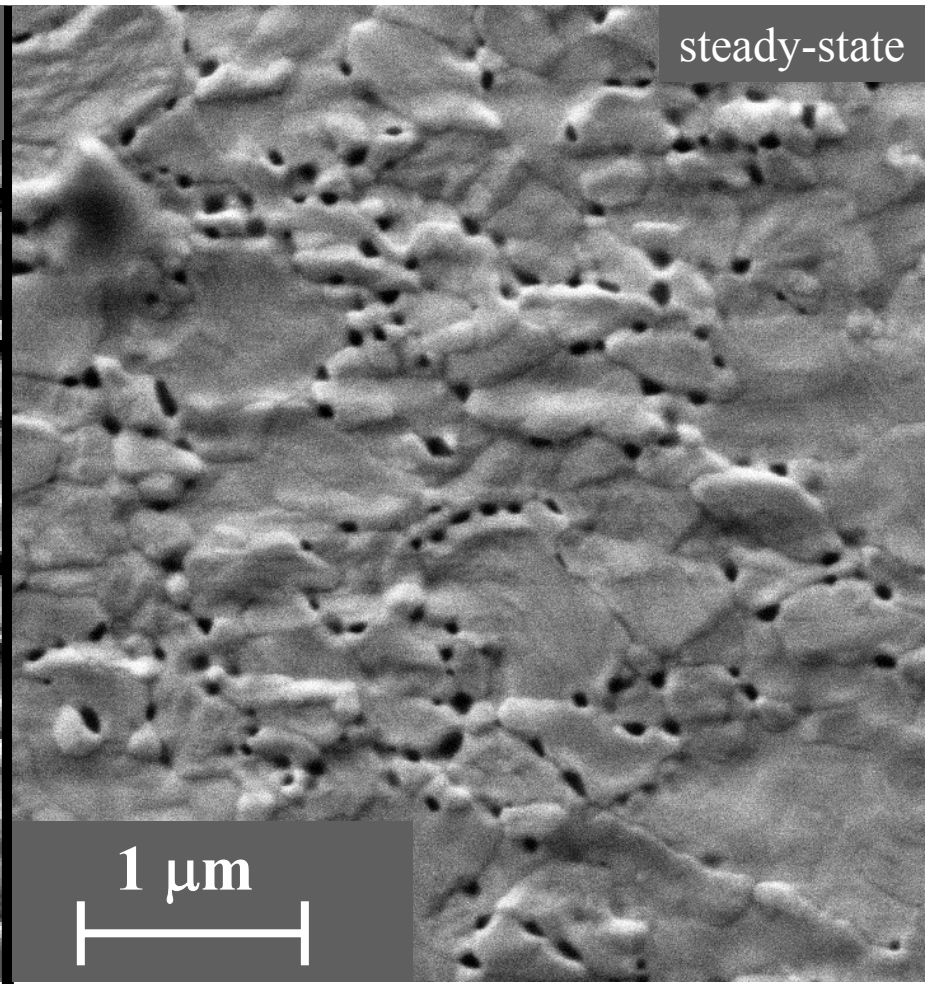




Pulsed Irradiation Caused Increased Damage to Tungsten Surface at 10^{18} He^+/cm^2

