Implantation of D^+ and He^+ in Candidate Fusion First Wall Materials

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Background

Motivation

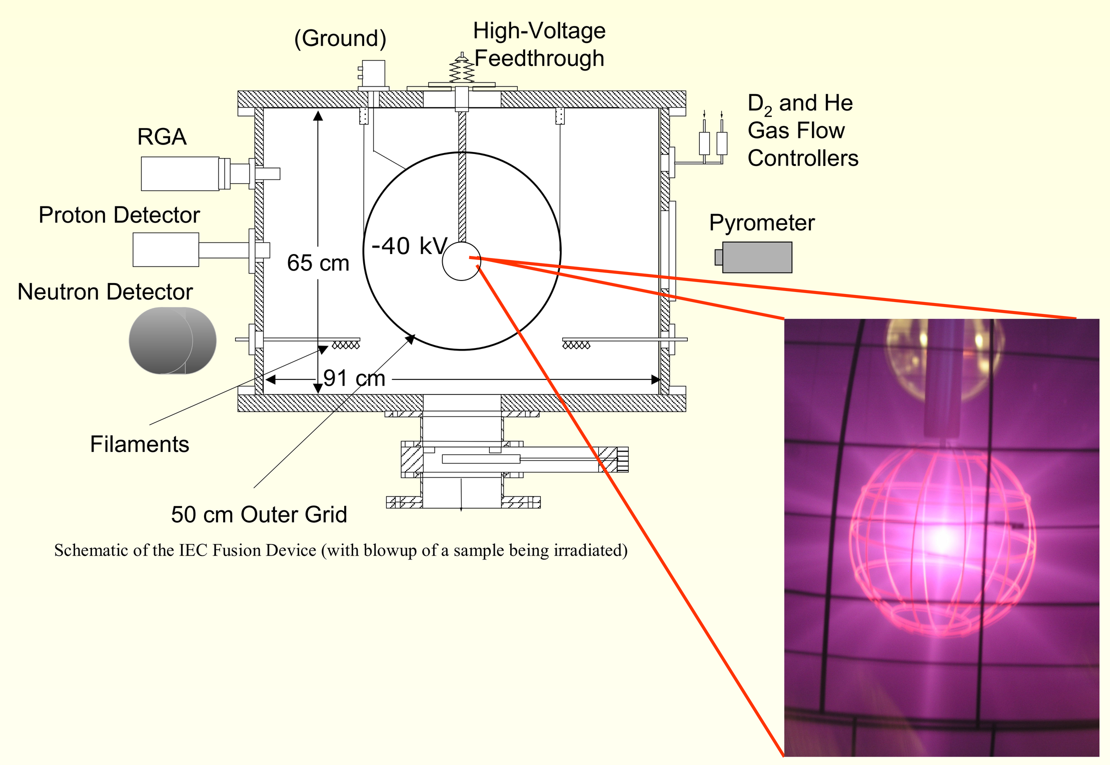
The durability and lifetime of thin tungsten coatings on the first walls of inertial and magnetic confinement fusion reactors is a key issue for the feasibility of such devices. Past studies at UW-Madison have indicated that tungsten coatings, when subjected to He^+ fluences in excess of $4x10^{17}$ He^+/cm^2, show extensive pore formation at 800 ºC. The current study has investigated alternative forms of tungsten for future use in fusion devices.

High Average Power Laser Program

Scientists from across the country are carrying out a multidisciplinary program to develop technologies for fusion energy and defense applications. This work is part of an ongoing effort to develop fusion first wall technology in conjunction with the HAPL program

The Electra KrF Laser Facility at NRL (Courtesy U.S. Naval Research Lab)

Inertial Electrostatic Confinement



Schematic of the IEC Fusion Device (with blowup of a sample being irradiated)

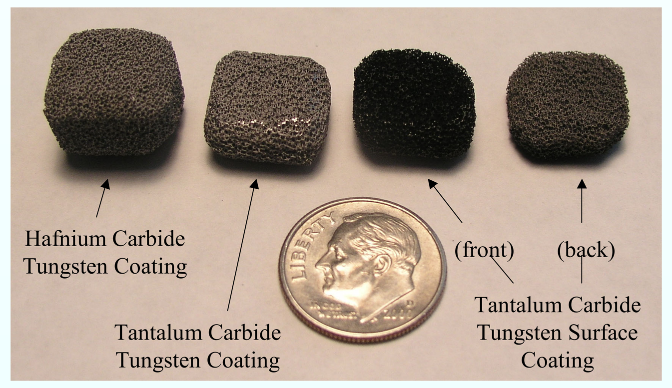
Example of a Sample Mounted in the IEC

The IEC fusion device was modified to conduct this set of experiments. The inner grid was replaced by solid target samples. The device was then run at lower pressure to ensure a more uniform ion energy distribution impacted the samples.

