Surface Effects of Steady State He^+ Implantation in CVD Silicon Carbide

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HAPL Meeting-General Atomics

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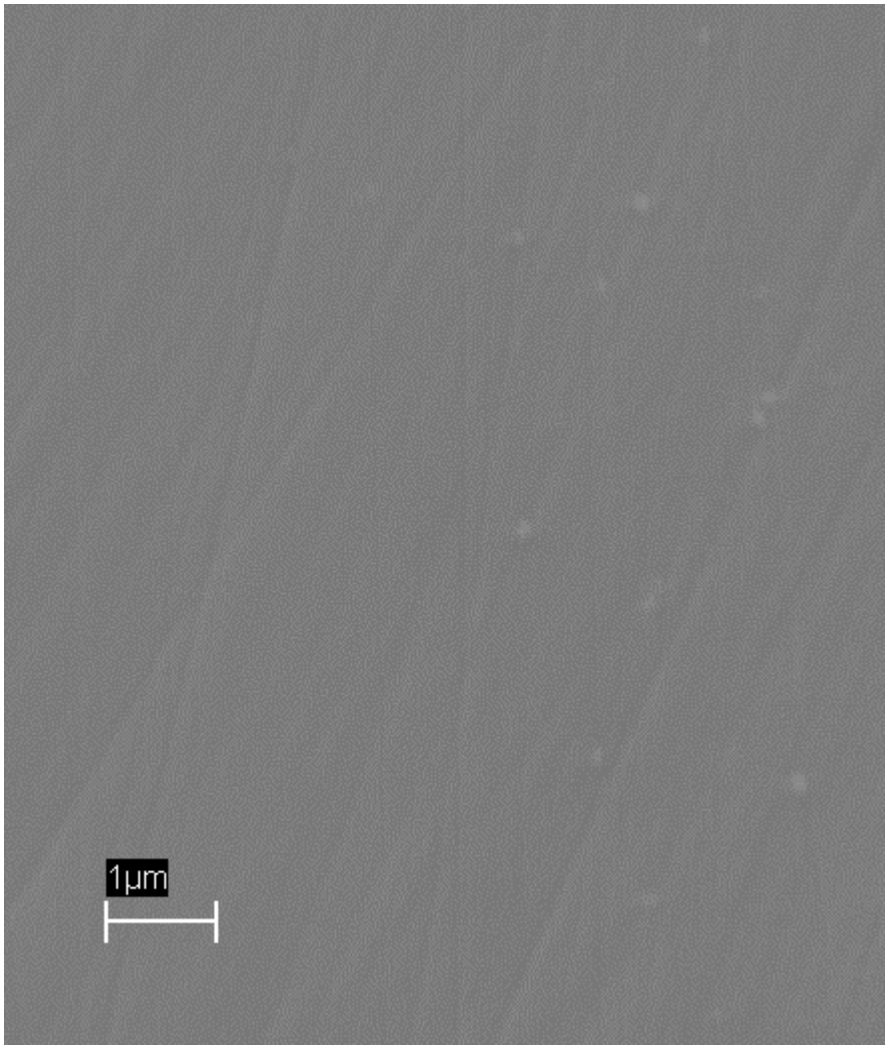
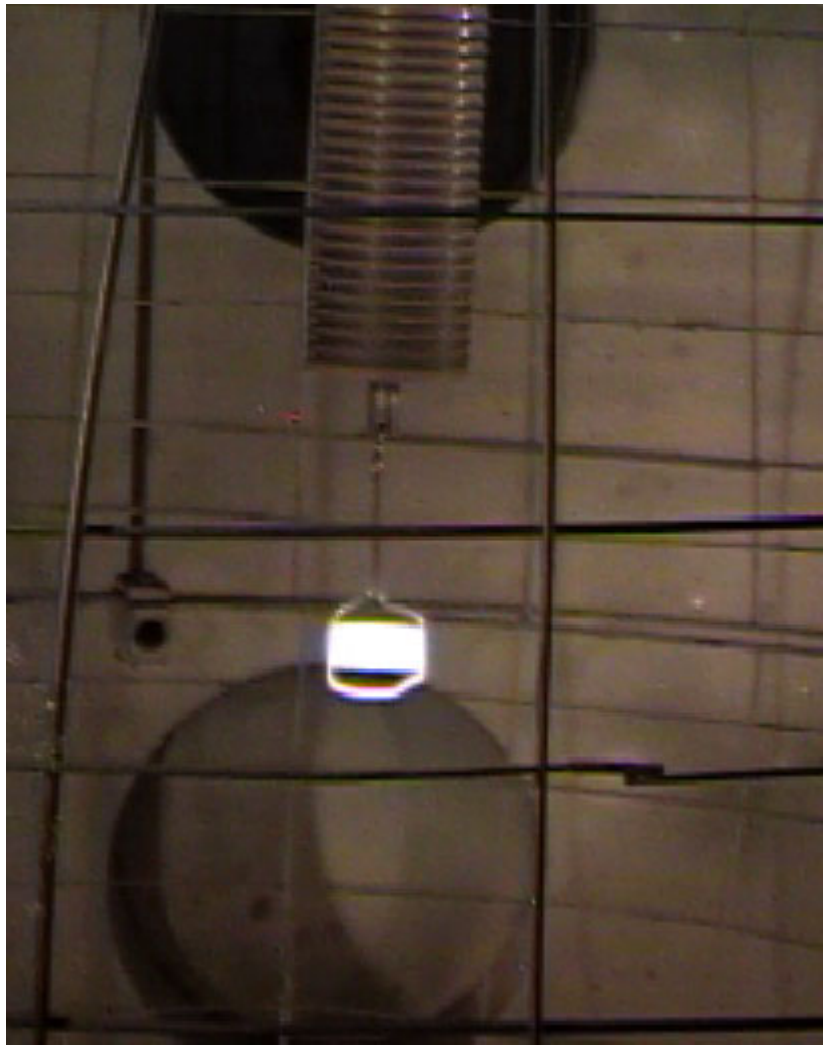
Progress Since Last Meeting

- The CVD Silicon Carbide (SiC) samples acquired from ORNL were irradiated in the UW IEC device to $1x10^{18}$ and $1x10^{19}$ He^+/cm^2 at 750, 850, and 950 °C
- A partially masked SiC sample was irradiated to ~$1.5x10^{19}$ He^+/cm^2 at 950 °C
- FIB and SEM analysis has been performed to evaluate the surface damage on SiC as functions of temperature and fluence.
- Two abstracts have been submitted for the ANS-TOFE conference in November:
  - S.J. Zenobia, G.L. Kulcinski, and R.F. Radel. "Implantation of He^+ in CVD Silicon Carbide"
  - R.F. Radel and G.L. Kulcinski. "Effects of High Temperature Pulsed Helium Implantation on Tungsten Surface Morphology"