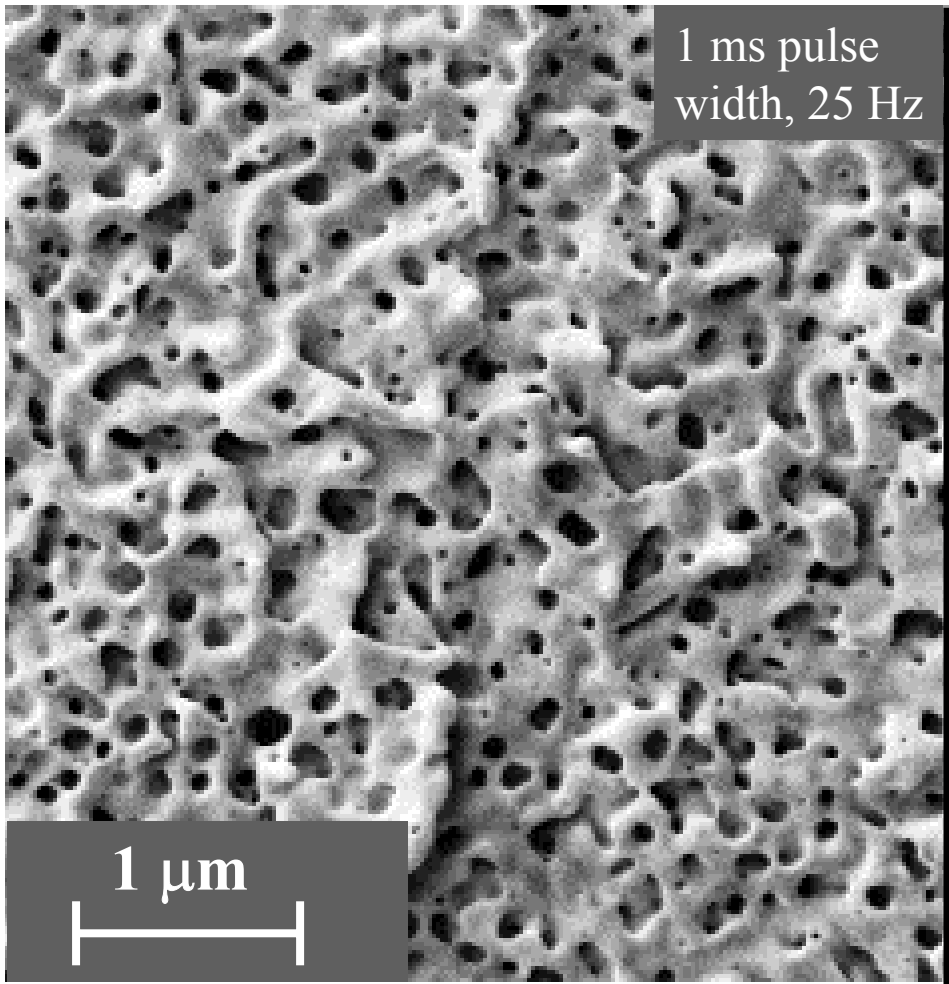


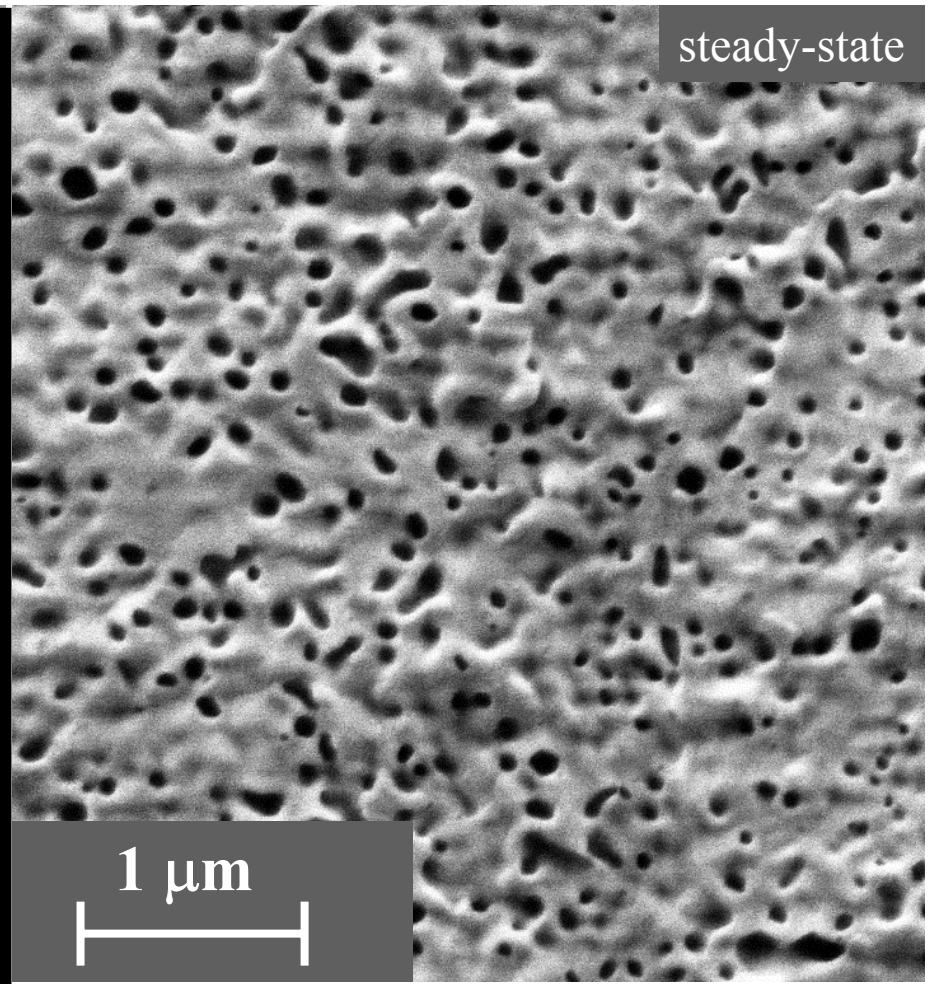
40 kV, 60 mA Pulsed (1170±20 °C baseline)
12 minute runtime