Experimental

As-Received Samples

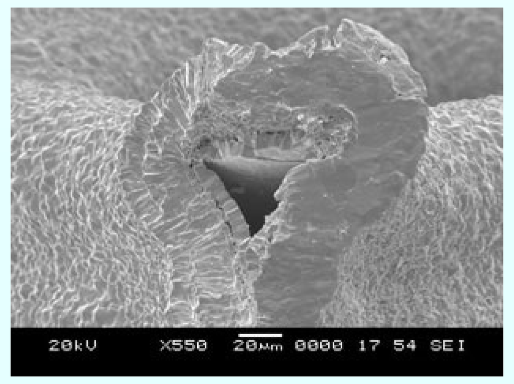
Single Crystal Sample Shown with a Dime



As Received HfC, TaC, and "High ε" Samples

Samples have been received both directly from HAPL scientists and from Ultramet, a manufacturer of tungsten coated foam. SEM micrographs were taken of all samples both before and after irradiation in the IEC

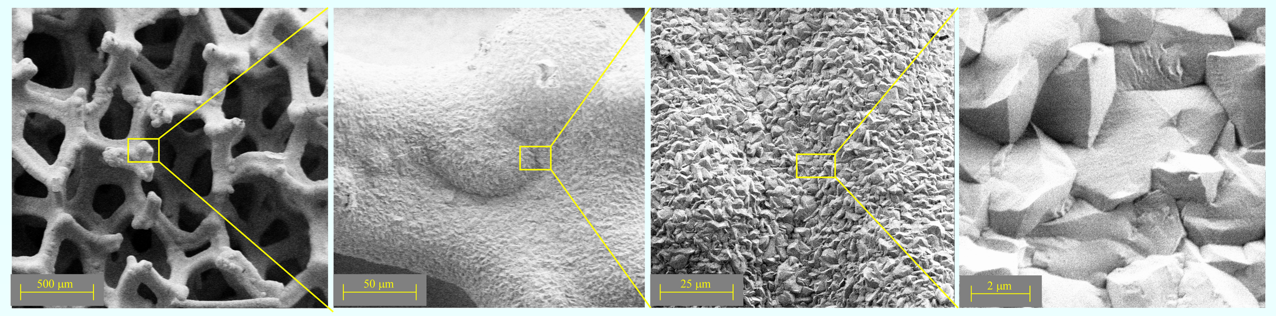
Cross-Section of Foam Ligaments



SEM micrograph of individual W foam ligament fracture surface (hollow TaC core). Reprinted with permission from Ultramet

The Ultramet samples are composed of a hollow TaC or HfC core with a chemical vapor infiltration technique used to coat the core with tungsten. The "high ε" foam has an extra layer of "black" dendritic W particles coating the sample.

SEM Micrographs of W-Coated Foam



SEM Micrographs. These shots show successive zoomed in views of the Ultramet Foam. The final picture reveals the small-scale structure of the tungsten coating.

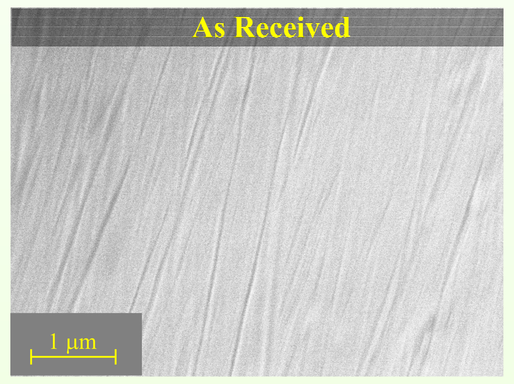
This series of micrographs of an as-received HfC sample shows the complex structure of the Ultramet Foam. The three types of foam appear similar at 50X magnification (the first picture), but vary significantly at higher magnification, as seen in the Results section.