Objective: Assess Viability of SiC as HAPL's First Wall Armor

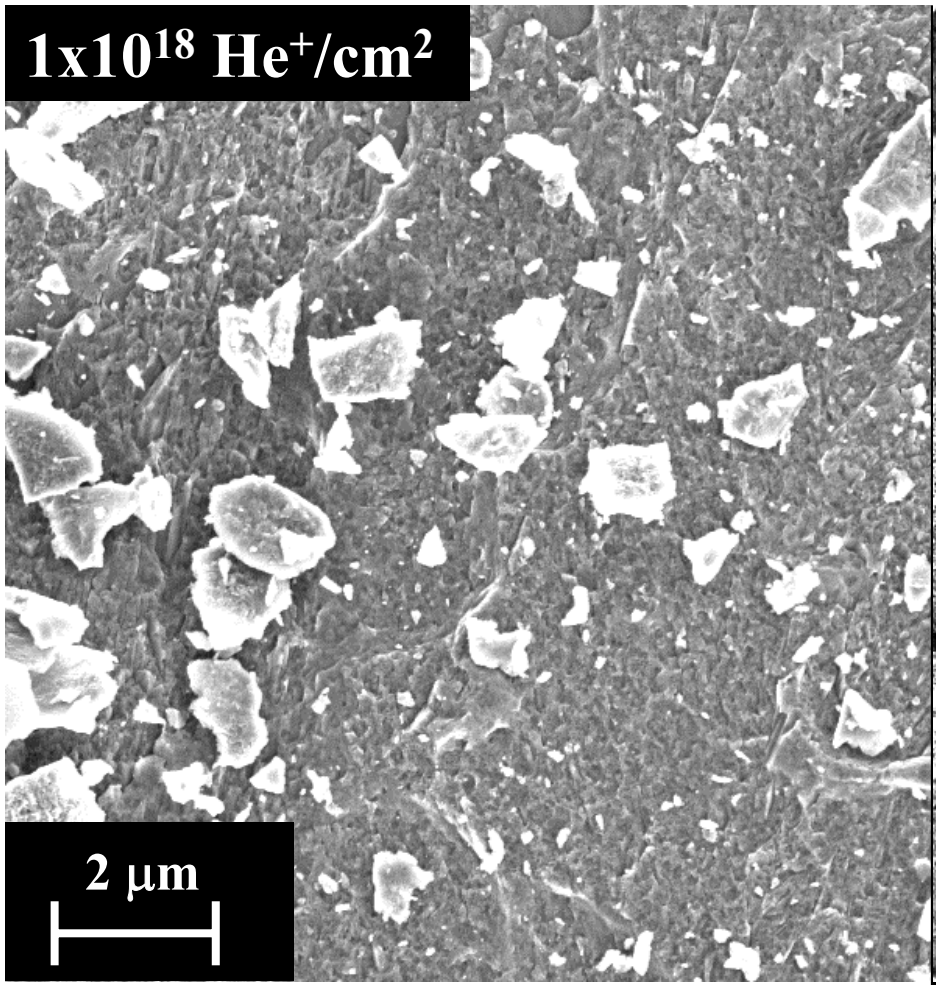


Unirradiated SiC

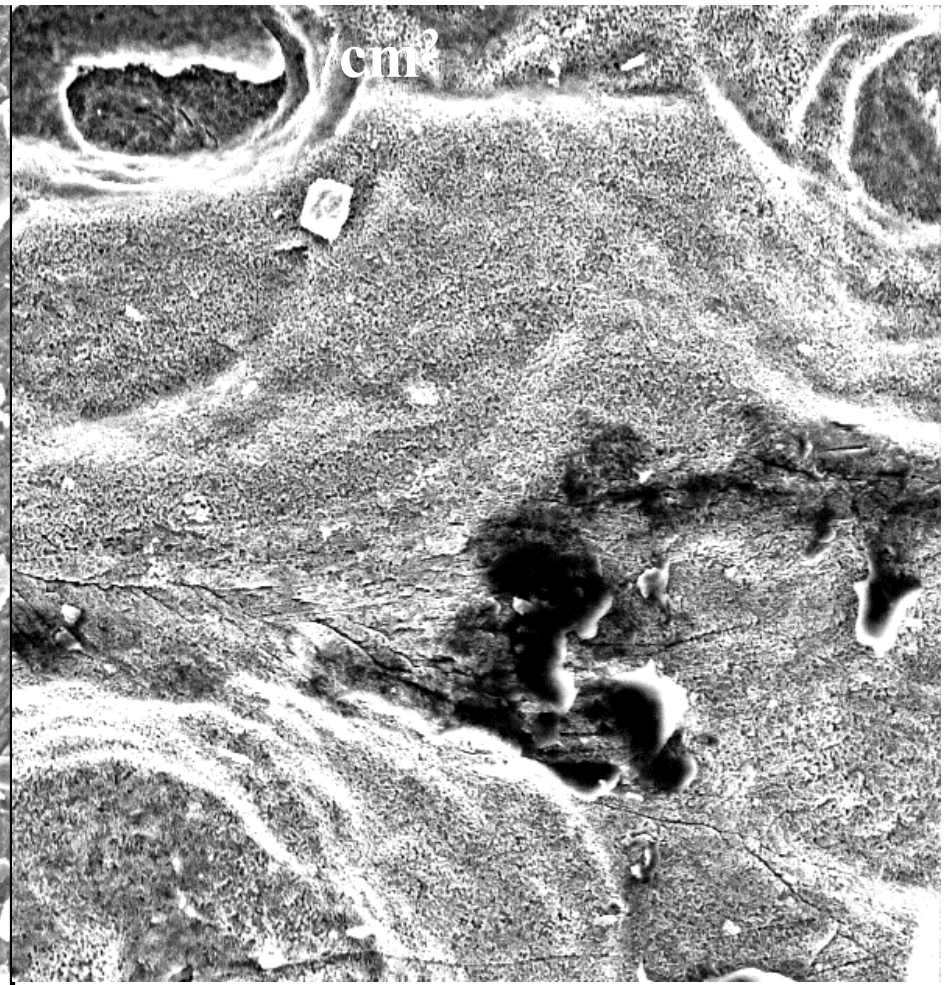


SiC During Irradiation 950°C

Irradiation at 950°C Causes Both Flaking and Pore Formation of SiC Surface

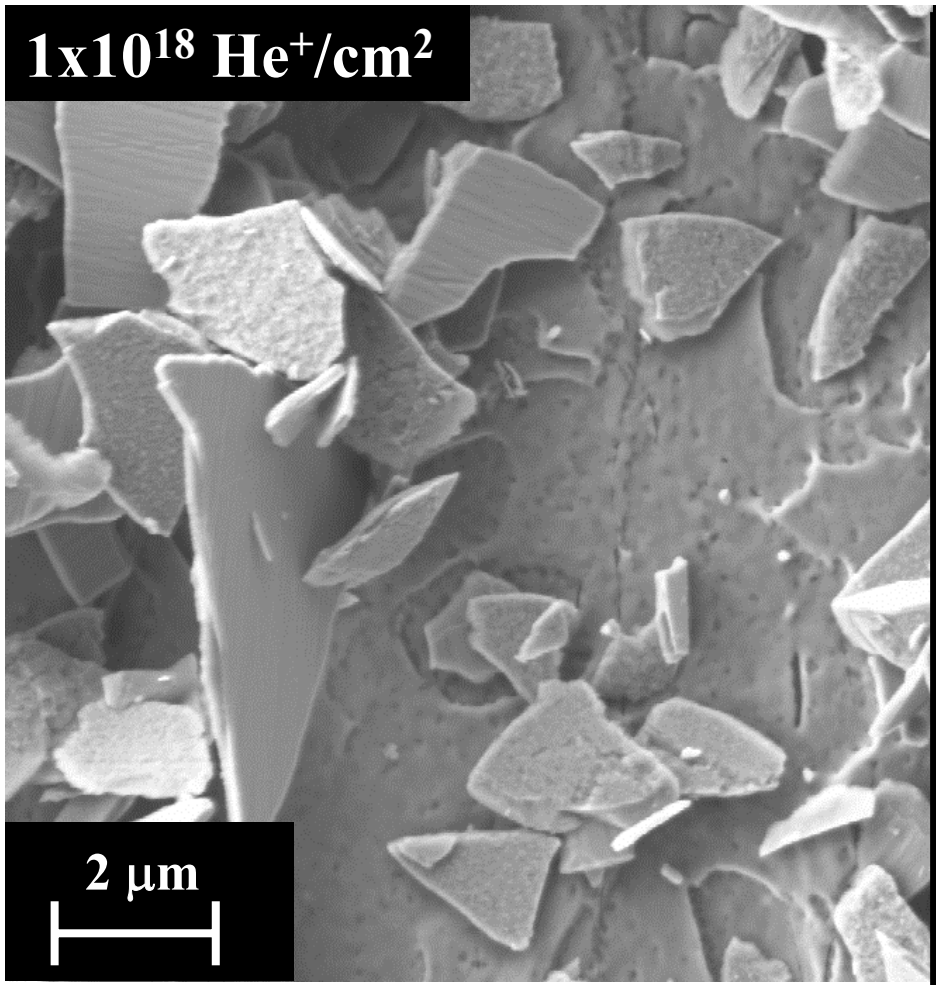


30 kV, 4.5 mA (950±20 °C)
7 minute runtime

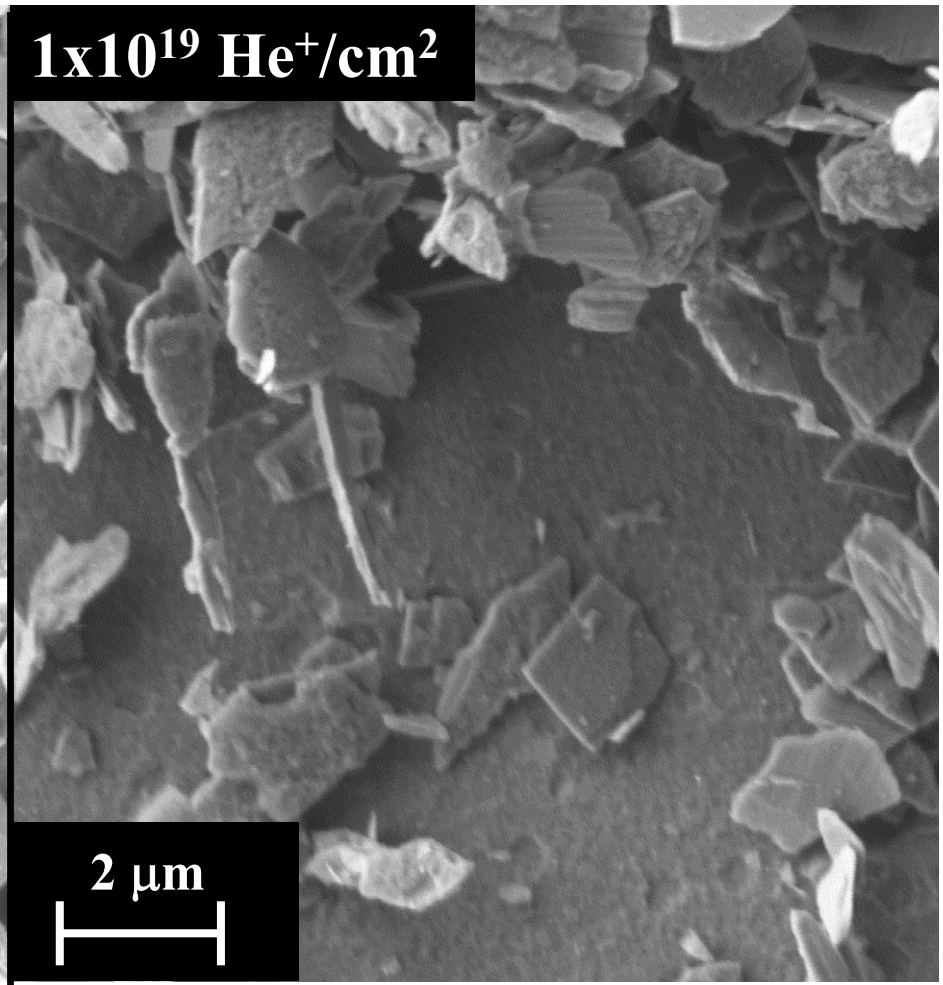


35 kV, 6 mA (950±20 °C)
50 minute runtime

SEM Inspection Reveals Extensive Flaking After Irradiation of SiC Sample at 850° C



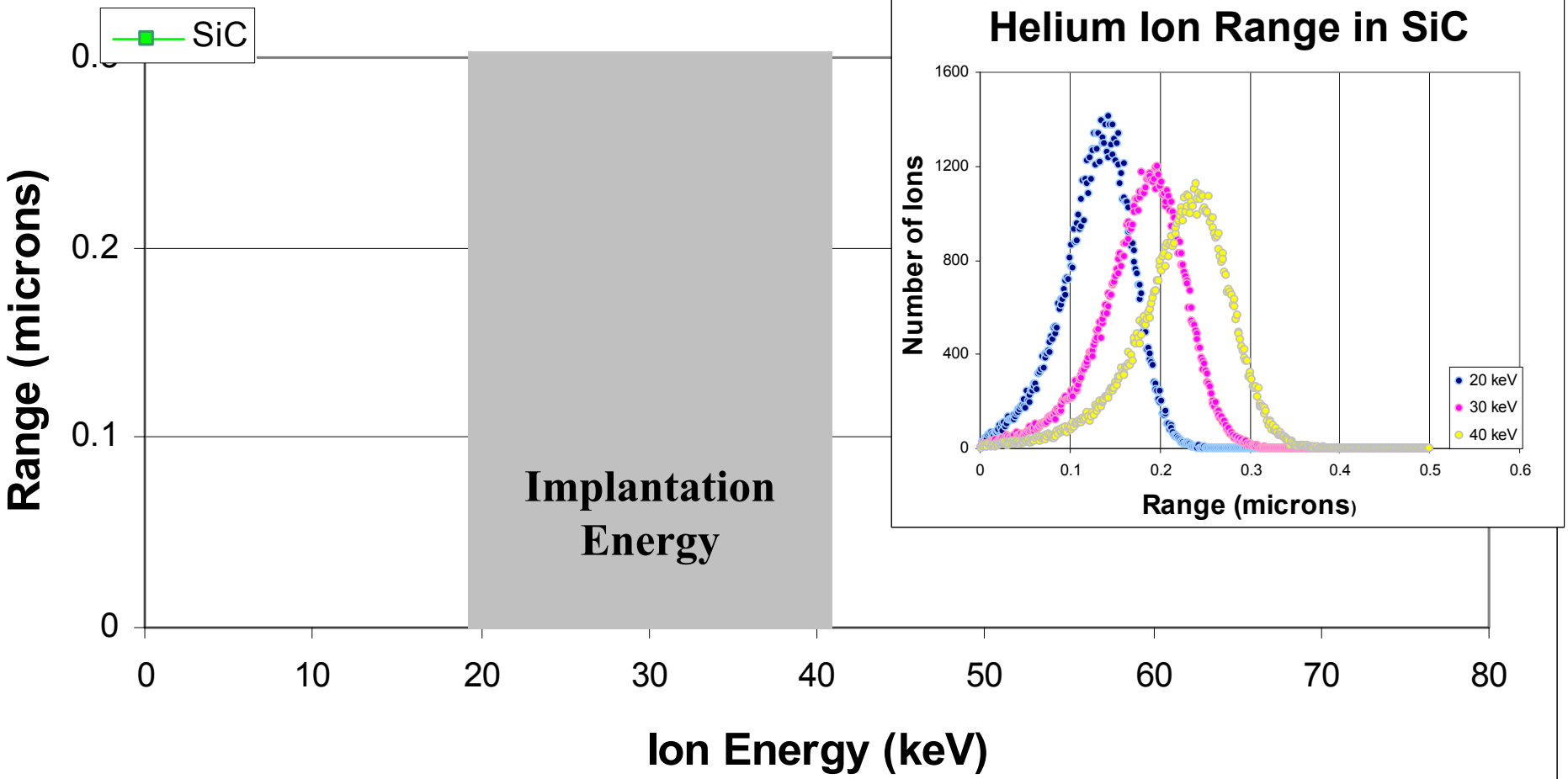
30 kV, 2 mA (850±20 °C)
19 minute runtime



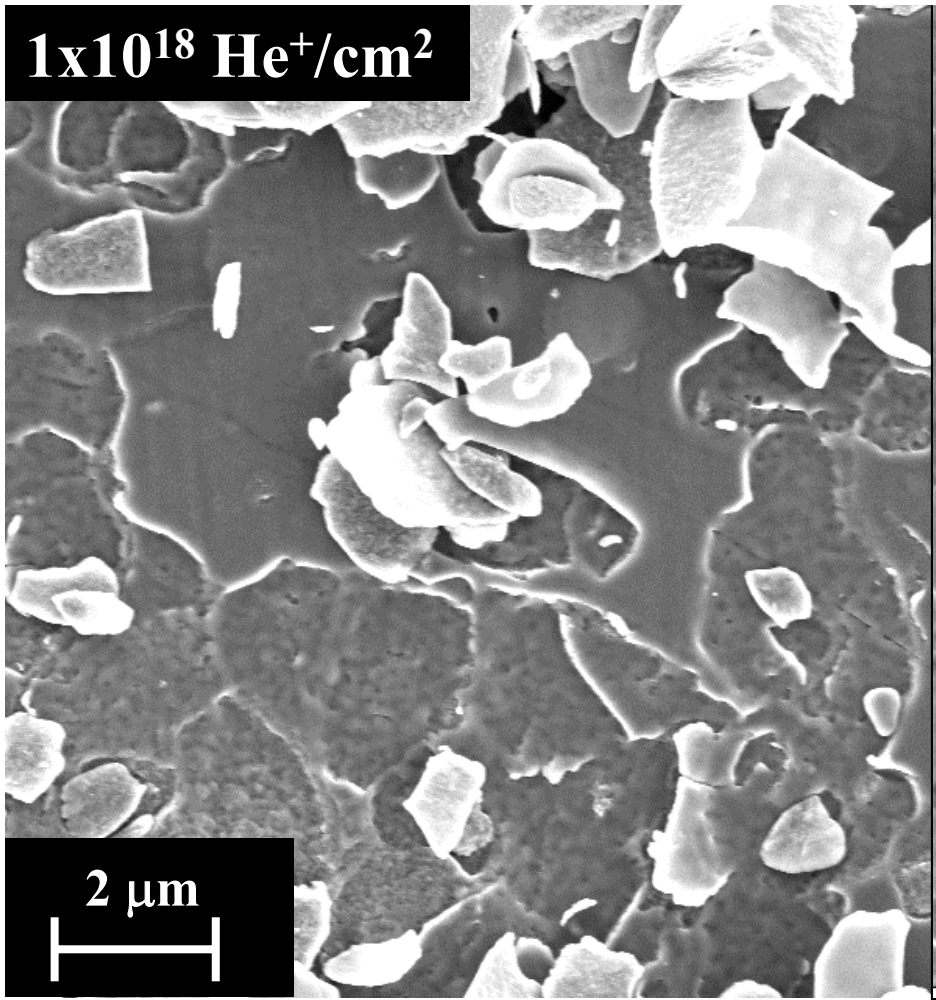
30 kV, 3.5 mA (850±20 °C)
1 hour 52 minute runtime

