Overview of the UW Materials Irradiation Program

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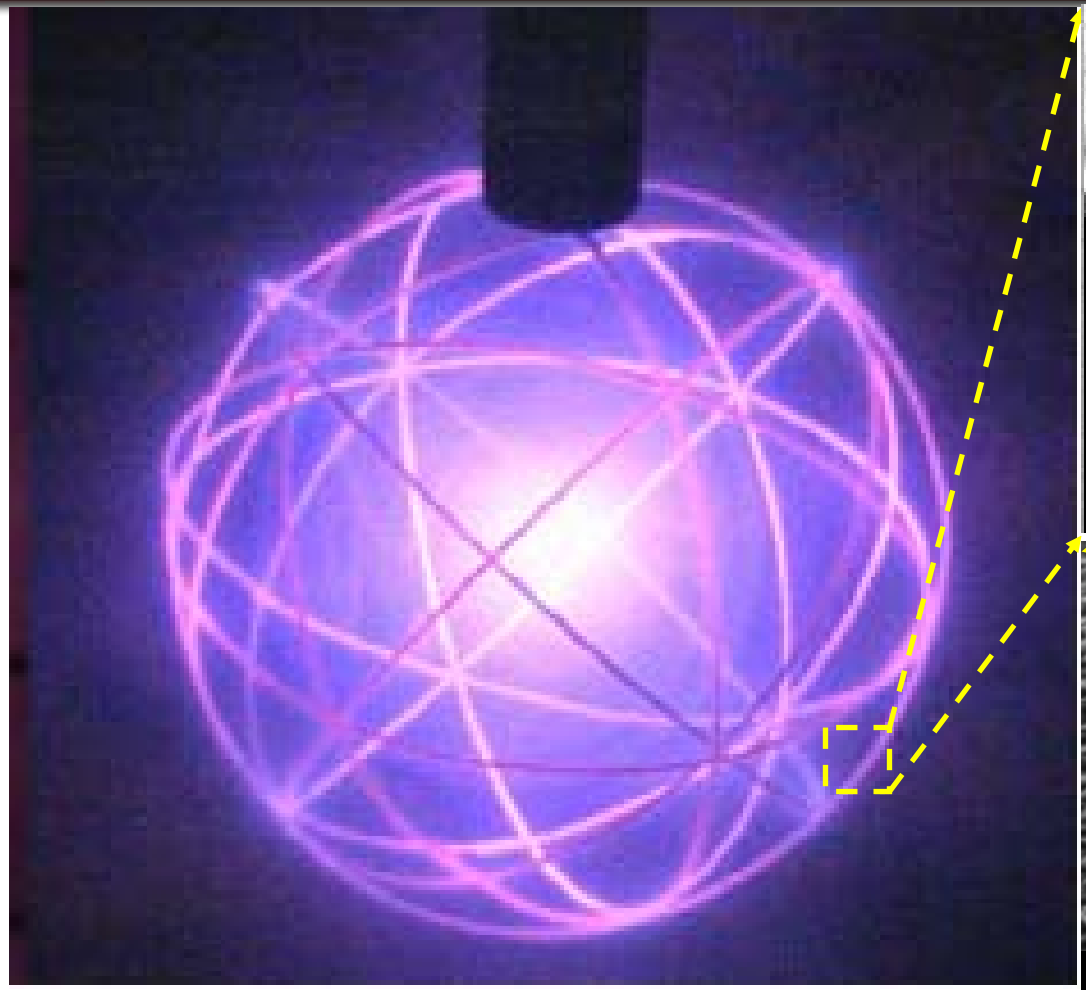
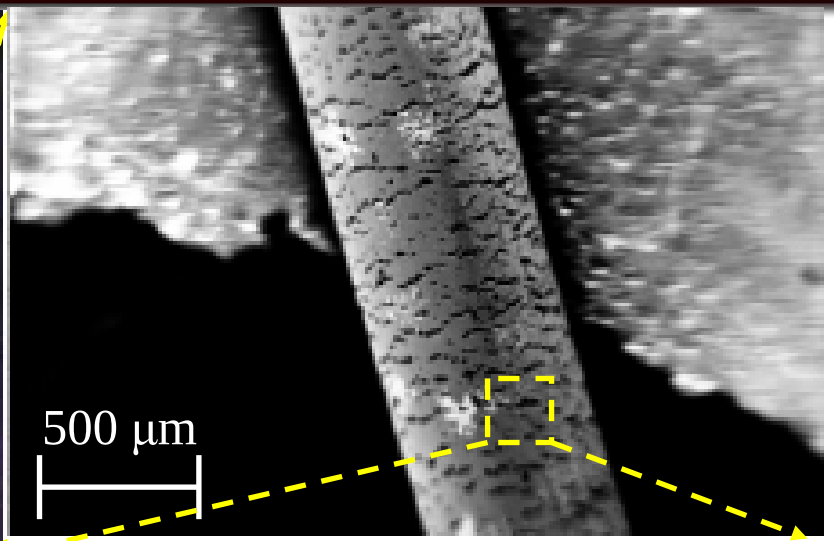
THE UNIVERSITY of WISCONSIN MADISON

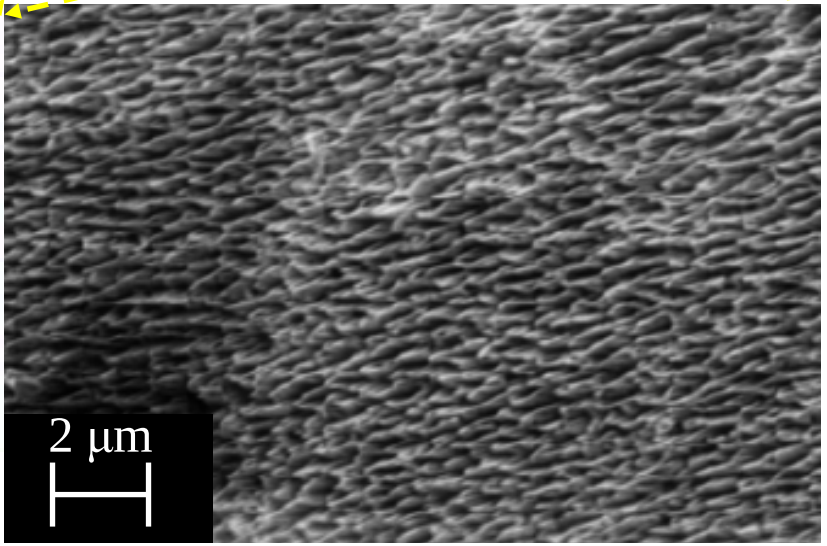
Outline

- Motivation
  - High voltage performance essential to burning advanced fuels in IEC devices
  - Helium ion damage to IEC grids at high temperature (>800°C) can degrade HV performance
  - ICF: first wall armor; MFE: divertor plates
- Results on polycrystalline W & nano-grain W
- The Materials Irradiation Experiment (MITE-E)
  - Improvements to previous apparatus
  - Conversion of SIGFE ion gun to material application
  - Precise fluence measurement & Nd:Yag laser heating system