Experimental Summary

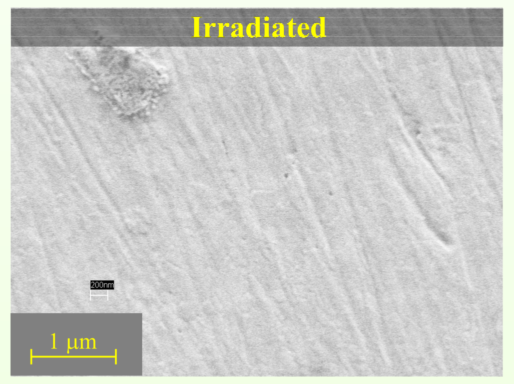
Sample	Ions	Fluence (#/cm2)	Temperature (C)	Voltage (kV)
W-1	$^4He^+$	$6x10^{17}$	1100	40
W-2	$^4He^+$	$4x10^{16}$	1100	40
TaC-1	D^+	$>6x10^{17}$	800+	up to 50
TaC-2	$^4He^+$	$6x10^{17}$	830	30
TaC-4	---	---	1200	---
HfC-1	$^4He^+$	$6x10^{17}$	775	30
HfC-4	---	---	1200	---
TaC-1 (high e)	$^4He^+$	$6x10^{17}$	varied	30
TaC-4 (high e)	---	---	1200	---
Single Crystal	$^4He^+$	$4x10^{16}$	830	30

