RHEPP-1 Ion Exposure
and Z X-Ray Exposure Update

Tim Renk
Sandia National Laboratories
Beam Applications & Initiatives Department

HAPL Program Workshop
Washington, DC
March 3-4, 2005

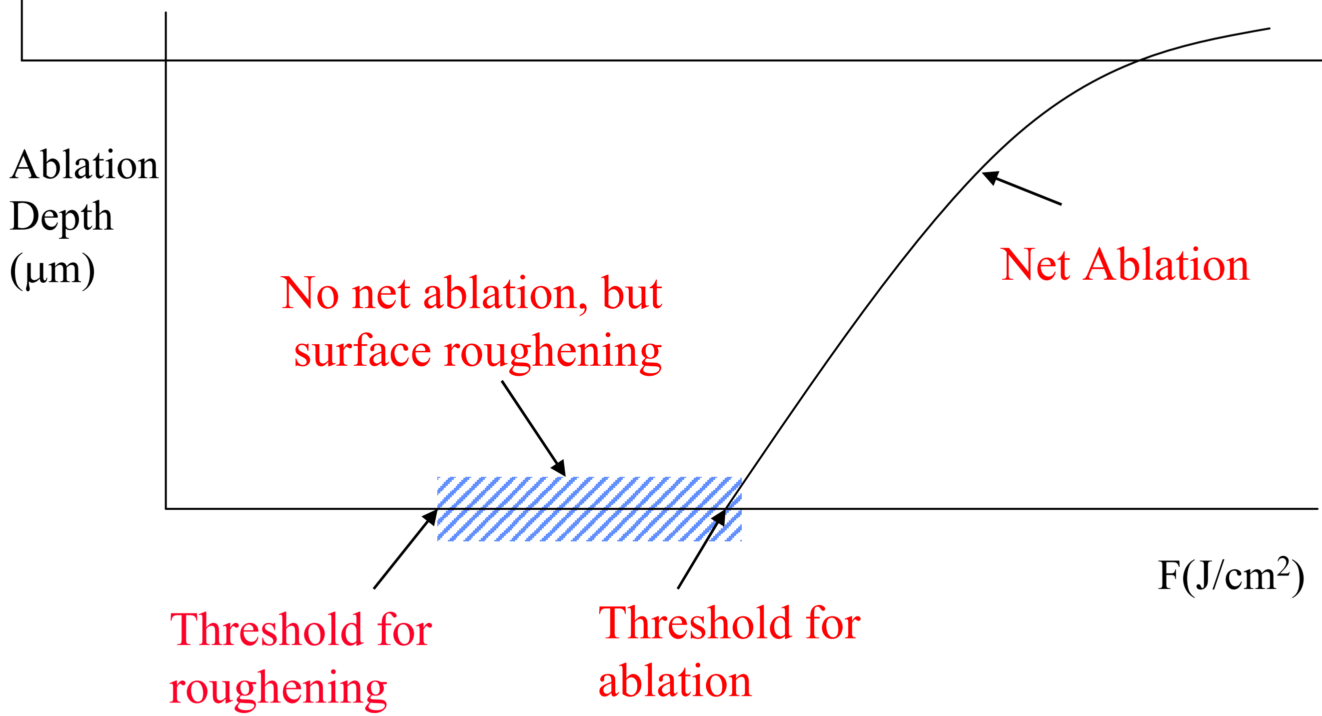
Supported by NRL by the HAPL program by DOE NNSA DP

Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy under contract DE-AC04-94AL85000.

Presentation Outline

- RHEPP - Z series: background briefing
- Z data: latest roughening threshold behavior for W
- Whither Baklava
- New RHEPP Super KS 2000 Series