SRIM Calculations Were Used to Estimate the Range of He^+ in SiC

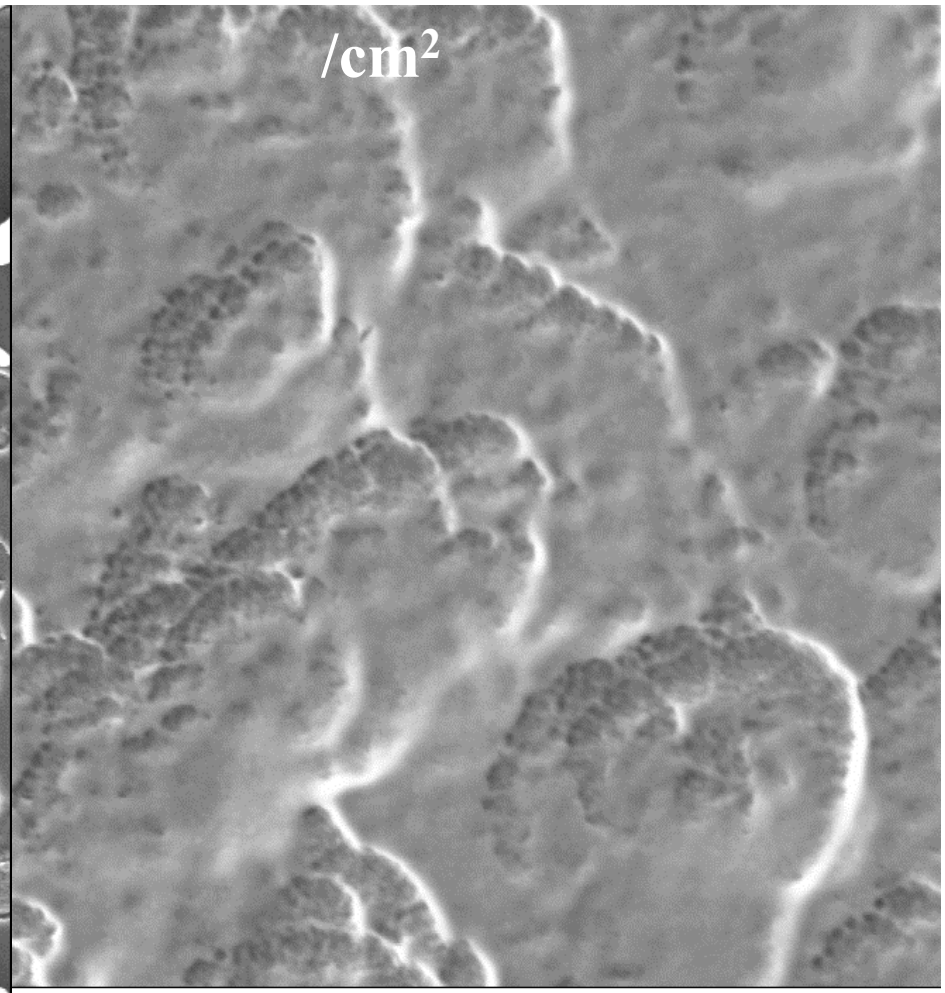
Peak of Helium Ion Concentration



Irradiation at 750°C also Causes Major Morphology Changes on SiC Surface

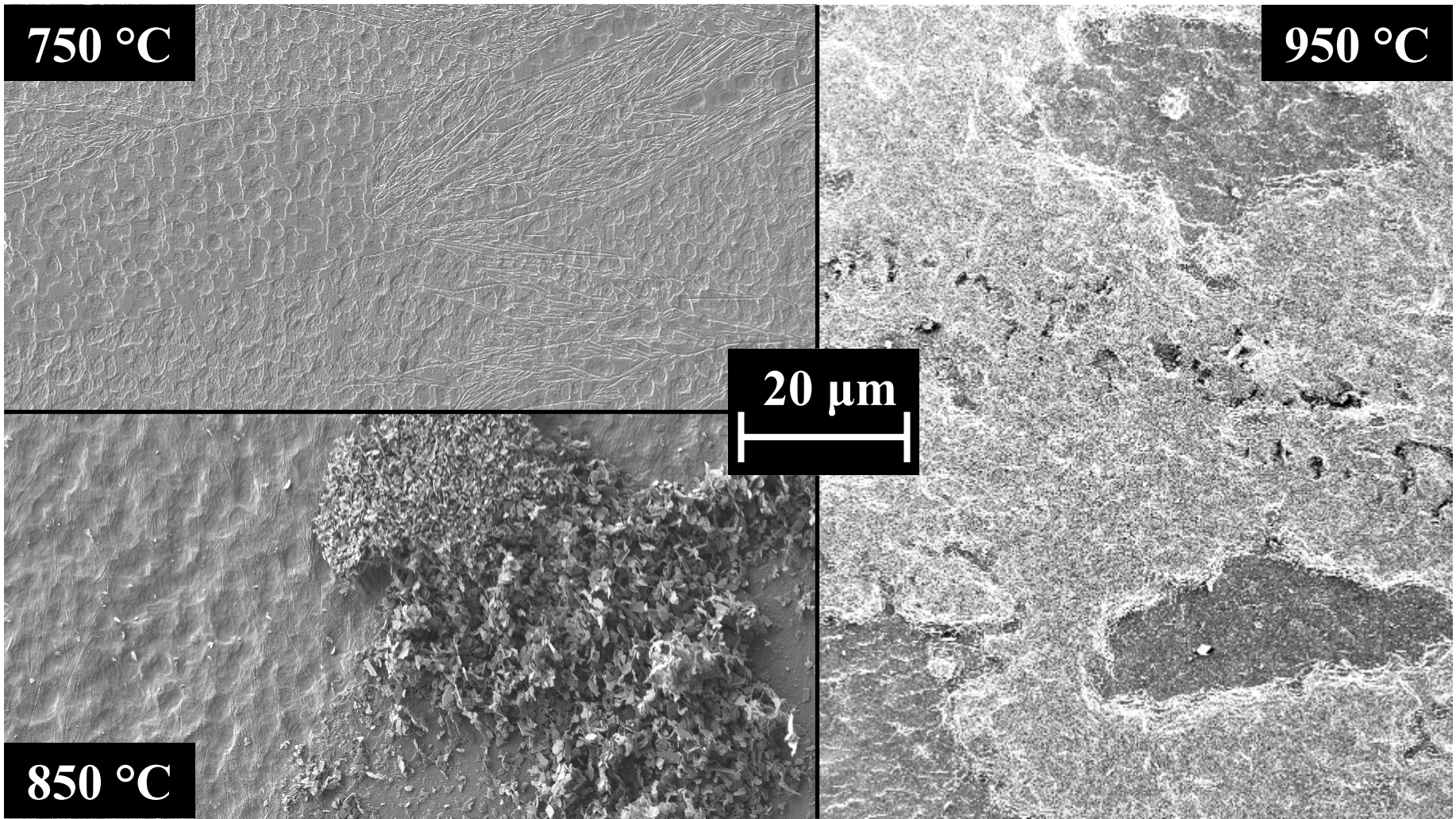


20 kV, 4 mA (750±20 °C)
9 minute runtime

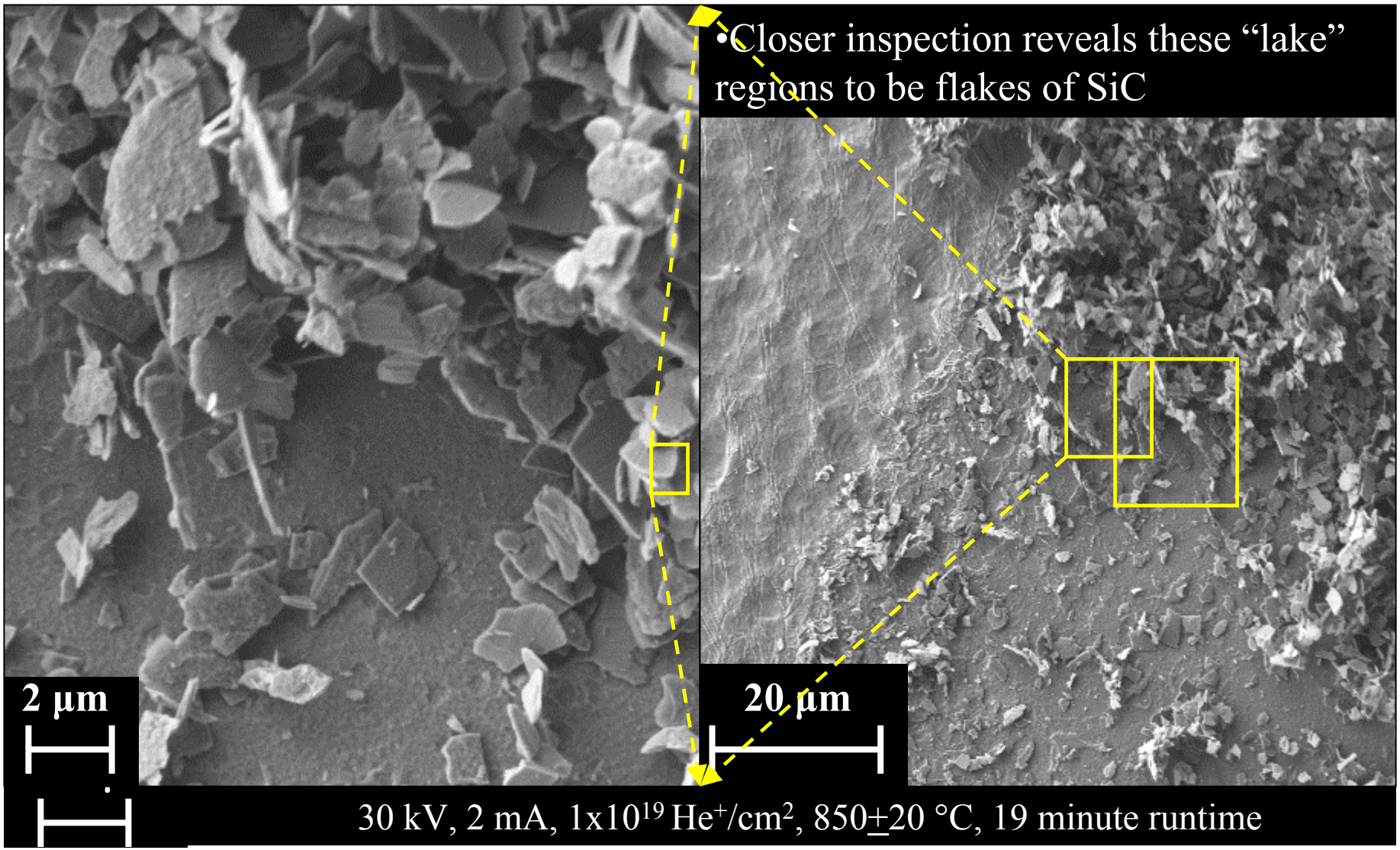


30 kV, 2 mA (750±20 °C)
2 hour 44 minute runtime

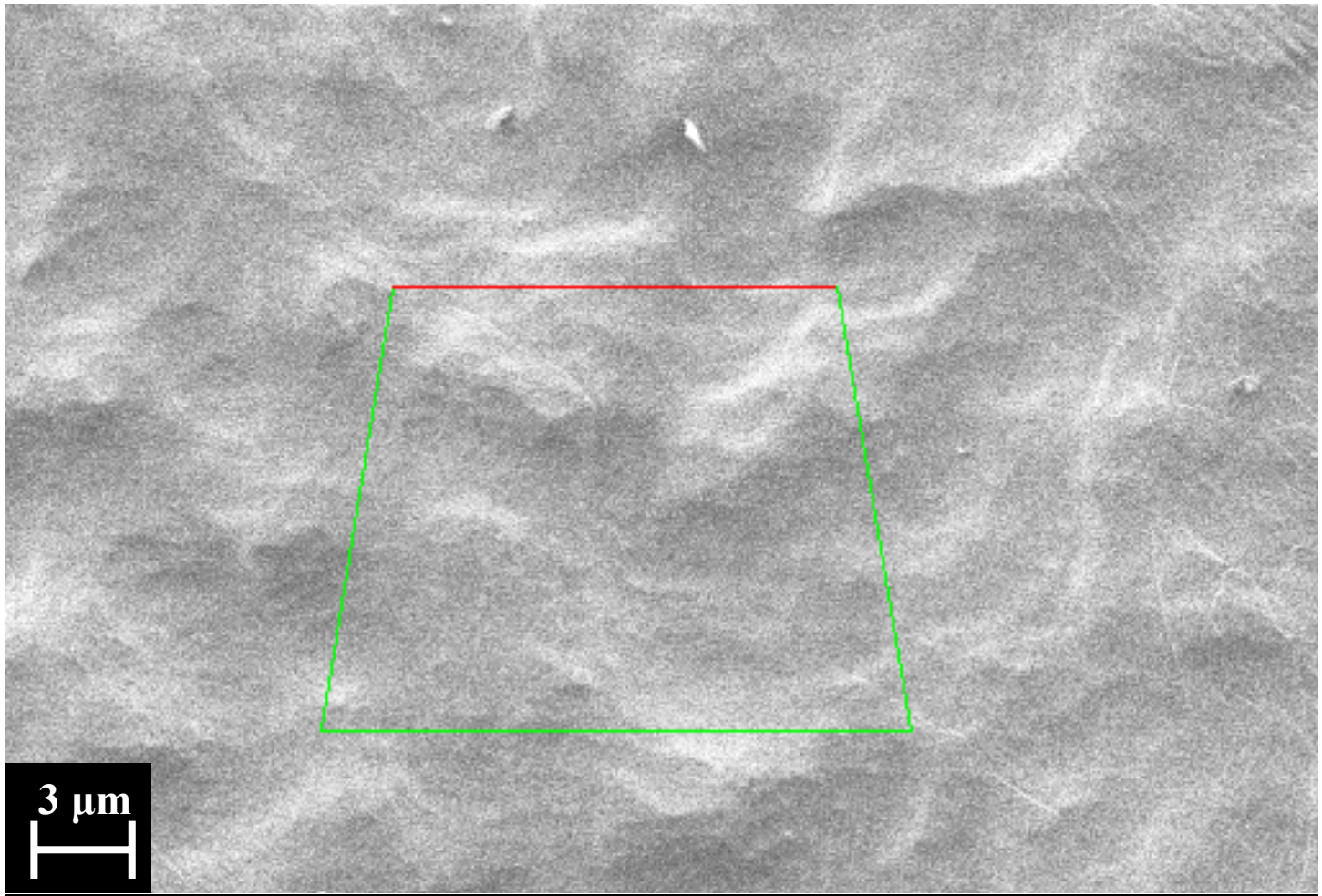
SEM Analysis Shows Changes in Surface Morphology are a Function of Temperature