Helium Ion Damage To IEC Cathode Grids Significantly Degrades High Voltage Performance





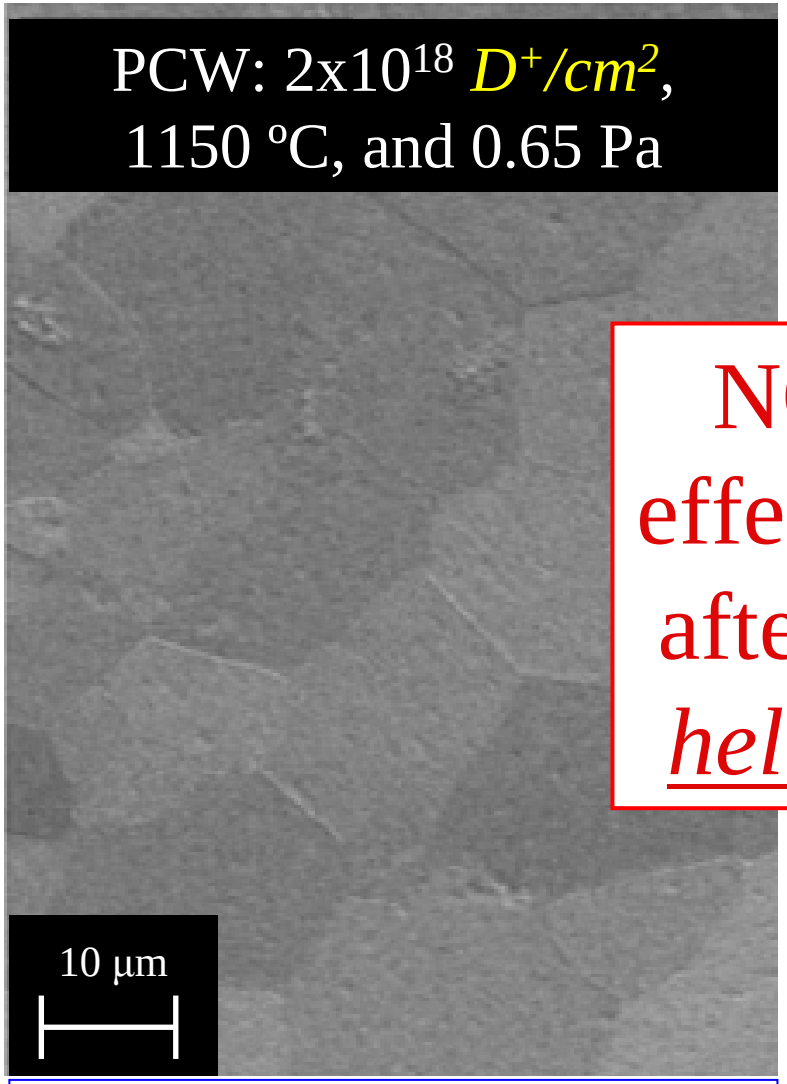


Cathode of UW IEC Device *HELIOS* in D_2 gas at ~1 Pa

G.R. Piefer, "Performance of a Low-Pressure, Helicon Driven IEC 3He Fusion Device" PhD Thesis, University of Wisconsin-Madison, 2006

IEC Cathodes Obtain Significant Surface Damage Within Minutes Of Helium Plasma Exposure

PCW: 2x10^{18} D^+/cm^2, 1150 ºC, and 0.65 Pa



B.B. Cipiti & G.L. Kulcinski, *J. Nucl. Mat.* 347, 2005

Implanted Fluence [He^+/cm^2]‡	Grid Diameter [cm] Transparency ~ 95%	Run Time [min]*,#
10^{18}	10	

NOTE: These effects occur only after exposure to *helium* plasmas!

ver the entire grid area

*Steady-state operation with 30 mA of meter current

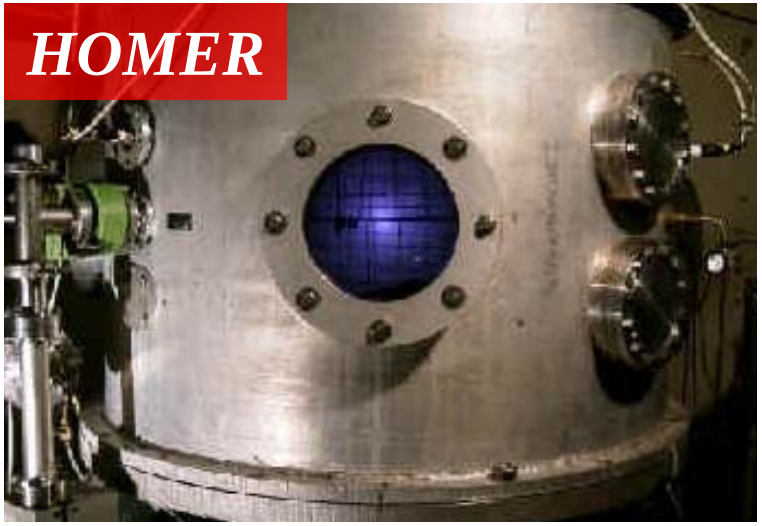
#Ion current (fluence) is calculated assuming a constant SEC, γ, of 2