Regimes of IFE Materials Response Studies for x-rays and ions



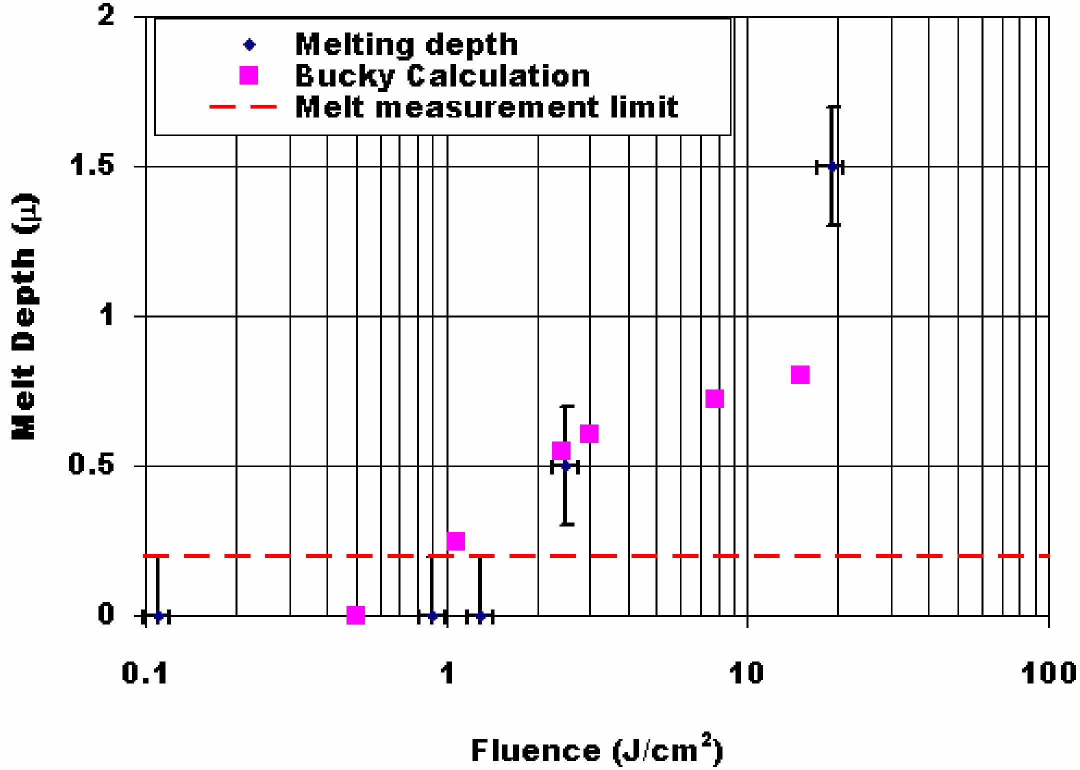
Goals (for each material):

- examine net ablation to validate codes
- find threshold for ablation
- understand roughening
- find threshold for roughening

Effect of X rays from Z on Tungsten: Surface Roughness

- Exposed tungsten samples to various fluence levels in Z machine with single shots.
  - Varied source-to-sample distance
  - Filter material: 8mm Be and 2mm Mylar
- Obtained polished tungsten from Lance Snead prepared in 3 different ways:
  - single crystal,
  - rolled powdered metal, and
  - chemical vapor deposition
- Preheated tungsten to 600° C
- Analyzed surfaces with
  - optical surface profilometer,
  - Scanning electron microscope (with backscatter detector) and
  - focused ion beam