At $1x10^{19}$ He^+/cm^2 and 850°C Surface Modifications on the Sample Exhibit Considerable Inhomogeneity

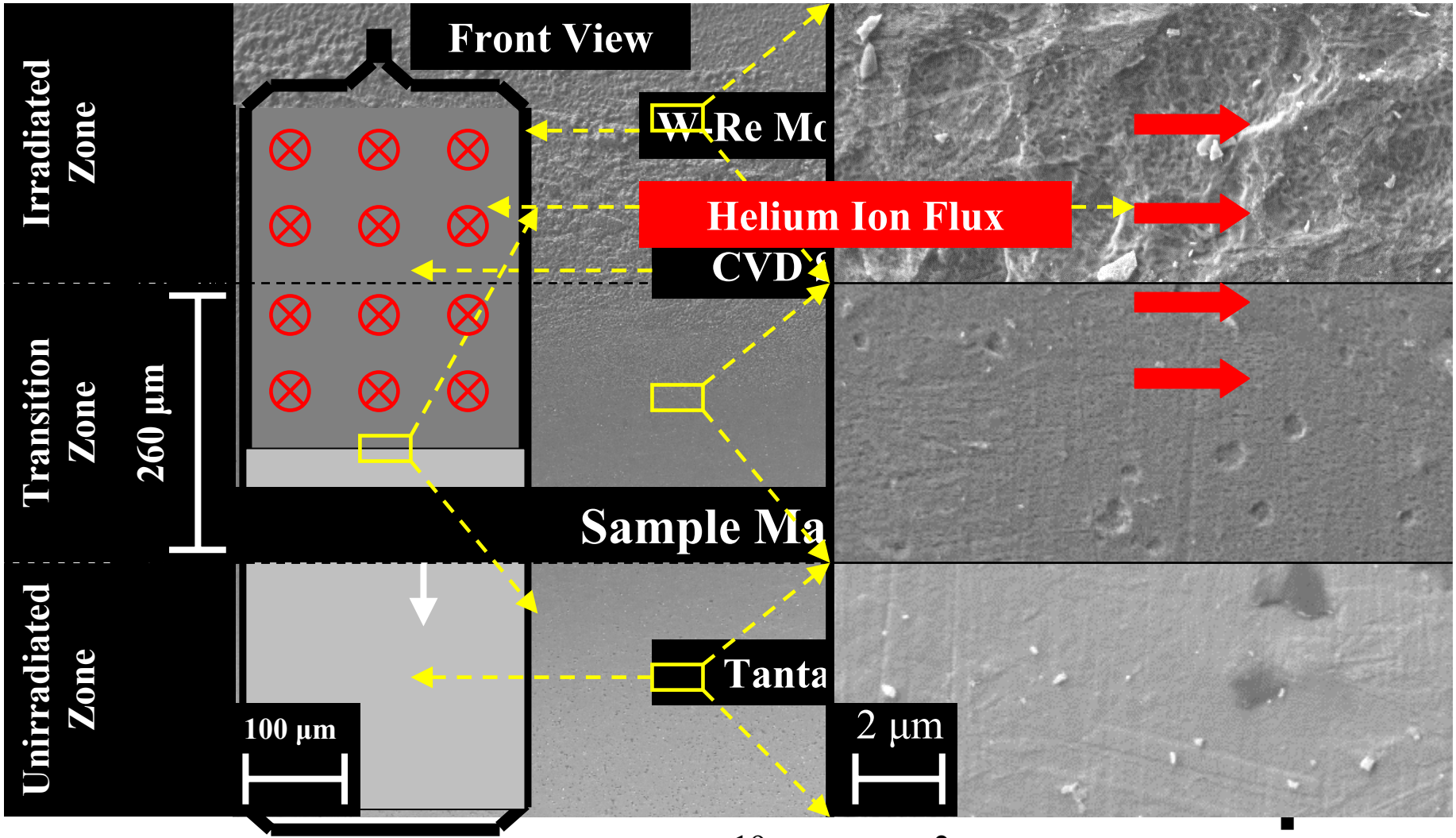


FIB Analysis Shows Substantial Surface Morphology Changes in Irradiated SiC Sample



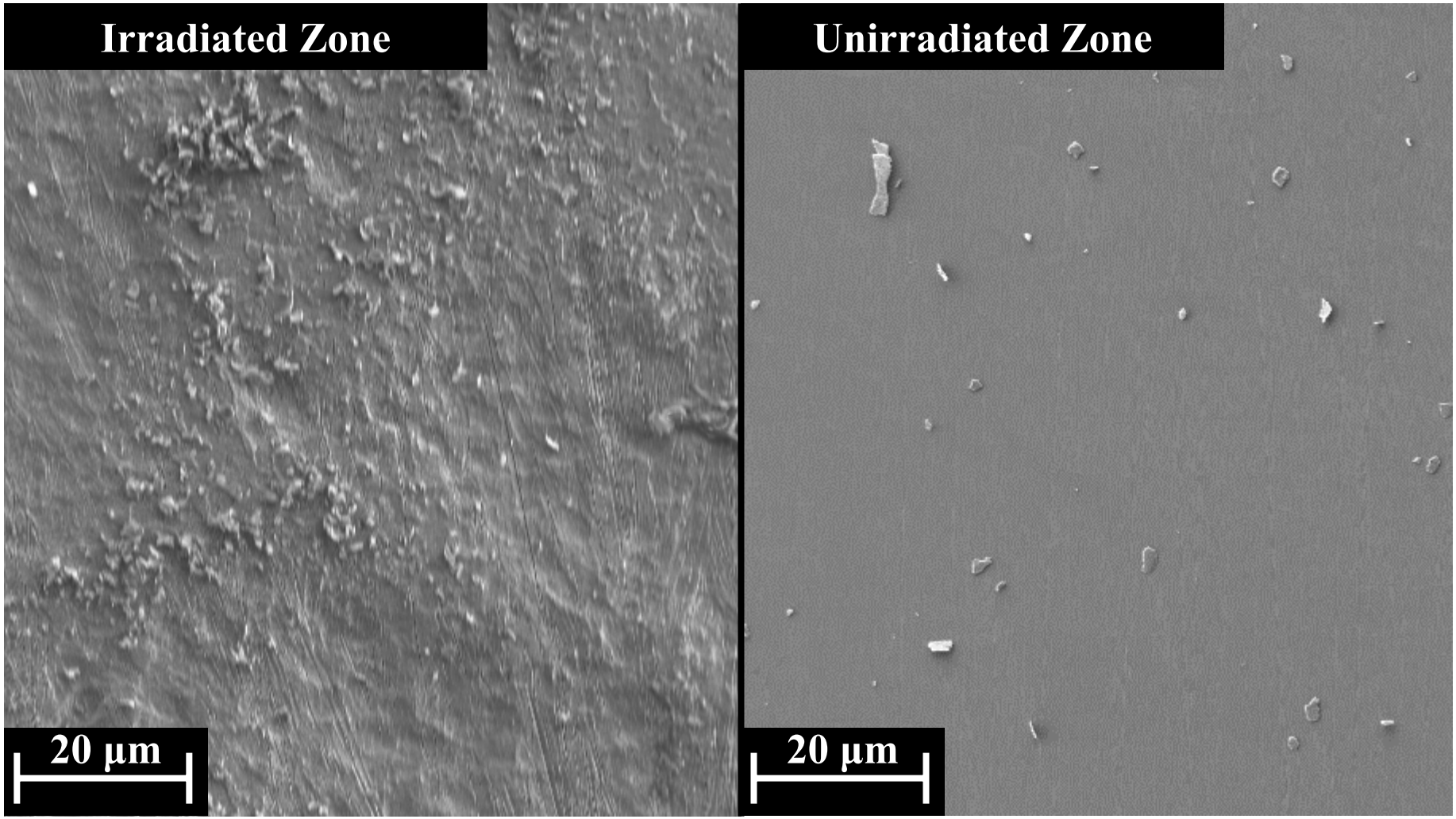
30 kV, 2 mA, $1x10^{19}$ He^{+}/cm^{2} , 850±20 °C, 19 minute runtime

Masked SiC Sample Shows Visible Contrast Between Irradiated and Unirradiated Zones



30 kV, 5.5 mA, 950°C, ~1.5x10^{19} He^{+}/cm^{2}, 147 minute runtime

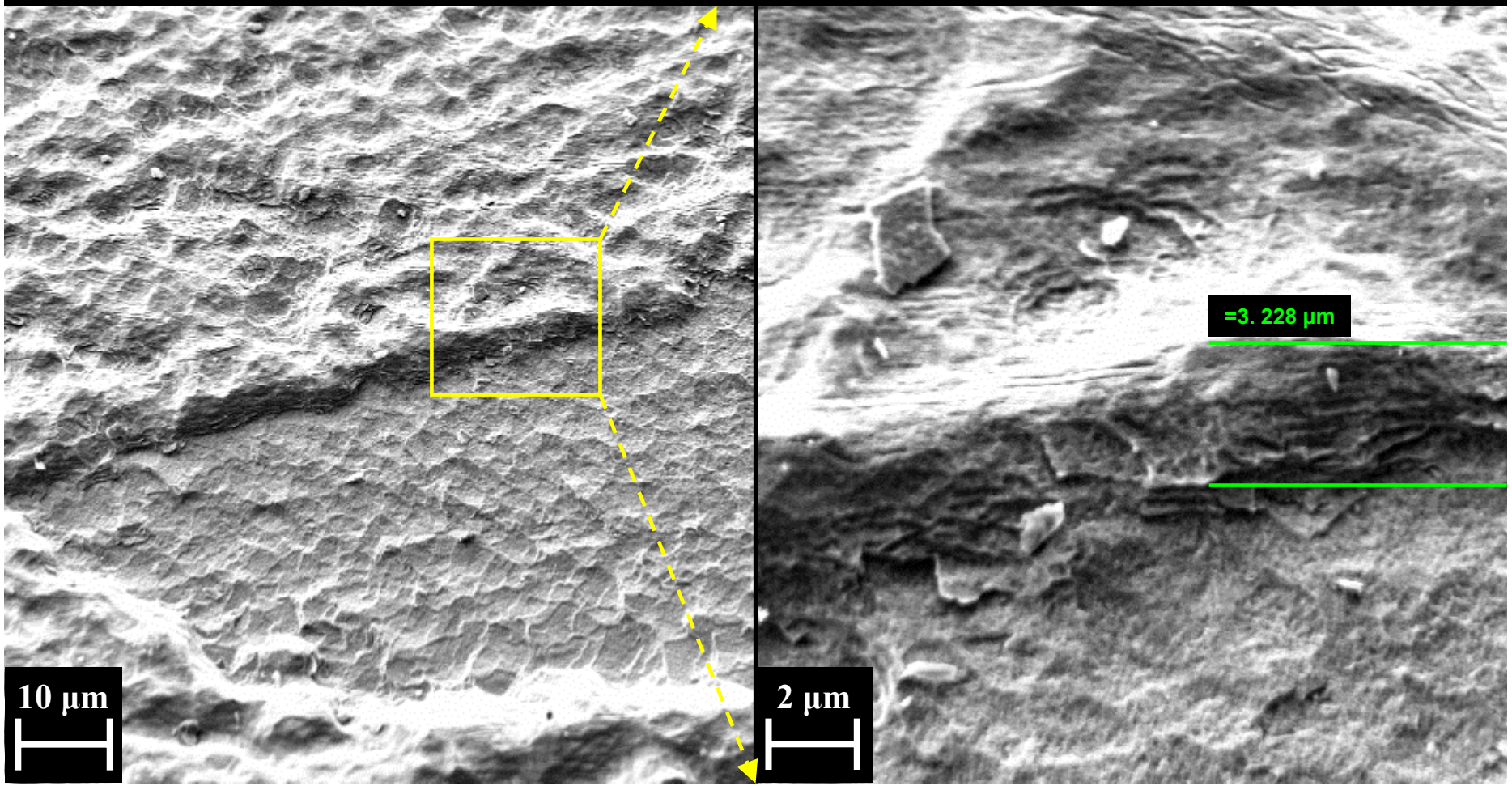
Masked SiC Sample Surface Roughening is Due to Irradiation Not Temperature Exposure