30 kV, 6 mA Steady-State (1150±20 °C)
3 minute runtime

Pulsed Irradiation Caused Increased Damage to Tungsten Surface at $6x10^{18}$ He^{+}/cm^{2}

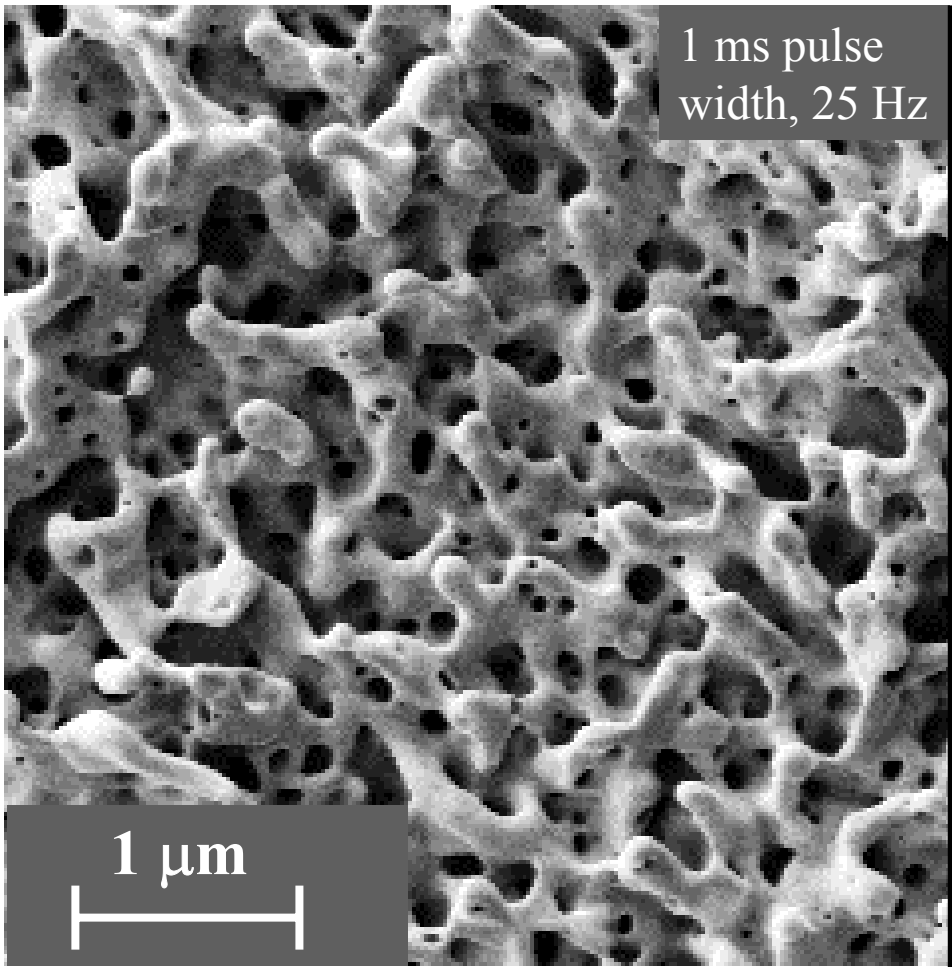




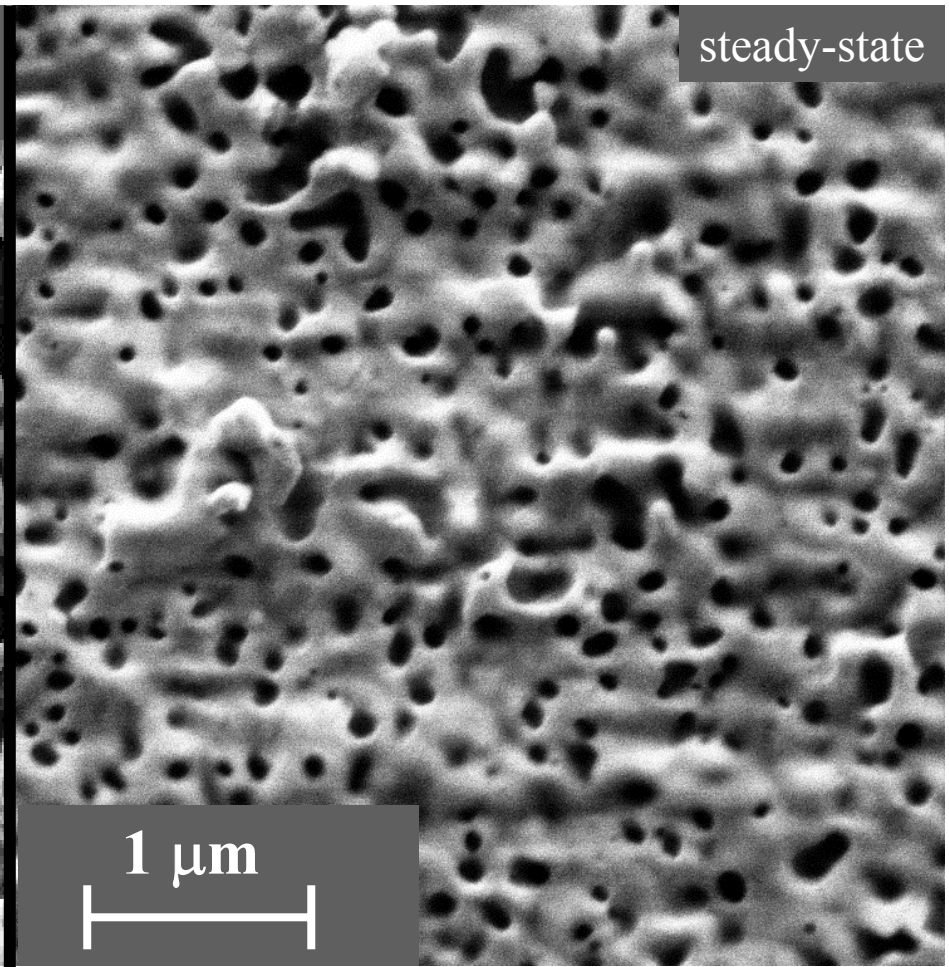
40 kV, 60 mA Pulsed (1170±20 °C baseline)
72 minute runtime