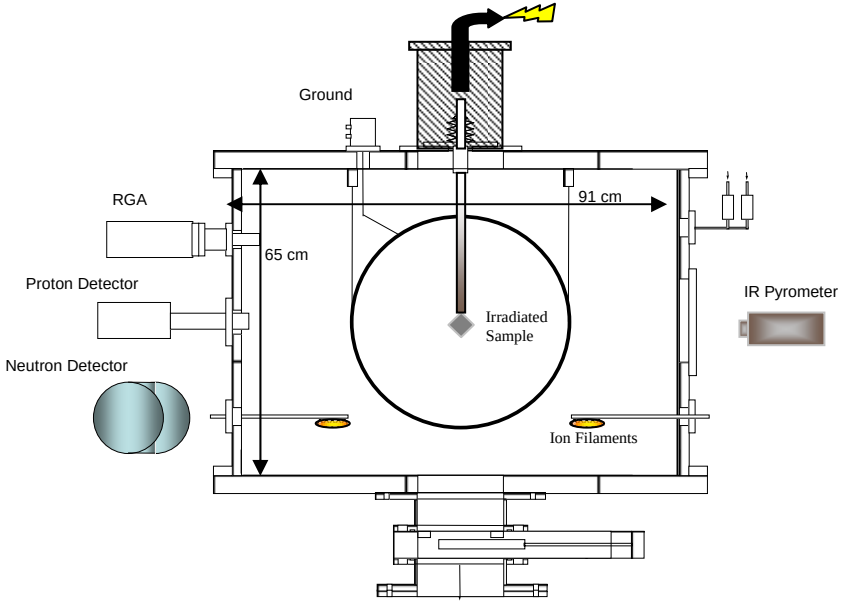
Grid diameters and areas are based on the design of UW IEC grids

This will be an issue for ion gun cathode lenses

Evolution Of UW Materials Irradiation Experiments From 2004-2008

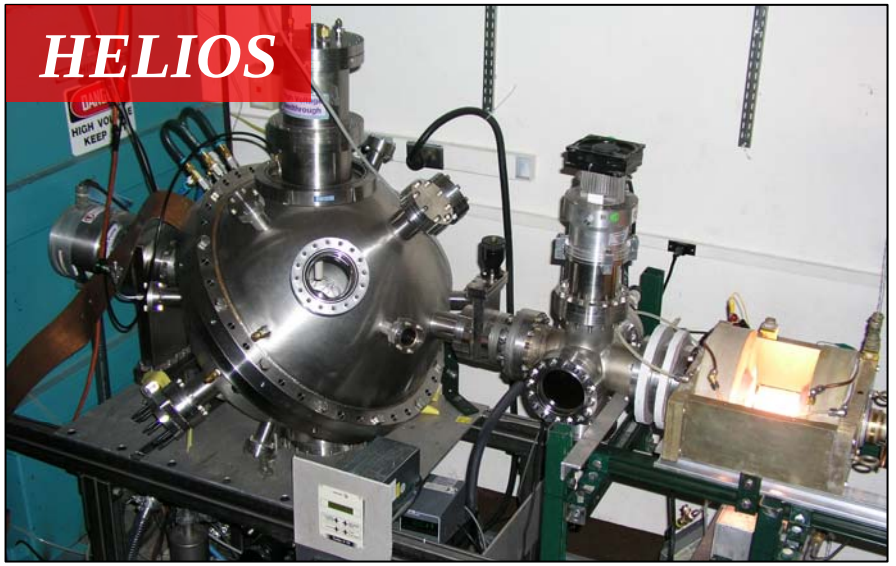
HOMER





- Initial irradiation experiments were performed in the IEC device ***HOMER*** (B.B. Cipiti, R.F. Radel, and S.J. Zenobia)
- Most recent experiments were performed in the IEC device ***HELIOS*** (S.J. Zenobia)

HELIOS

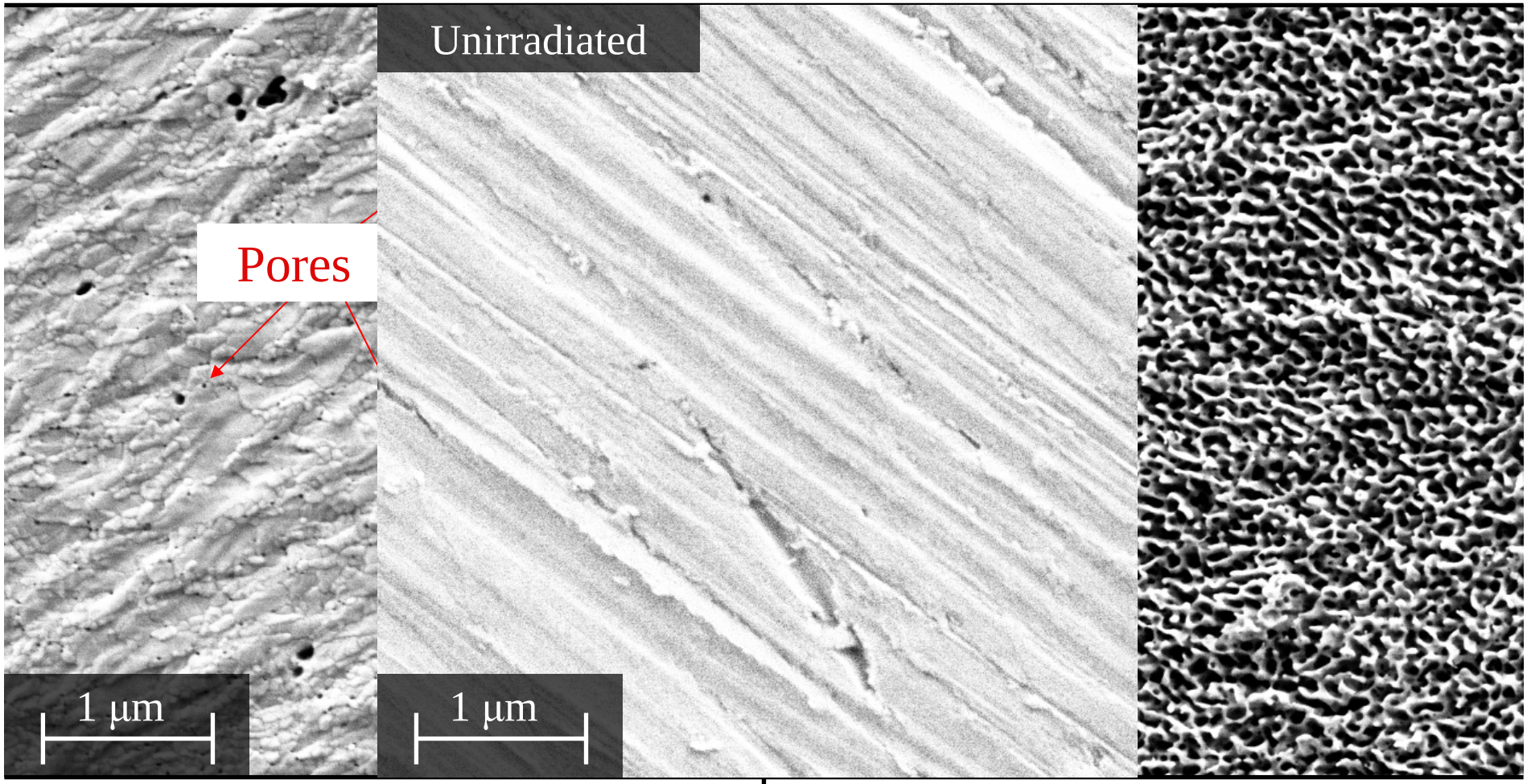


Summary Of Polycrystalline W (PCW) And Nano-Grain W (NGW) Implantation Experiments