30 kV, 5.5 mA, 950°C, ~1.5x10^{19} He^{+}/cm^{2}, 147 minute runtime

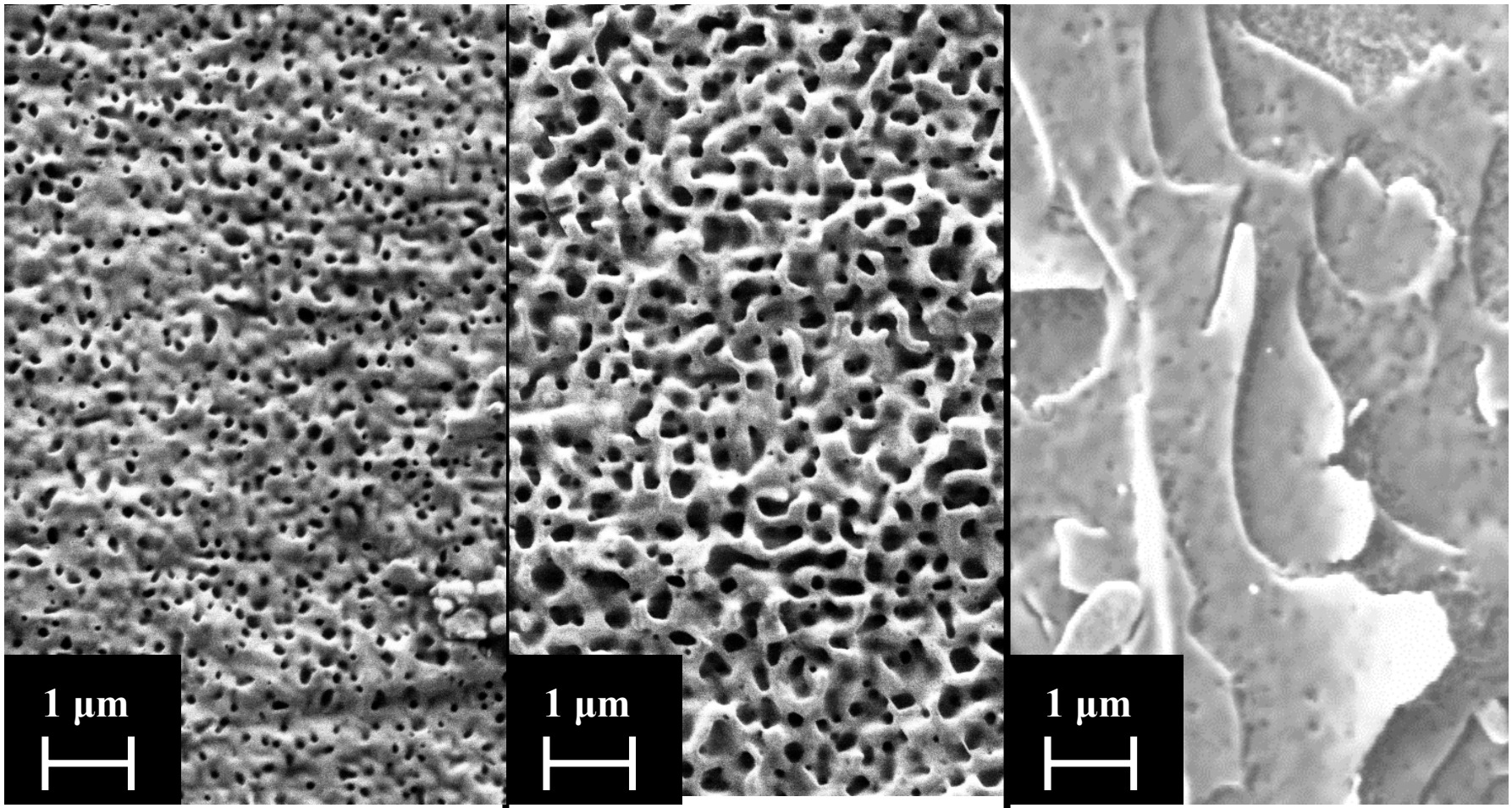
Irradiated Zone of *Masked* SiC Sample Illustrates the Effects of Repeated Flaking

Sample Tilted 35° in SEM Stage



30 kV, 5.5 mA, 950°C, ~1.5x10^{19} He^{+}/cm^{2}, 147 minute runtime

Steady State He^+ Damage to SiC is Considerably Different That to W and W Alloy at $1x10^{19}$ He^+/cm^2



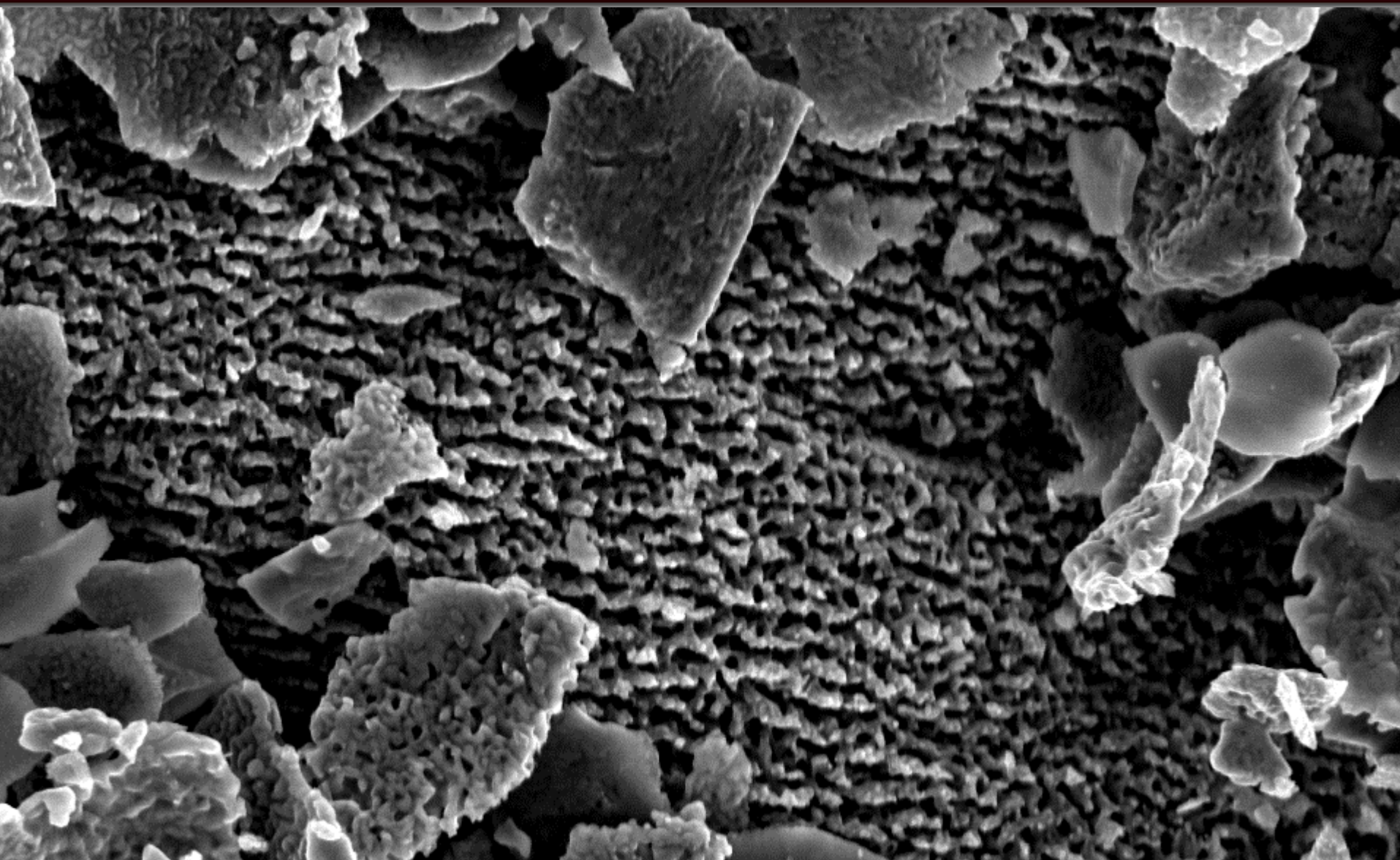
Conclusions

- Significant changes in SiC surface morphology occur at all temperatures (750 – 950 °C) and fluences ($1x10^{18}$ He^+/cm^2 to $1x10^{19}$ He^+/cm^2)
- At constant He^+ fluence, the characteristic damage of the sample is a function of the temperature at which the sample is irradiated
- However, ion fluence - NOT temperature, causes these surface morphology changes
- Substantial differences in surface damage are observed between all SiC samples and W and W-Re alloys

Possible Future Work

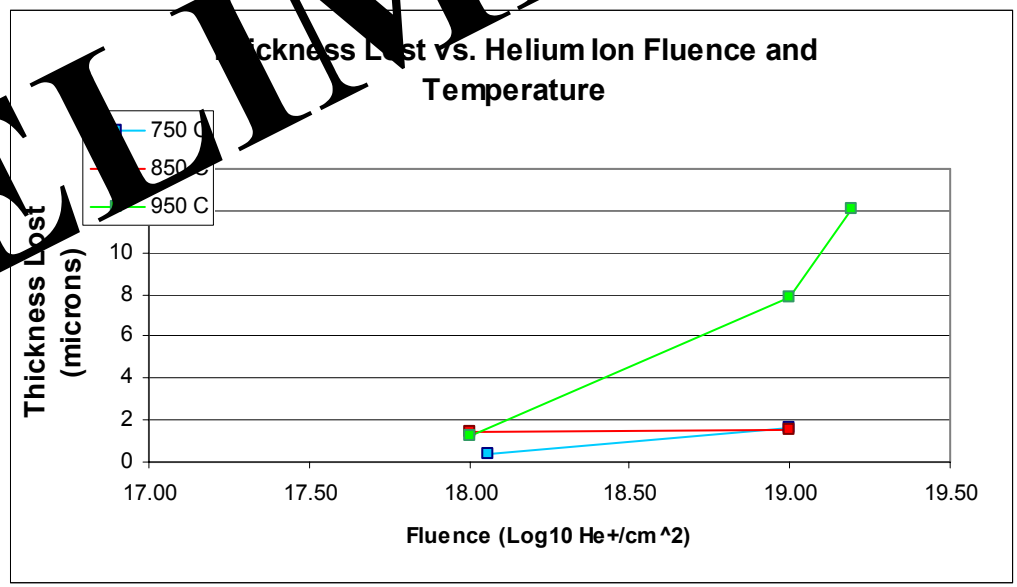
- More careful and detail measurements of mass loss and thickness loss over irradiated area (i.e. analysis with profilometer)
- Pulsed irradiation experiments with He^+ for corresponding temperatures and ion fluence
- Steady state and pulsed deuterium ion implantation
- Simultaneous He^+ and D_2^+ implantation in both steady state and pulsed modes of the UW IEC device

Questions?