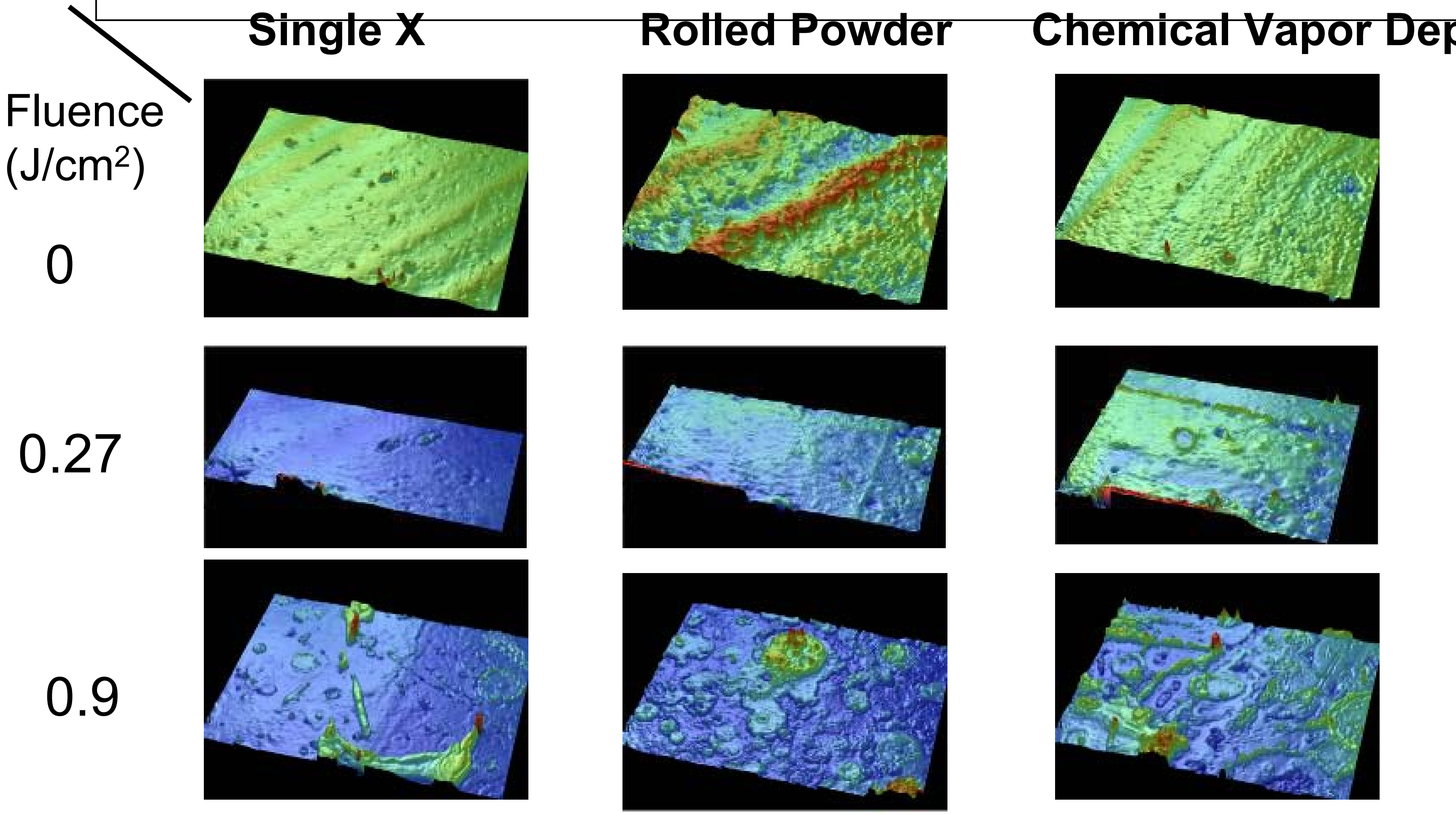
Melt depth vs. Fluence on Z



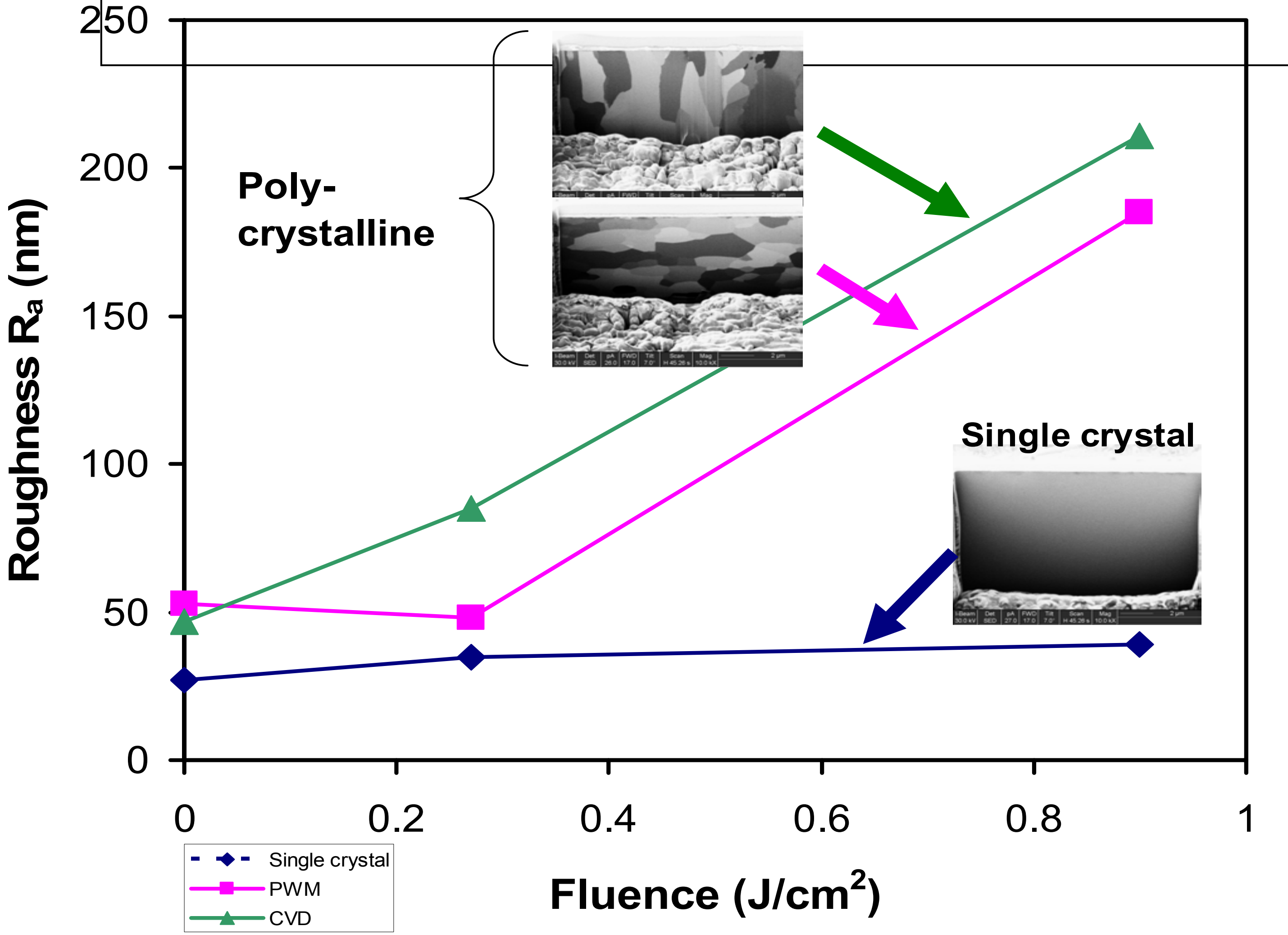
•Experimental points (error bars) and BUCKY calculation (squares) using filtered fluence numbers.