Irradiation conditions using 30 keV He^+ in *HELIOS*				
PCW	Fluence [He^+/cm^2] Temperature [C]	$4x10^{17}$ cm^{-2} 1000±50 ºC	$5x10^{18}$ cm^{-2} 1000±50 ºC	--
NGW	Fluence [He^+/cm^2] Temperature [C]	10^{18} cm^{-2} 1050±50 ºC	10^{19} cm^{-2} 1000±50 ºC	10^{20} cm^{-2} ($^4He^+$) 1000±50 ºC

- Scanning electron microscopy (SEM) & focused ion beam (FIB) milling analyses were performed to diagnose surface morphology change
- Pre- & post- irradiation masses were measured to determine the extent of mass loss
- Retained helium fluence was measured using $^3He(d,p)^4He$ nuclear reaction analysis (NRA) at the UW 1.7 MV tandem accelerator facility

Polycrystalline W Implanted With $^{3}He^{+}$ Shows Extensive Morphology Changes Above $5x10^{18}$ cm^{-2} At ~1000 ºC



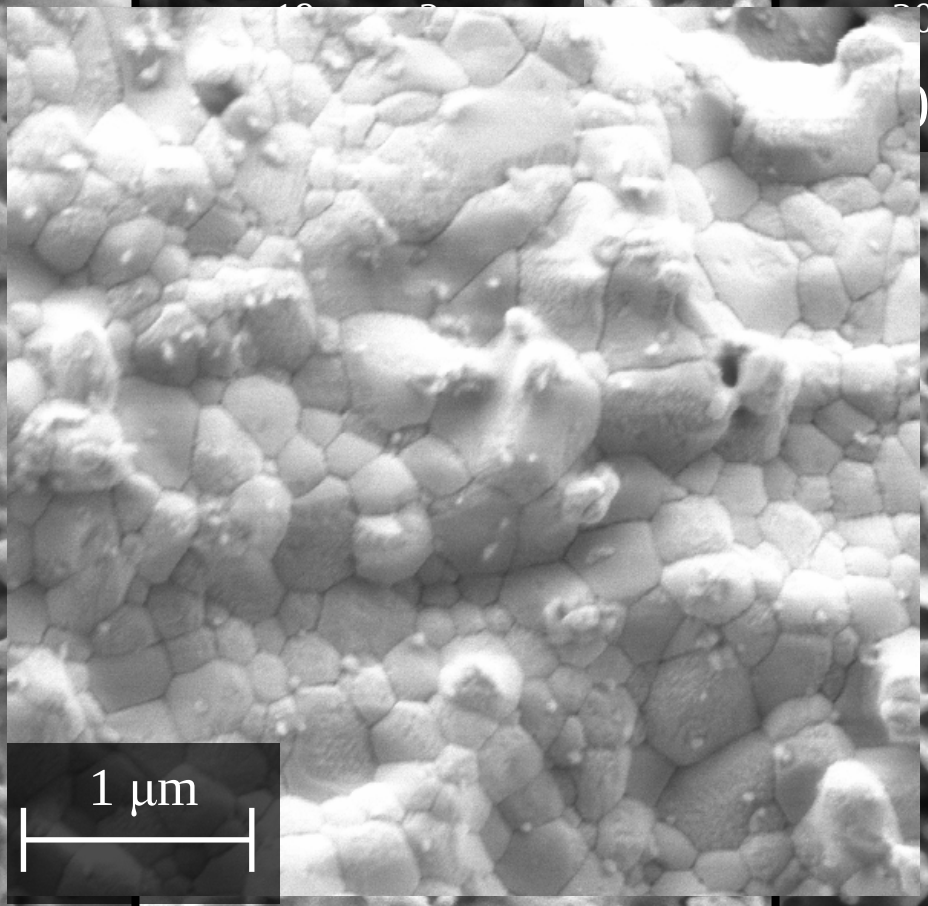
PCW: $4x10^{17}$ cm^{-2}, 1000 ºC, and 0.013 Pa