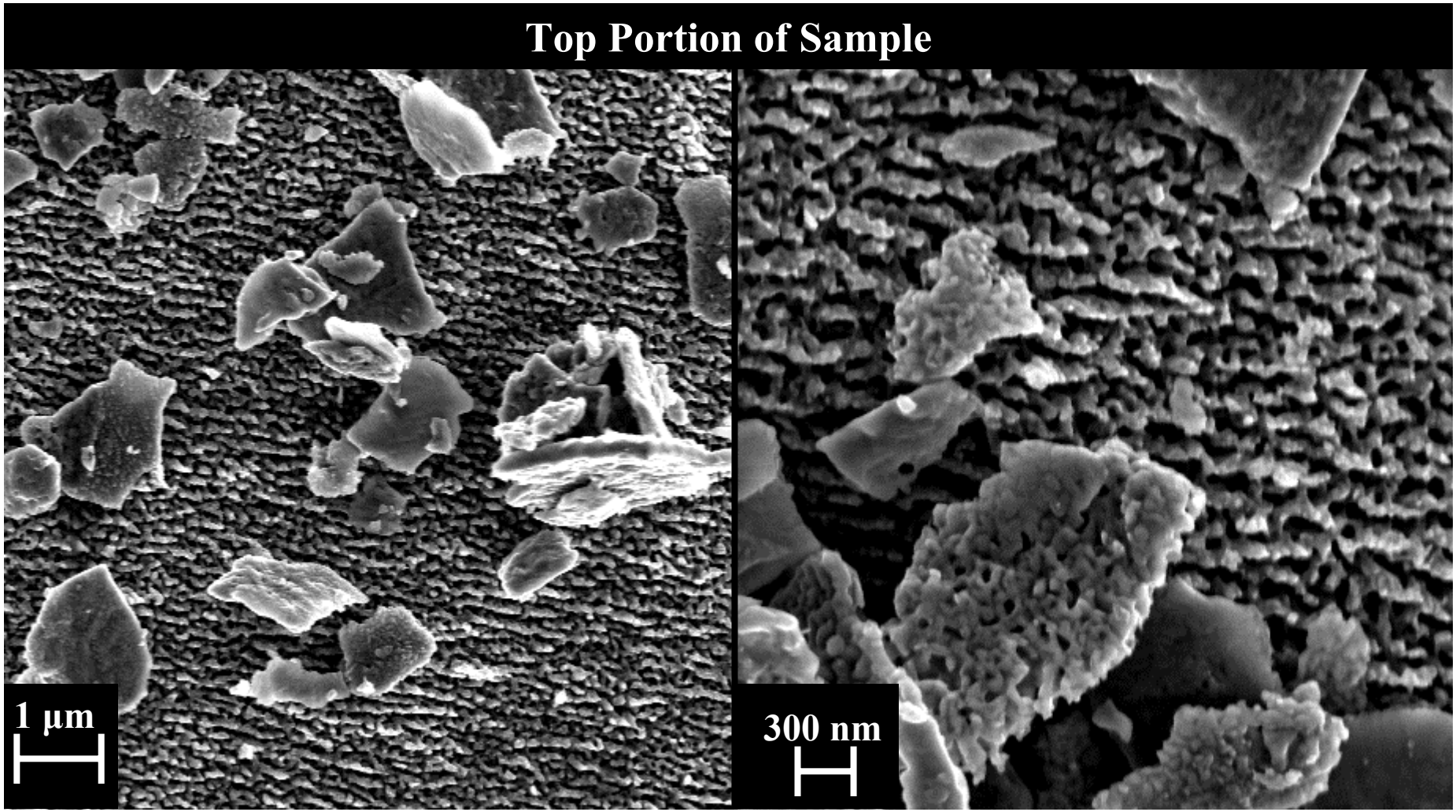


Mass Losses Occurred for SiC Samples at all Temperatures and Fluences

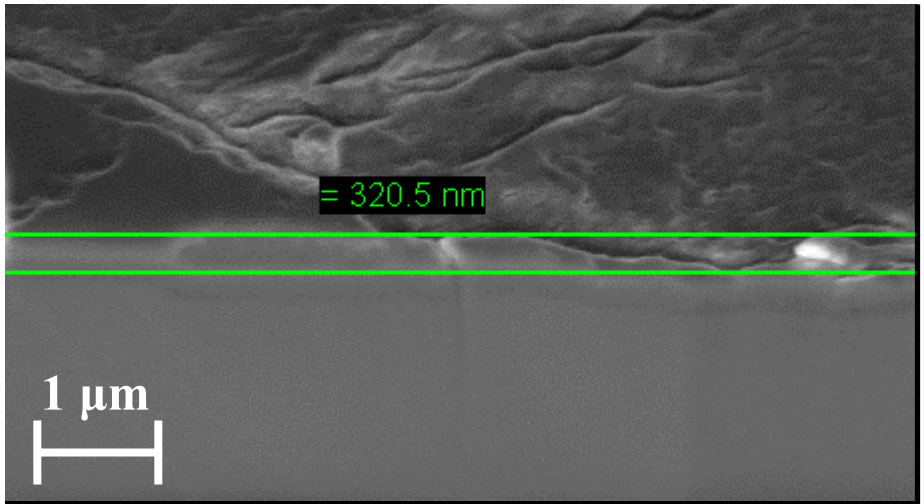
- Preliminary results indicate mass losses ranging from 0.2 – 9 mg
- Certain variables that might effect mass loss calculations
  - Certain samples experienced minor chipping when tensioned in W-Re wire mount
  - Unpolished side of the samples were washed with ethanol to remove SEM tape residue
- Measured mass loss and corresponding thickness loss for irradiation and temperature is plotted below:



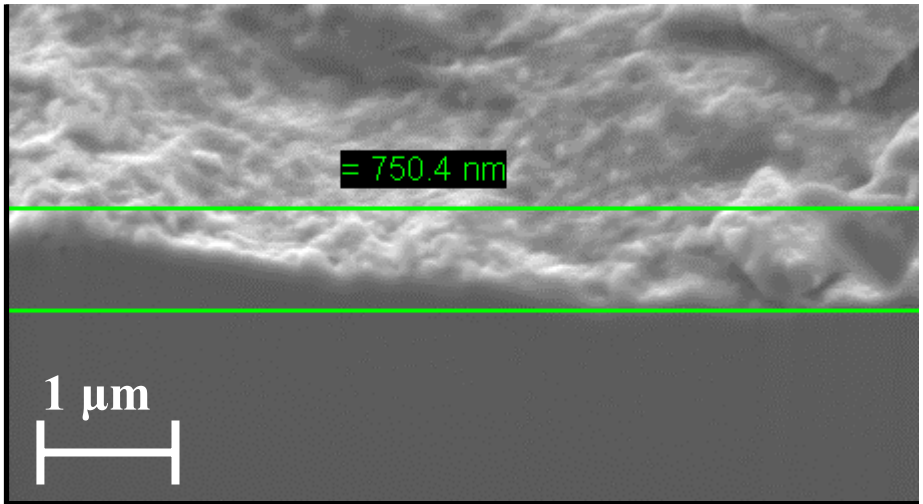
Massive Flaking and Pore Formation Appeared on the First SiC Samples Irradiated with He^+



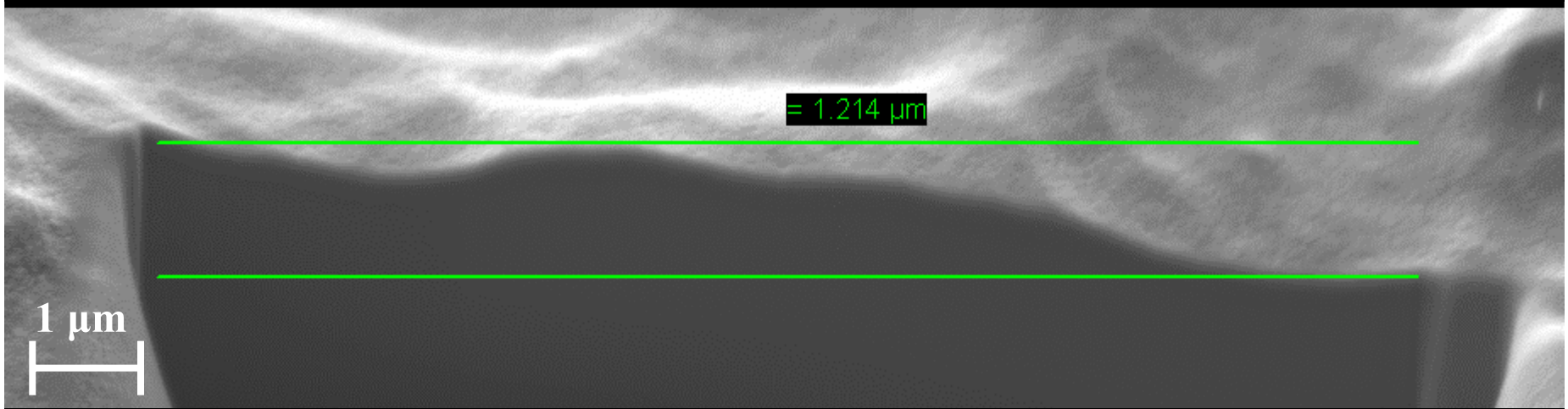
~950°C (Mid-Sample), 30kV, 8mA, 38 minute runtime



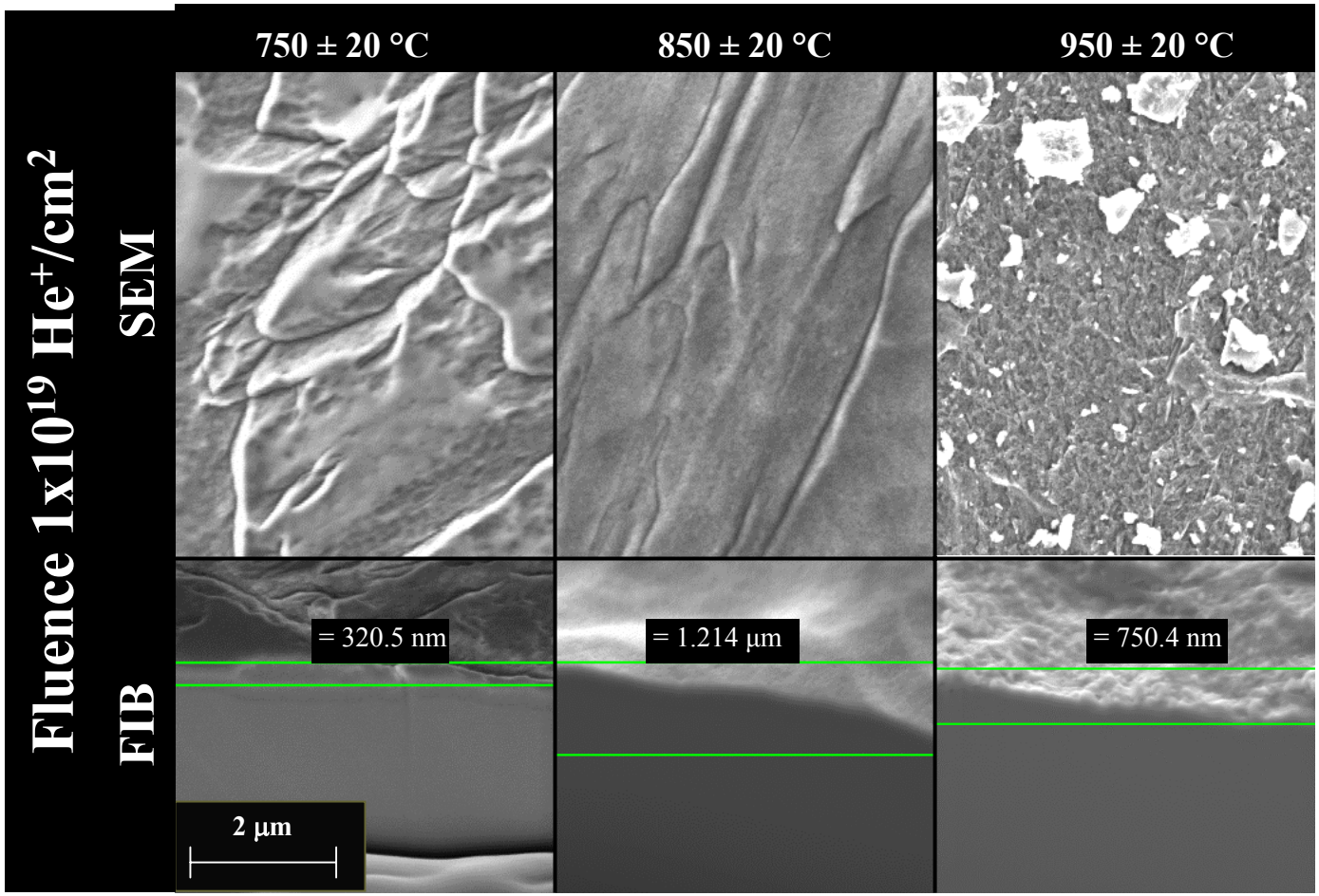
30 kV, 2 mA (750±20 °C)



30 kV, 6 mA (950±20 °C)