30 kV, 6 mA Steady-State (1130±20 °C)
18 minute runtime

Pulsed Irradiation Created Coral-Like Tungsten Features at 10^{19} He^{+}/cm^{2}

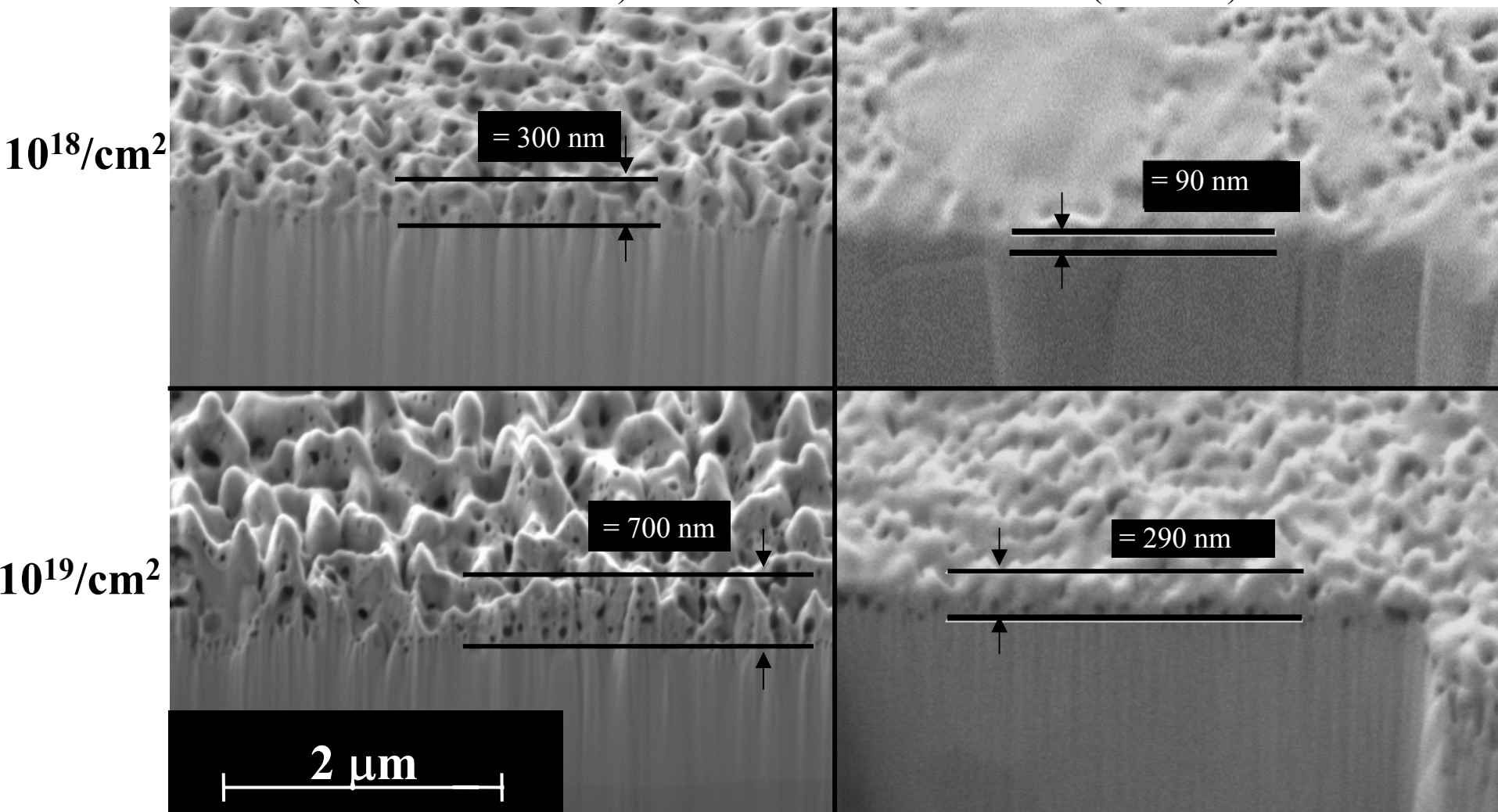


40 kV, 60 mA Pulsed (1140±20 °C baseline)
2 hour runtime



30 kV, 6 mA Steady-State (1150±20 °C)
30 minute runtime

FIB Analysis Reveals Increased Porous Layer in Pulsed Samples



Mass Loss was Measured for Pulsed Tungsten Samples

- There has been no observable mass loss at fluences below $10^{19}/cm^2$ for steady-state irradiation at 1150 °C
- Measured mass loss and corresponding thickness loss for pulsed irradiation is shown below:

Helium Fluence	**$1x10^{19}$**	**$6x10^{18}$**	**$1x10^{18}$**
Mass Loss (2 g sample)	4.2±0.1 mg	3.6±0.1 mg	0.5 ± 0.1 mg
Thickness Loss	1.1±0.03 μm	0.93±0.03 μm	0.13±0.03 μm

1 ms pulse width, 25 Hz, 1150 °C

- Reference HAPL W armor could lose 50 μm/FPY (~1200 kg/FPY) due to low energy He irradiation alone
- Losses as high as 200 mm/FPY are predicted for full He spectra