PCW: $5x10^{18}$ cm^{-2}, 1000 ºC, and 0.013 Pa

Helium Implantation Of Nano-Grain W Also Results In "Coral-Like" Morphology

10^{18} cm^{-2} @ 1050 ºC , $^{3}He^{+}$

^{20} cm^{-2} @) ºC, $^{4}He^{+}$



400 nm

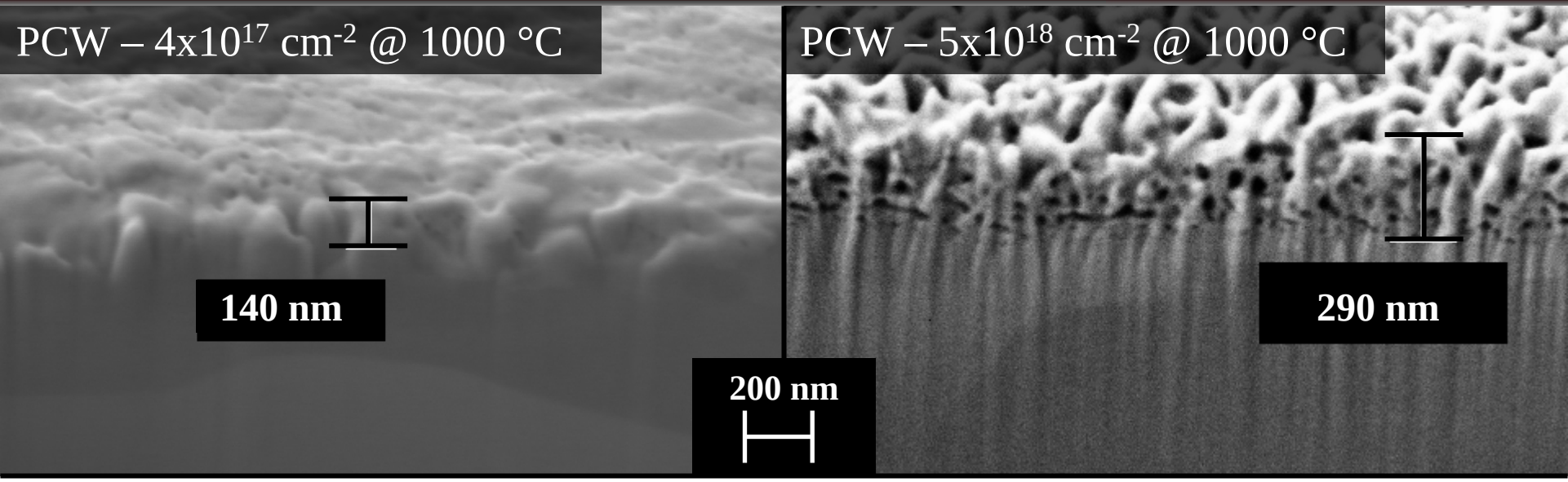
400 nm

400 nm

Nano-Grain Tungsten

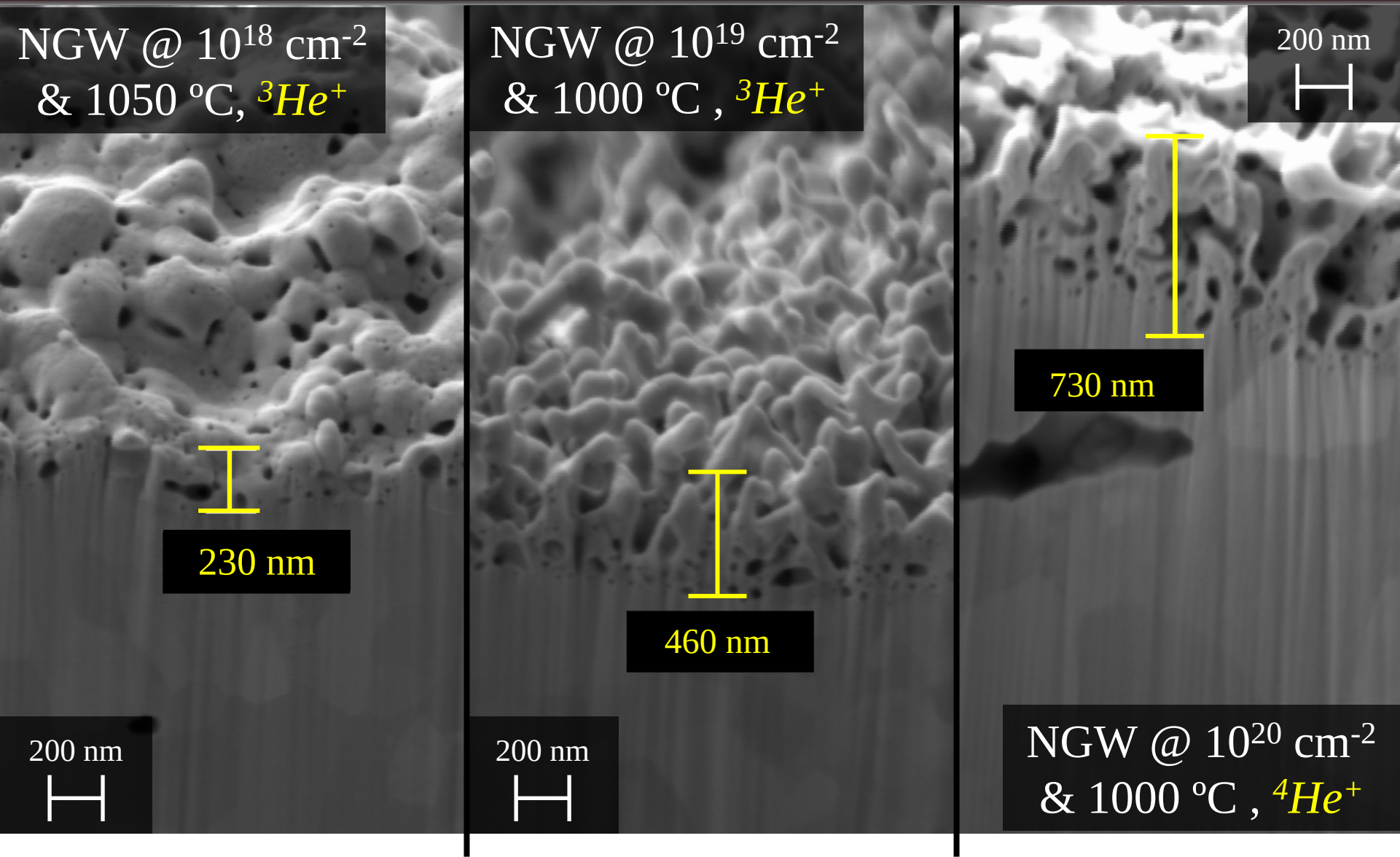
- 8 9 % dense
- Grain size ~ 240 nm

FIB Analysis Reveals Bubble Penetration Depth Extends Up To ~290 nm In PCW