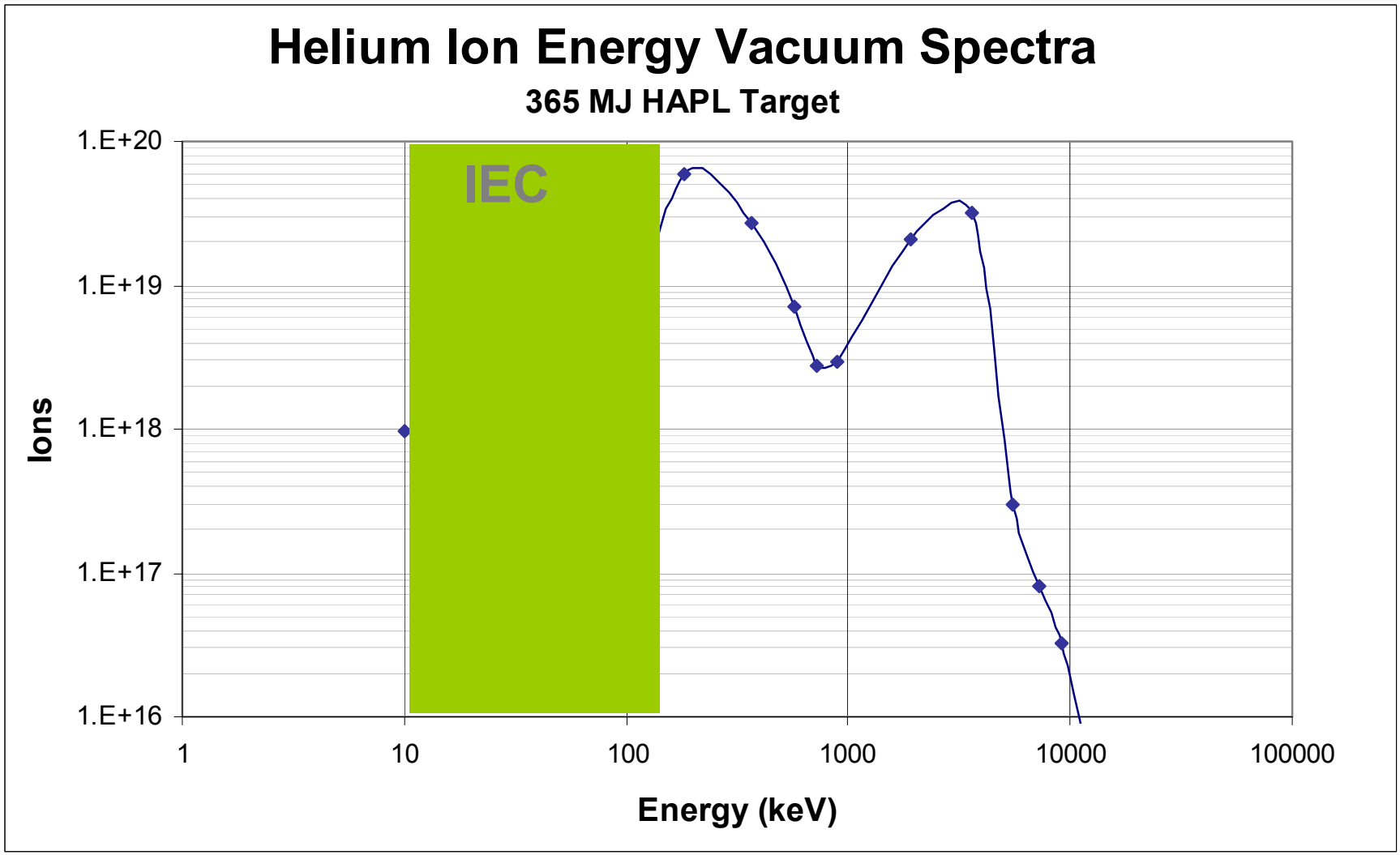
30 kV, 3.5 mA (850±20 °C)


750 ± 20 °C
850 ± 20 °C
950 ± 20 °C
Fluence 1x10^19 He+/cm2
SEM
FIB
= 320.5 nm
= 1.214 µm
= 750.4 nm
2 µm

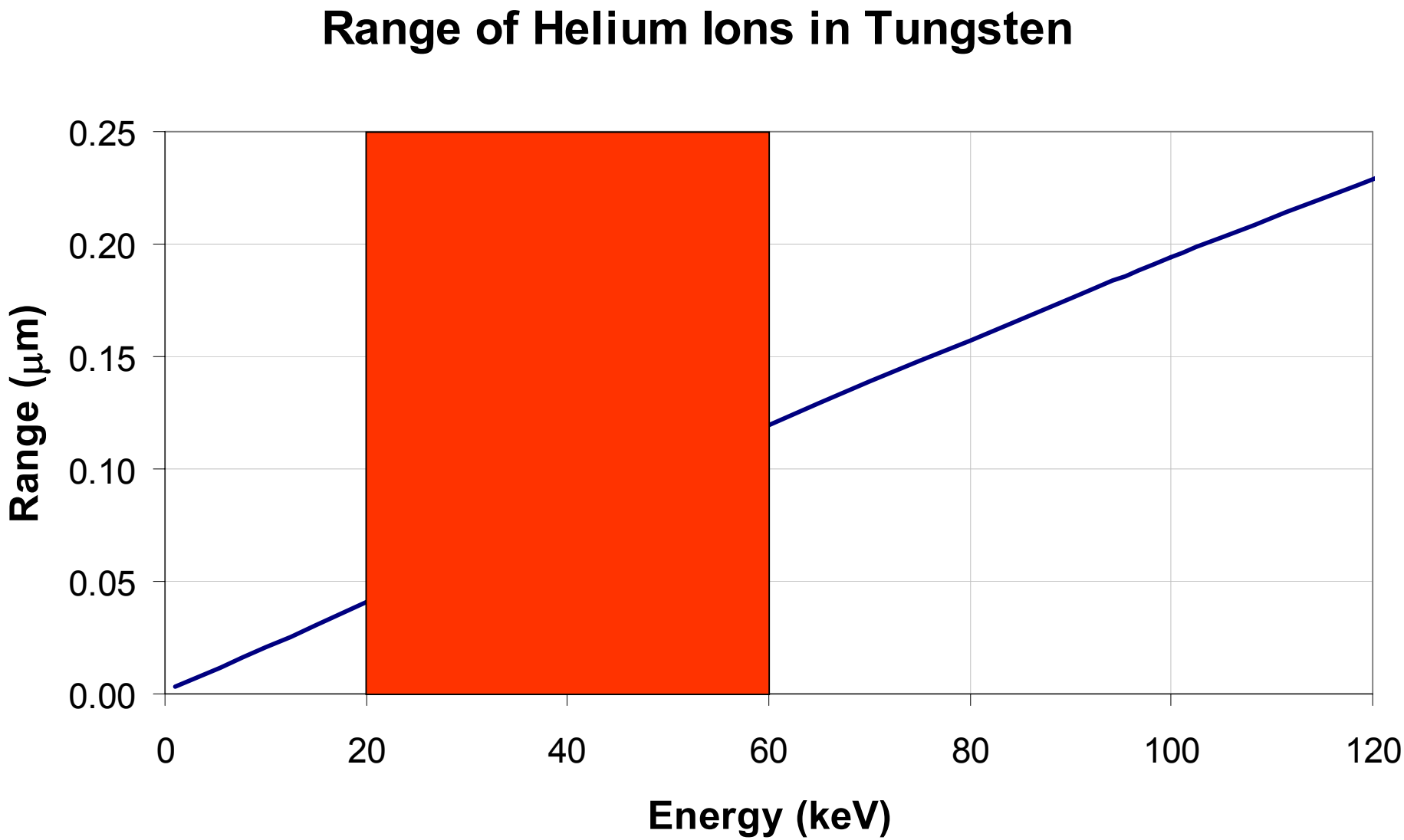
Some Interesting Numbers

- HAPL total He dose (5 Hz, 10.5 m radius) is ≈ 6 x 10^{12}/cm^2 per pulse (3 x 10^{13}/cm^2s ave.)
- IEC steady state He flux @ 6 mA ≈ 10^{14}/cm^2s
- IEC pulsed instantaneous He flux (10 Hz, 1 ms, 60 mA) ≈ 10^{13}/cm^2 per pulse--->(≈ 10^{16}/cm^2s)

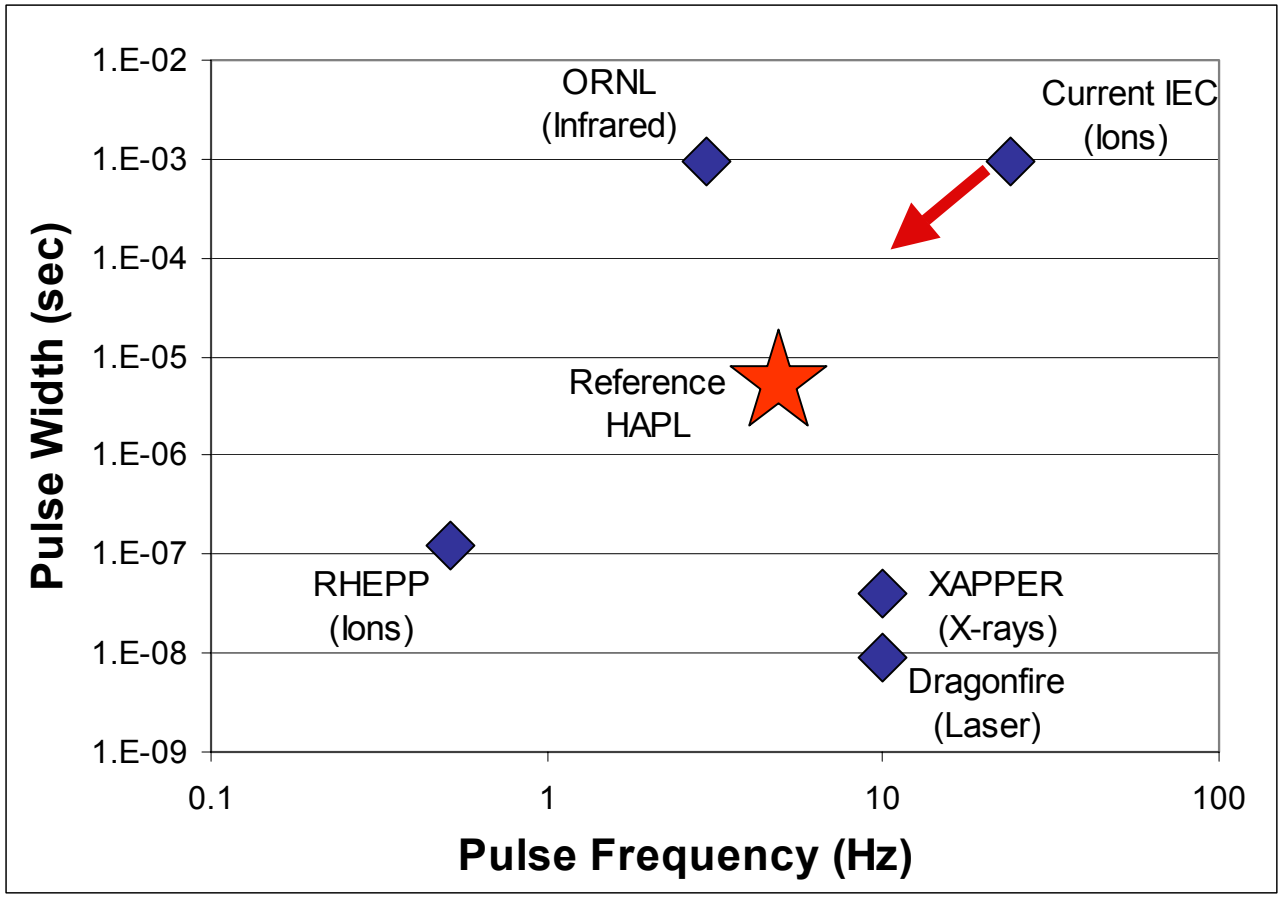
The IEC Voltage Capability Covers Nearly 25% of the Ions at the First Wall



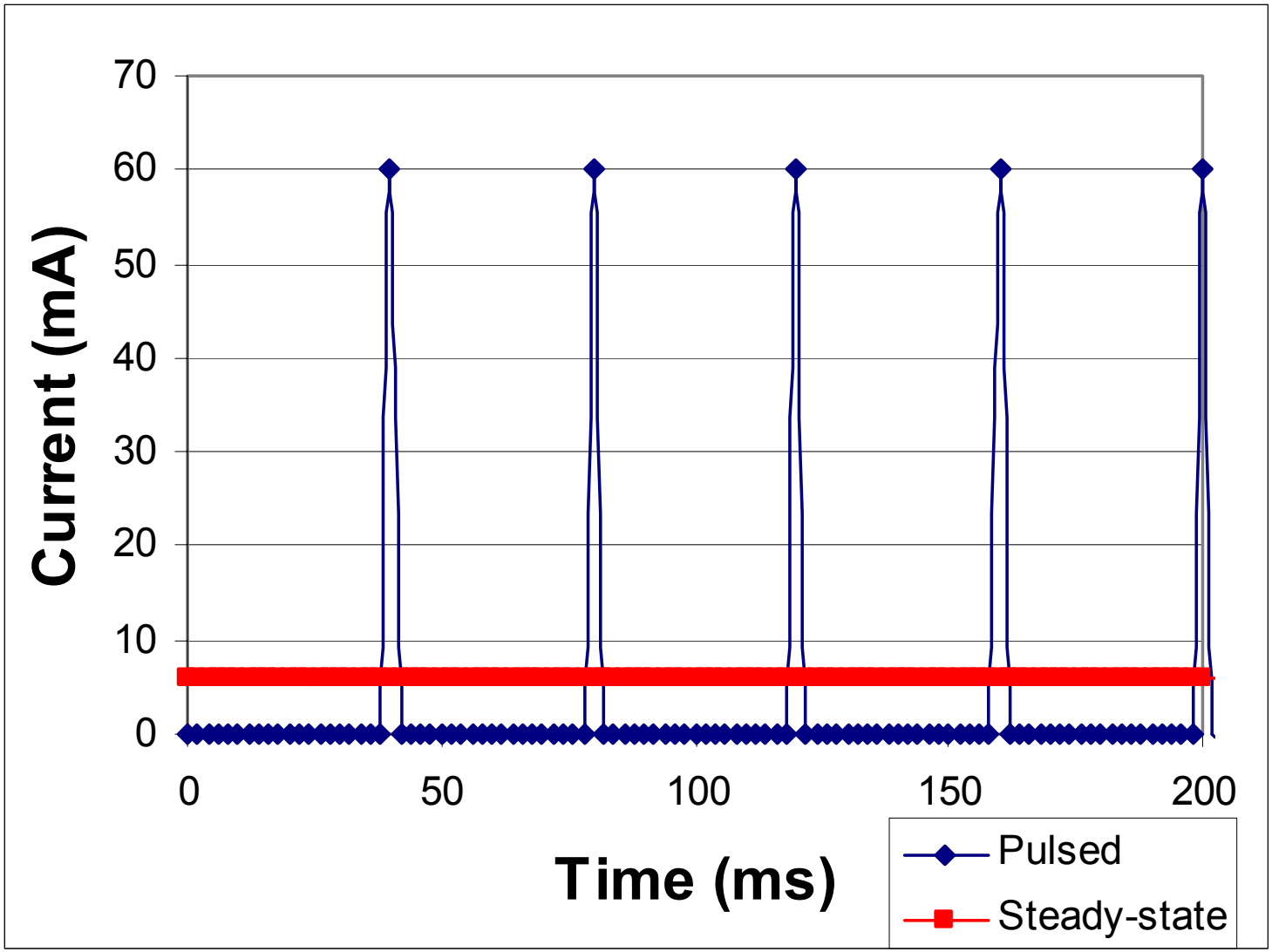
Implantation Covered a Small Range of the Helium Energy Spectrum