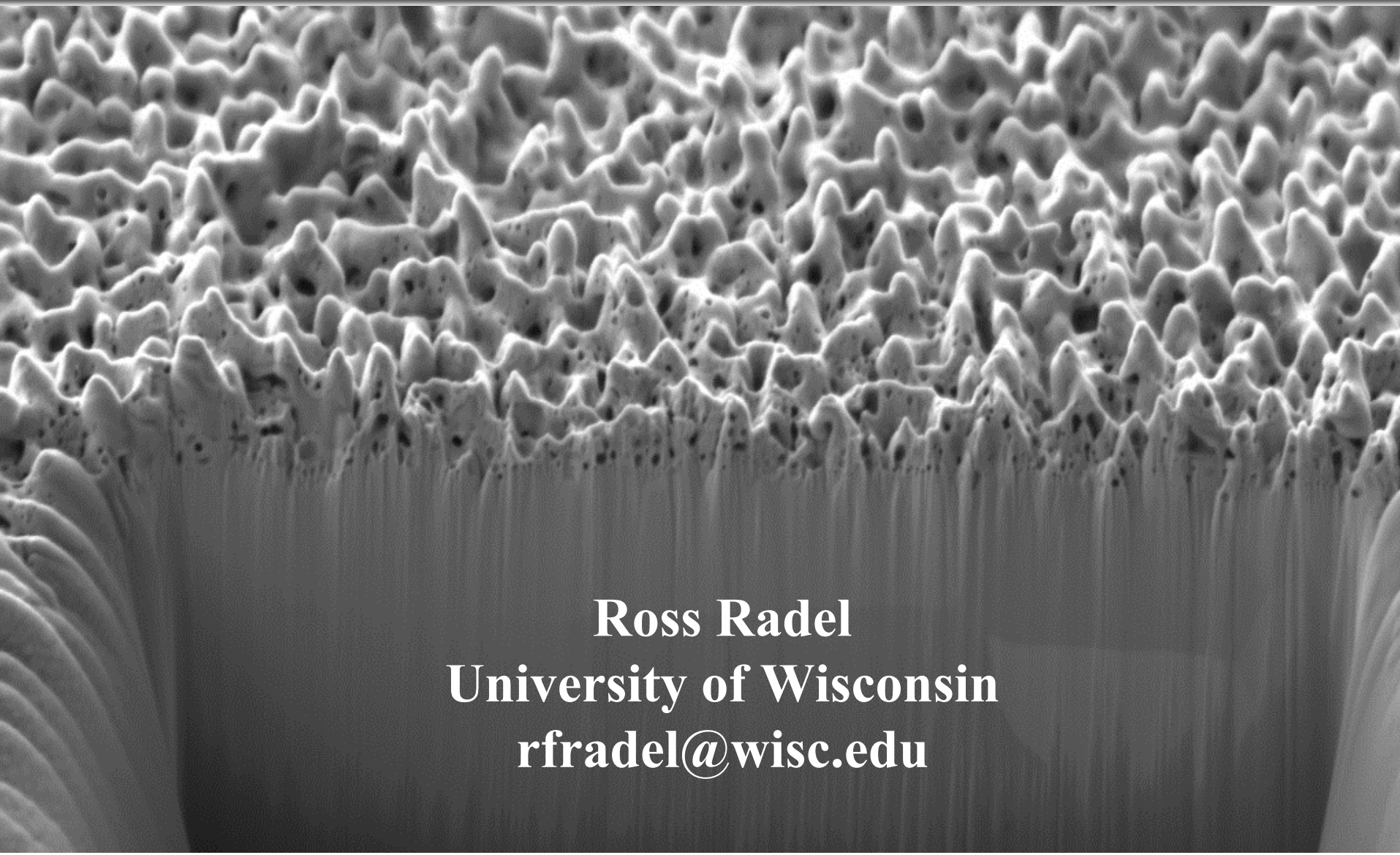
Implications

- In ICF first walls and MFE divertors, the high density of small pores could act as:
  - Nucleation sites for cracks under repeated shock loading
  - Sites for initiating the formation of "dust"
  - Release sites for implanted He
- In IEC cathodes:
  - Embedded helium contributing to the D-^{3}He rate appears to saturate around 10^{18} He/cm^{2}
  - Sharp points created by pore formation may cause high voltage breakdown

Conclusions

- Switching from steady-state to pulsed irradiation at 1150 °C resulted in an increased surface roughening over 10^{18} to 10^{19} He^{+}/cm^{2} range
- Porous layer in tungsten was ~3x thicker after pulsed irradiation compared to steady-state
- Mass loss of tungsten armor in Reference HAPL design could be as much as 50 μm/FPY (~1200 kg/FPY), which is well beyond calculated physical sputtering values

Questions?



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