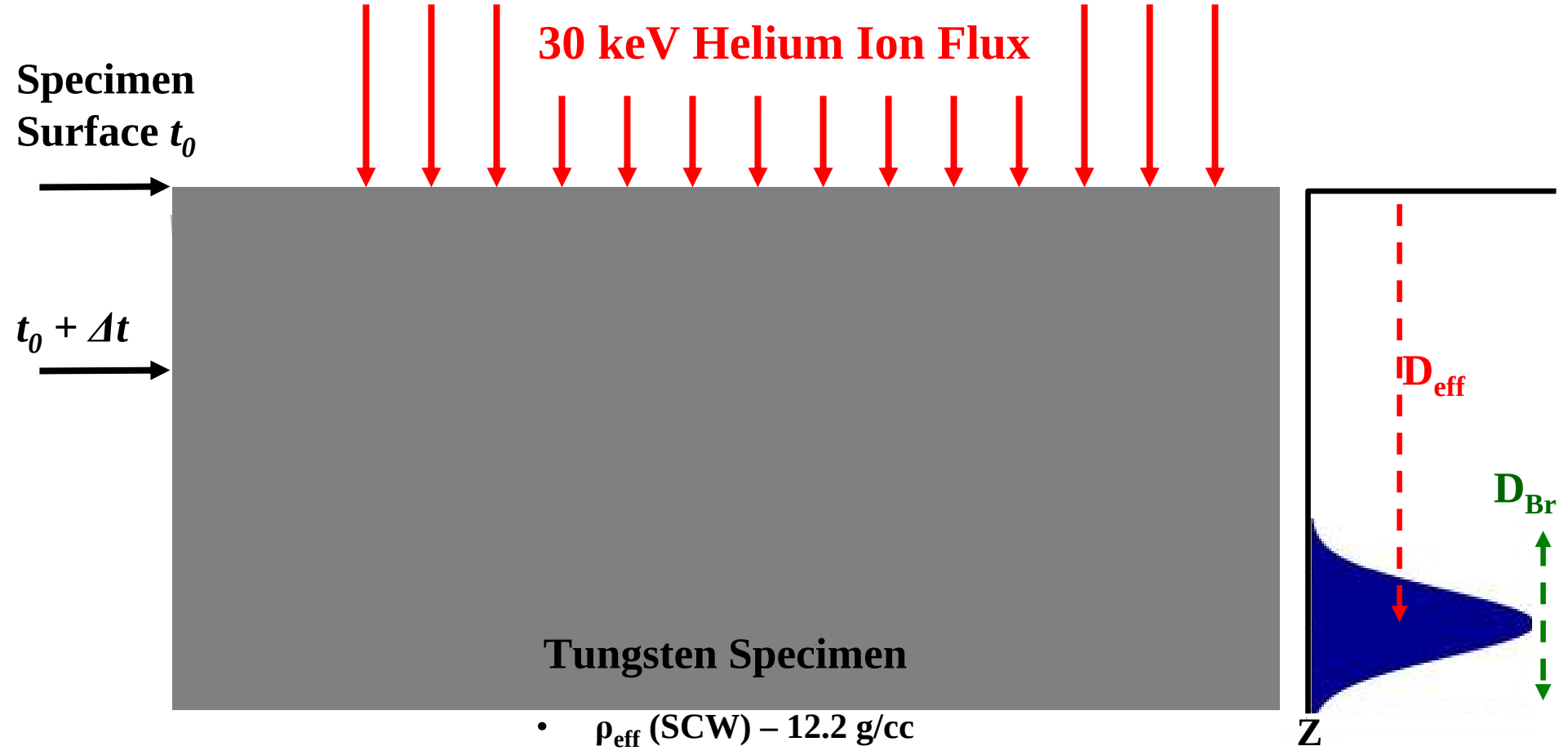


- The range of 30 keV $^{3}He^{+}$ in tungsten is ~73 nm
- Bubble layer depth increases with increased fluence
- The bubble layer ends abruptly, indicating growth is not purely diffusion dominated

FIB Reveals Substantial Penetration Depth Of Helium Bubbles Up To ~ 750 nm Below NGW Surface



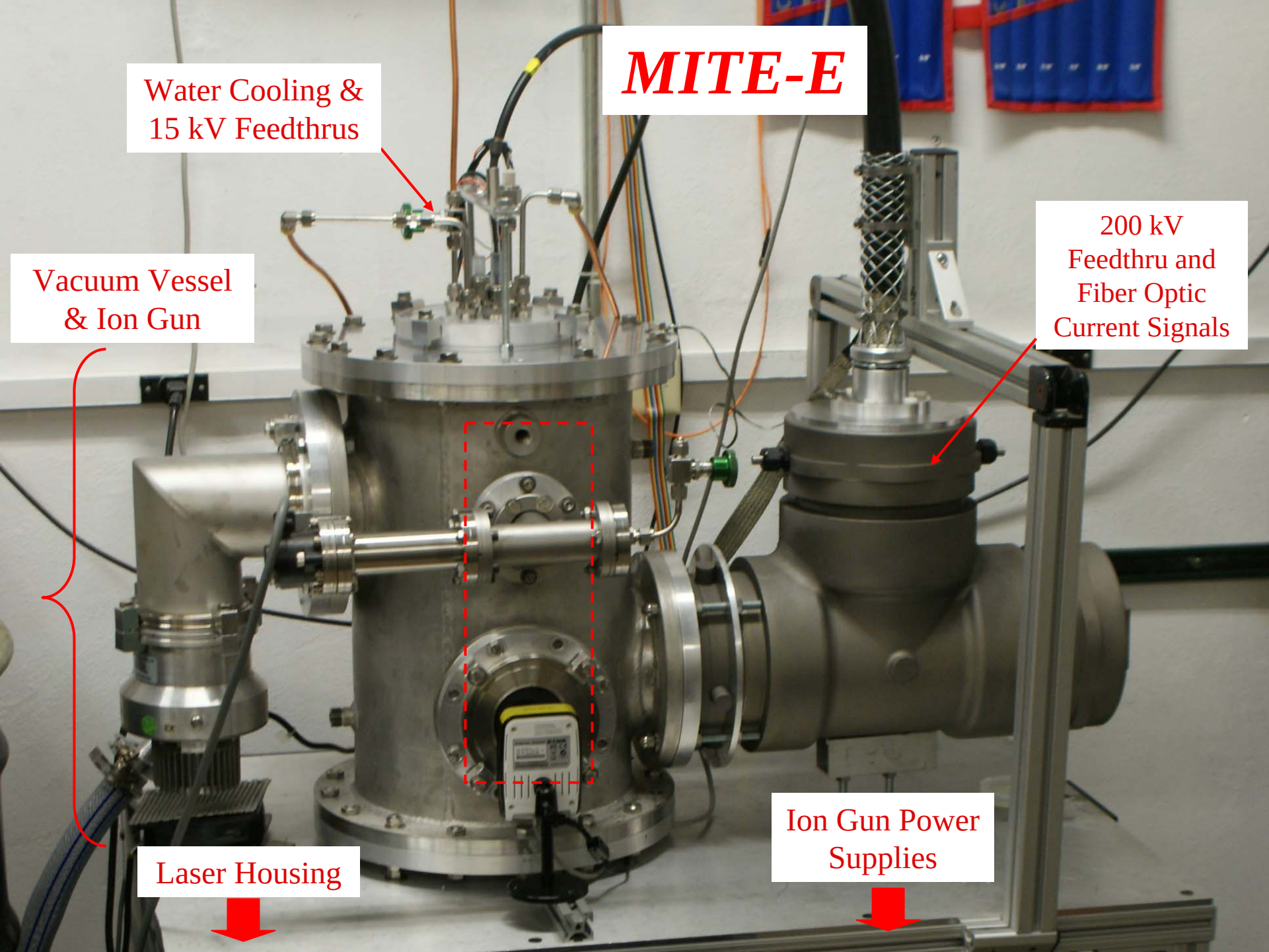
Bubble Distribution & Depth: A Combination Of Decreasing Layer Density And Diffusion Processes