•For melt depths < 0.2 (dashed line), melt depth < crystal grain size, so may or may not result in observable effect

Images from samples on Z from VEECO surface profiler



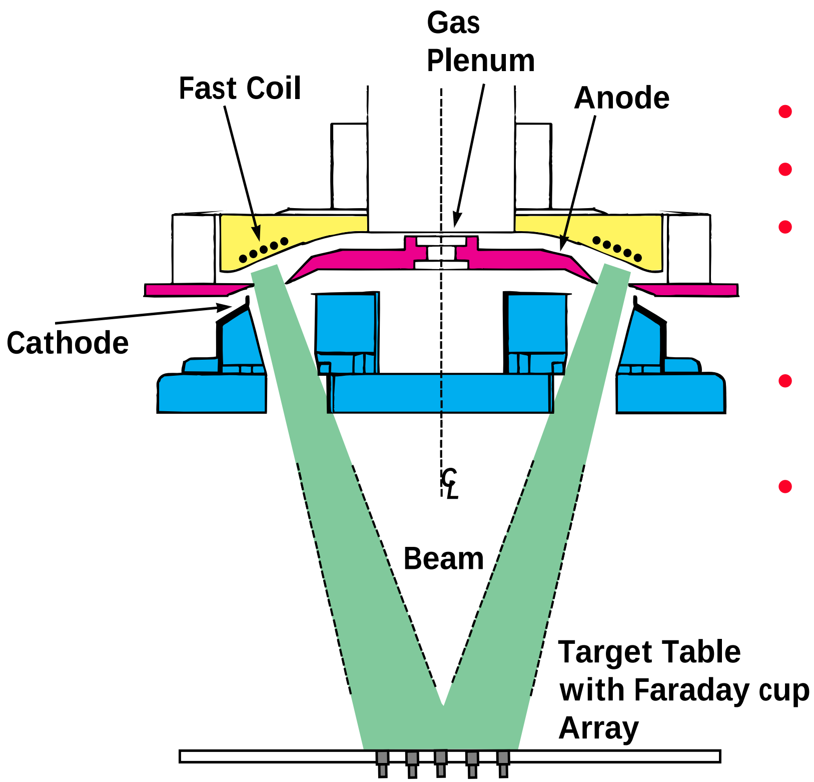
Roughening Depends on Fluence and Grain Boundaries