Results

Single Crystal Tungsten Sample

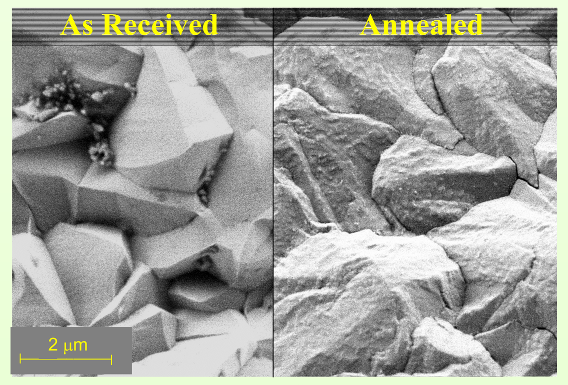


As Received Single Crystal Sample

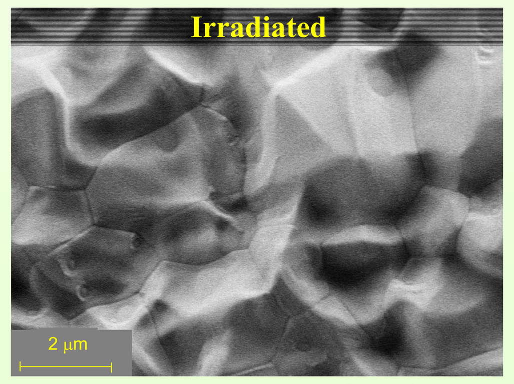


Single Crystal Sample Irradiated at 800 C with a $4x10^{16}$ He^+/cm^2 Fluence

D^+ Implantation

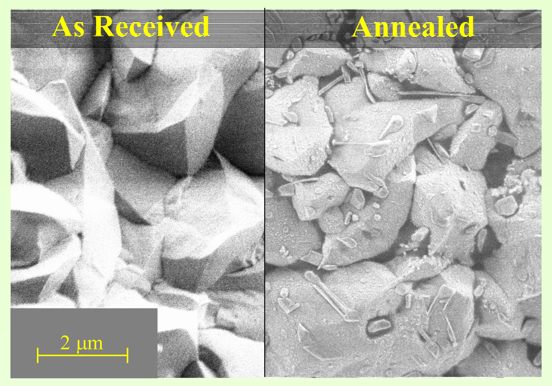


TaC Sample Before and After Annealing at 1200 C for 30 Minutes

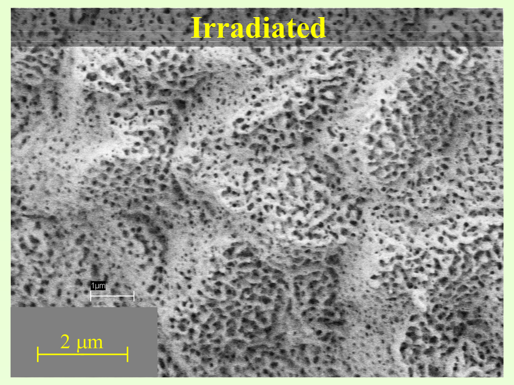


TaC Sample Irradiated at 830 C with > $6x10^{17}$ He^+/cm^2 Fluence

He^+ on TaC and HfC Foams



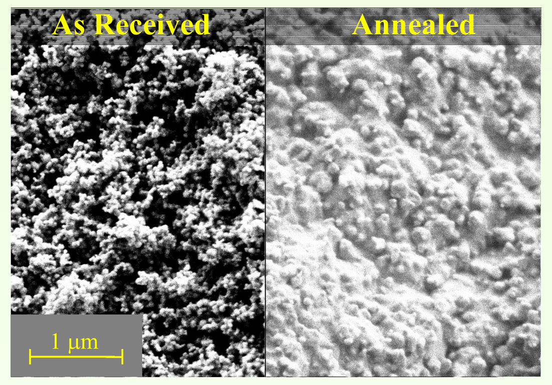
HfC Sample Before and After Annealing at 1200 C for 30 Minutes



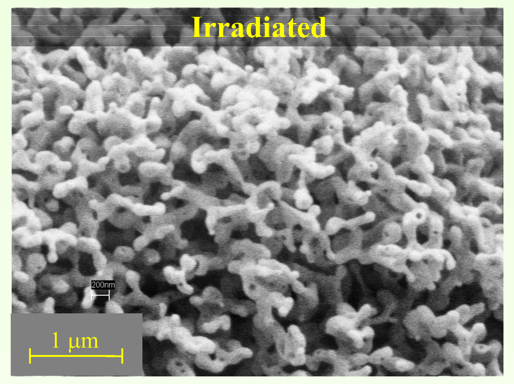
HfC Sample Irradiated at 775 C with a $6x10^{17}$ He^+/cm^2 Fluence

High emissivity W-Coated Foam

Deposited Side

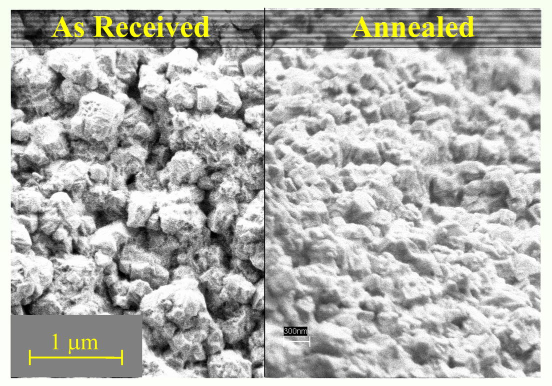


"High ε" Sample Before and After Annealing at 1200 C for 30 Minutes

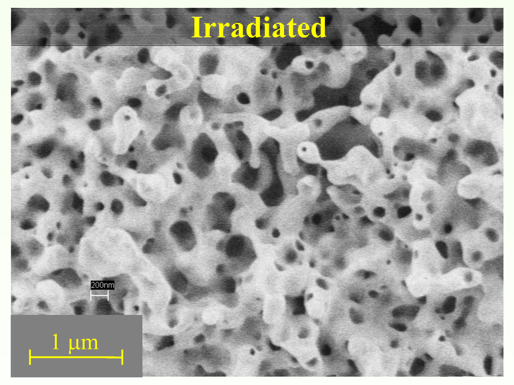


"High ε" Sample Irradiated with a $6x10^{17}$ He^+/cm^2 Fluence

Non-Deposited Side



"High ε" Sample Before and After Annealing at 1200 C for 30 Minutes



"High ε" Sample Irradiated with a $6x10^{17}$ He^+/cm^2 Fluence

Conclusions

Single Crystal

- At a fluence of $4x10^{16}$ He^+/cm^2, single crystal tungsten showed less pore formation than polycrystalline tungsten at 800 ˚C

D^+ vs He^+ Implantation on Foam

- D^+ implantation on TaC foam at $>6x10^{17}$ ions/cm² showed no pore formation at 830 ˚C
- When subjected to a $6x10^{17}$ He^+ fluence at 800 ˚C, both TaC and HfC samples showed pore formation similar to polycrystalline samples

High Emissivity (ε) W Foam

- The uncoated side of the "high ε" foam showed similar damage to the TaC and HfC foams when subjected to fluences of $6x10^{17}$ He^+/cm^2
- The coated side showed growth in the tungsten dendrites

Future Work

Single Crystals

- High fluence irradiations at varying temperatures will be performed to determine the behavior of pore formation

TaC and HfC Foams

- Fluence and temperature ranges will be expanded to evaluate foam performance as compared to poly-crystalline samples

Tungsten Rhenium

- Polycrystalline W-25%Re samples will be used to evaluate the performance of these samples for temperatures ranging from 700 – 1200 ˚C