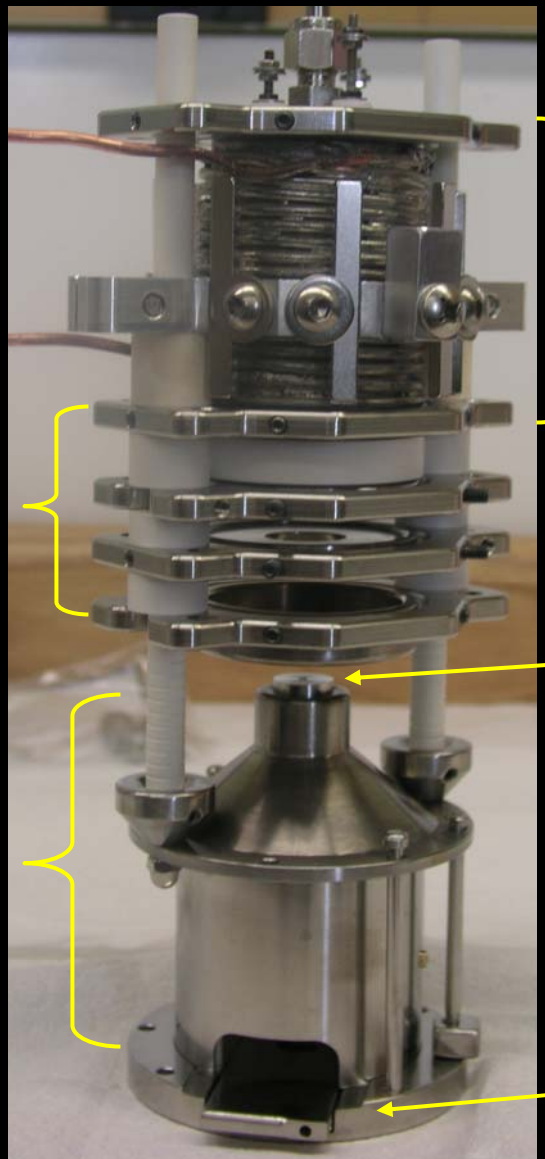
- ρ_{eff} (SCW) – 12.2 g/cc
- ρ_{eff} (PCW) – 8.0 g/cc
- Nominal value for W – 19.6 g/cc

Decoupling Material Irradiation Parameters & Response From The IEC Environment

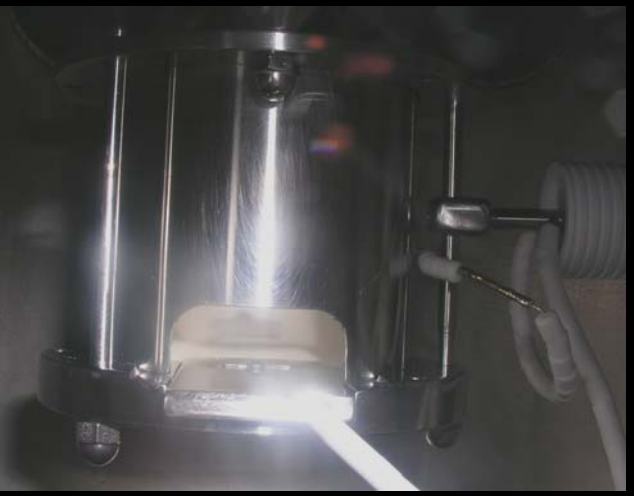
- HOMER/HELIOS constraints:
  - Interdependence of temperature, current, and voltage
    - Limited energy range to ≤ 30 keV
    - Unable to achieve temperatures below ~800°C
    - Limited ability to examine low fluences ($\leq 10^{17}$ cm^{-2})
  - Uncertain ion current to irradiated specimens
    - Difficult to achieve precise fluence scans
    - Examination of dose rate effects not possible
- *MITE-E decouples these parameters allowing for more dynamic experimentation*

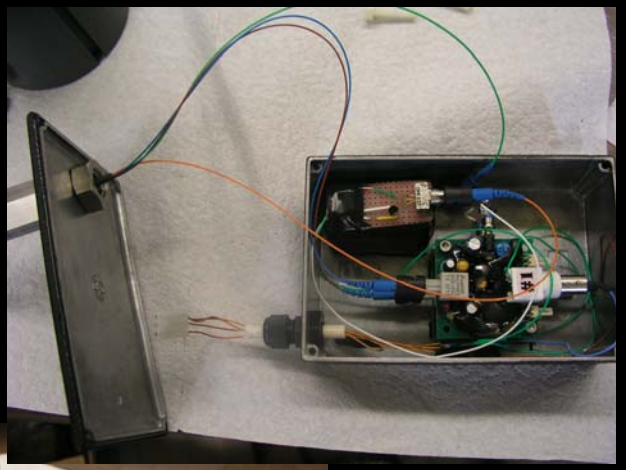

MITE-E
Water Cooling & 15 kV Feedthrus
Vacuum Vessel & Ion Gun
200 kV Feedthru and Fiber Optic Current Signals
Laser Housing
Ion Gun Power Supplies

Conversion Of SIGFE Ion Gun Technology For Materials Implantation Experiments



Sample Current Measured By Optical Signal Transmission Directly From 200 kV Feedthru