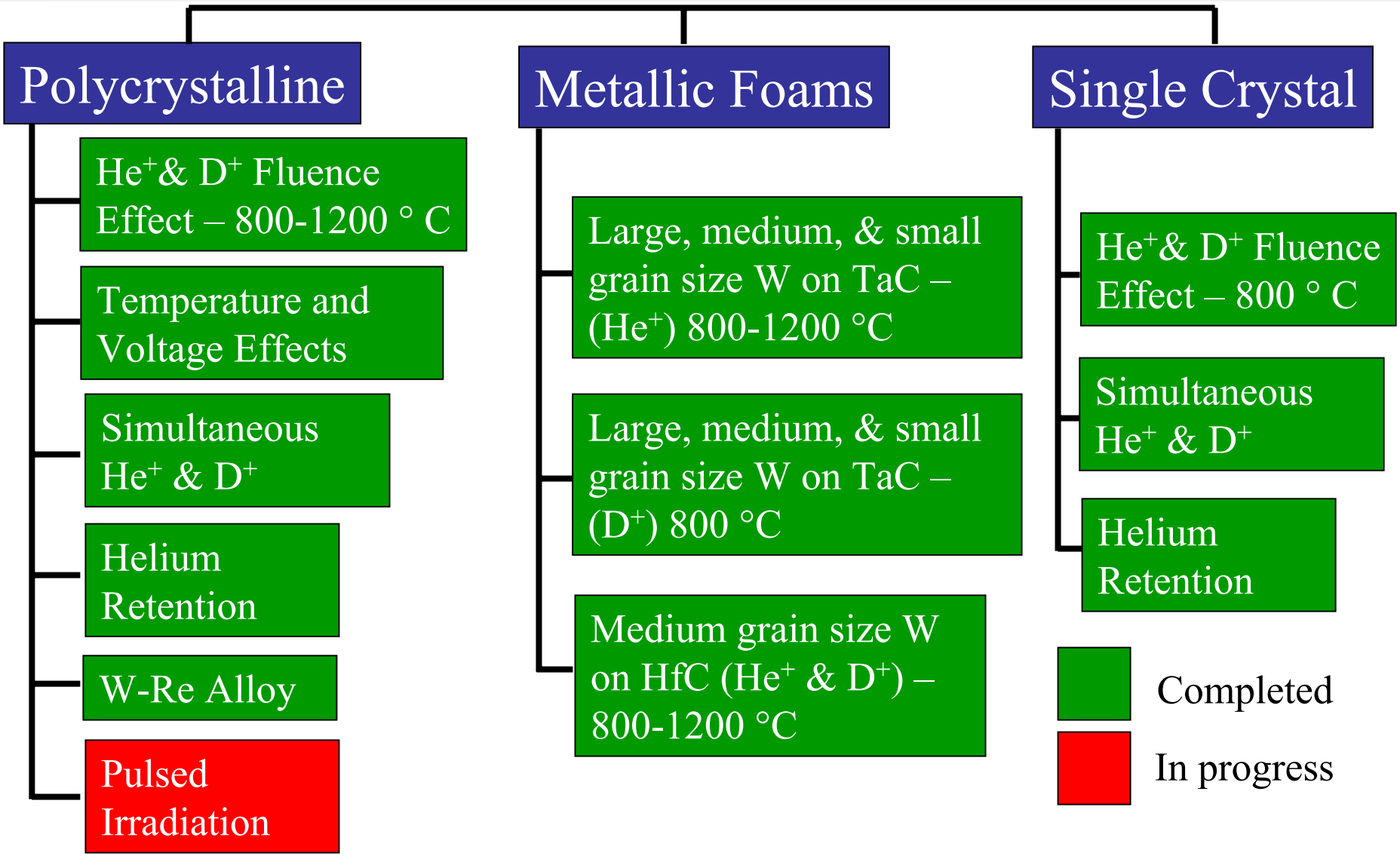
- Expand pulsed operation to pulse widths that are closer to Reference HAPL conditions

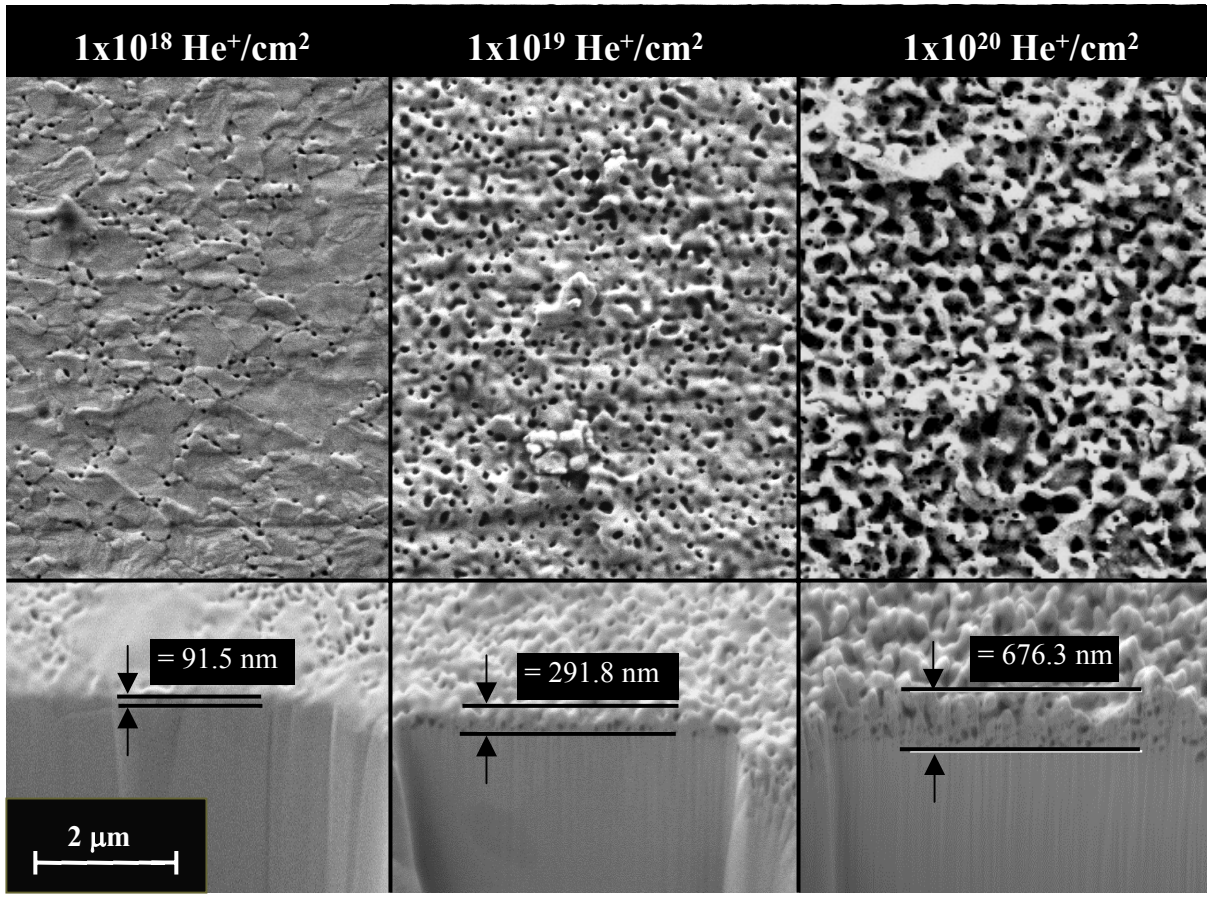


Pulsed IEC Irradiation Better Simulates HAPL Flux

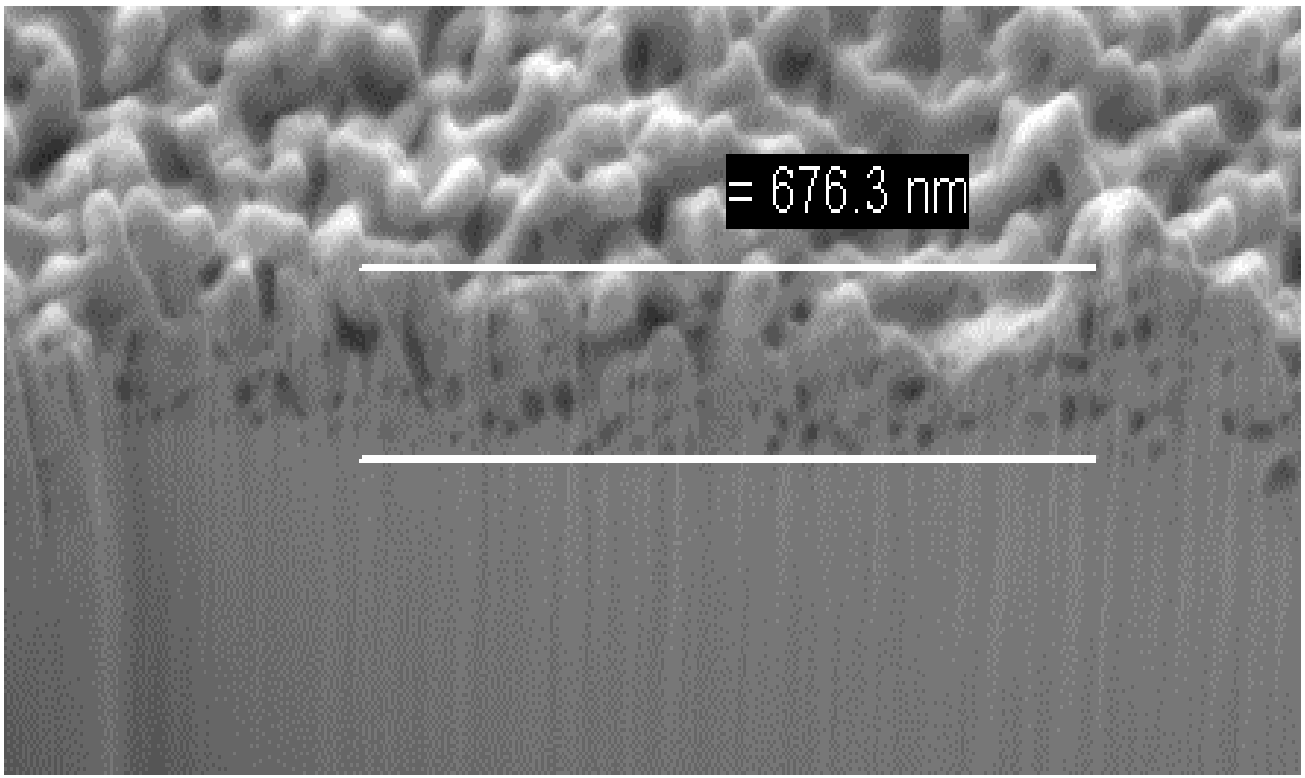


The Campaign to Assess Ability of W Coatings to Operate in HAPL Environment is Proceeding




1x10^18 He+/cm2
1x10^19 He+/cm2
1x10^20 He+/cm2
= 91.5 nm
= 291.8 nm
= 676.3 nm
2 μm

10^{20} He^{+}/cm^{2} steady-state (~1150 °C)



IEC Ion Implantation Process