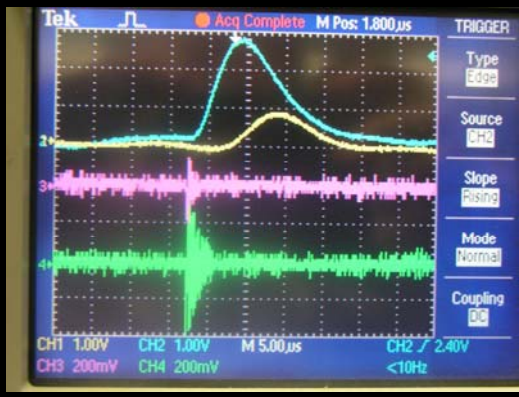




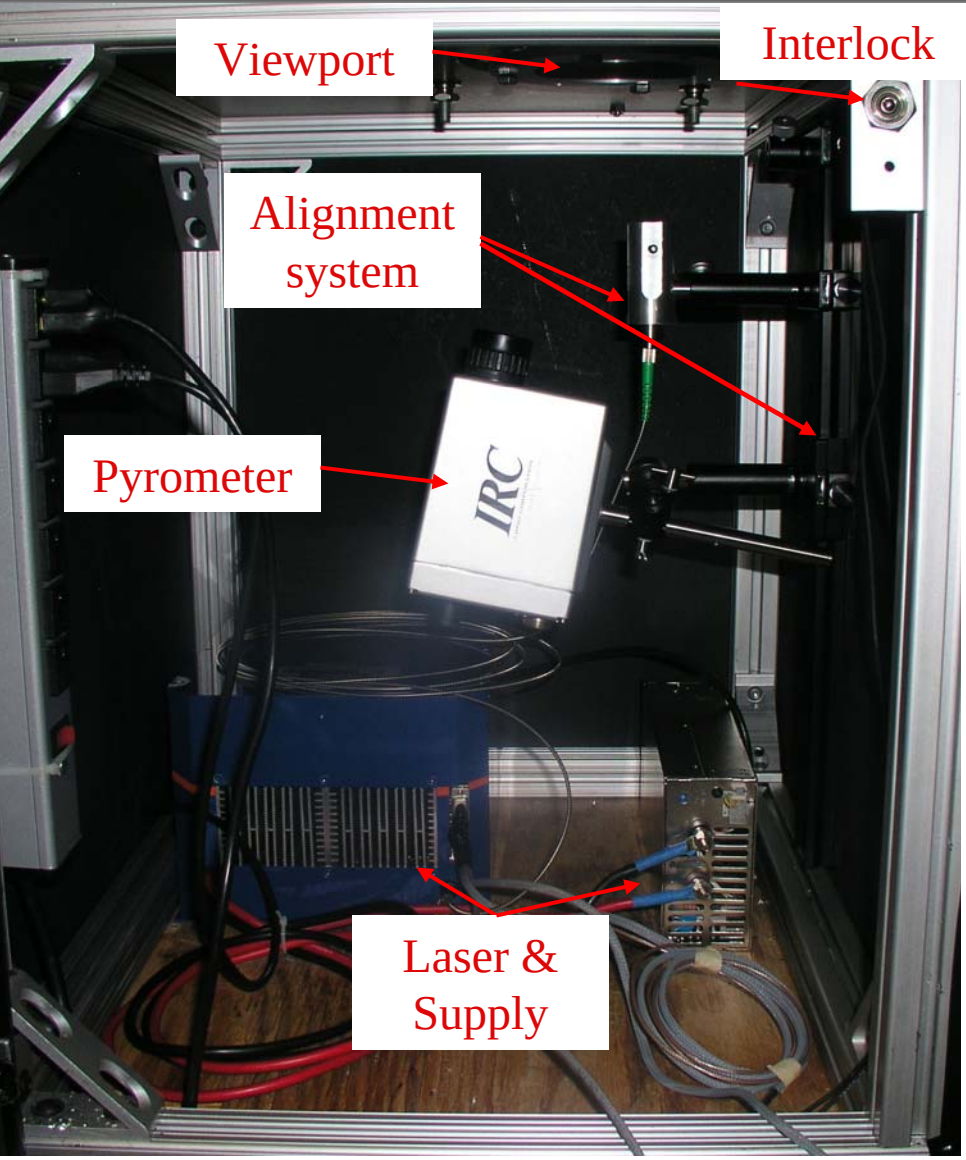
Vacuum

LabView DAQ

-200 kV Feedthru

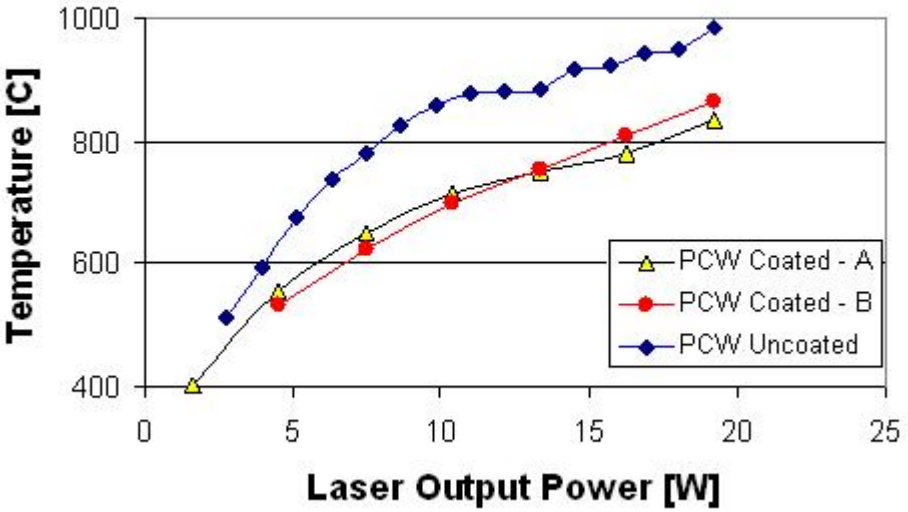


Specimen Heating Provided By A CW Nd:YAG Fiber Laser



- Power: 0 – 20 W
- $\lambda_{Nd:YAG}$: 1064 nm
- Beam size: 2.2 mm
- Pyrometer: 400 – 3000 ºC

Initial Heating Results from Polycrystalline W Specimen (1cm x 1cm x 0.1cm)



Summary

- Helium ion damage is a critical issue for IEC cathodes and also ICF and MFE applications
  - Resultant “coral-like” morphology degrades HV performance
  - Every W species implanted with He^+ at high temperature has sustained surface damage
- MITE-E enhances characterization of materials through improved measurement and experiment control
  - Conversion of SIGFE ion gun technology to a materials application
  - Precise fluence measurement and the Nd:Yag laser heating system

Questions