The roughening threshold is ~0.9 J/cm^2 for single crystal and is ~<0.3 J/cm^2 for polycrystalline tungsten

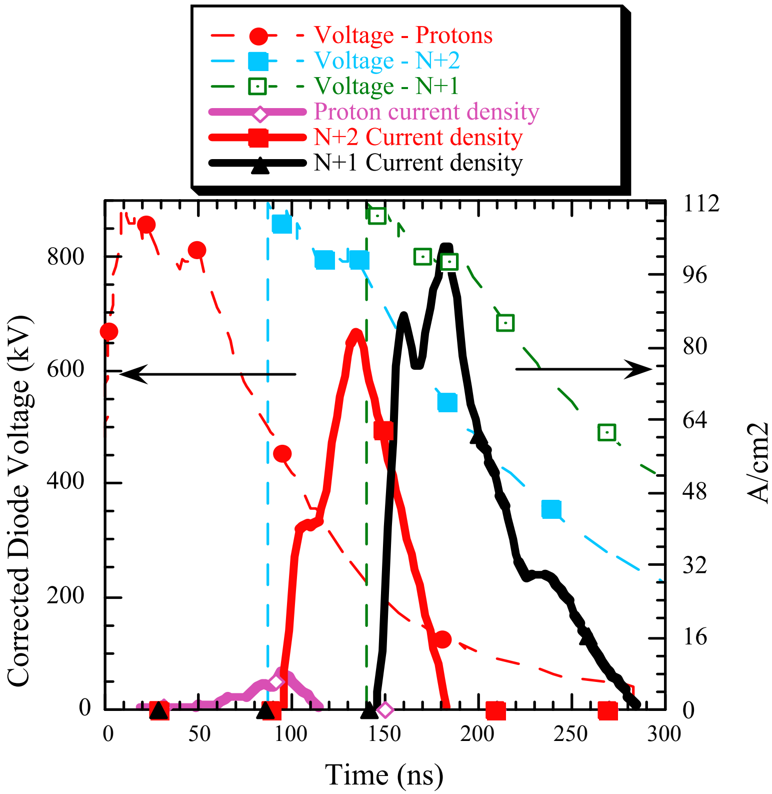
Sandia National Laboratories

The MAP (Magnetically Confined Anode Plasma) Ion Source is used for surface modification experiments on RHEPP-1



- 600-800 kV
- < 250 A/cm^2
- Beams from H, He, N_2, O_2, Ne, Ar, Xe, Kr, CH_4
- Overall treatment area ~ 100 cm^2
- Diode vacuum ~ 10^{-5} Torr

Nitrogen injection into MAP produces 3-component beam of mostly N++, N+



Shot 31661

- Beam predominantly N++ and N+ after small proton pulse at front
- Peak voltage = 850 kV
  Peak current density (total) ~145 A/cm²
- Total fluence = 7.9 J/cm² - will ablate almost all materials
- Total pulse width ~ 200 ns
- Ion range (TRIM):
  - N+ 0.9 μm, N++ 1.2 μm
- Oxygen, Neon beams similar

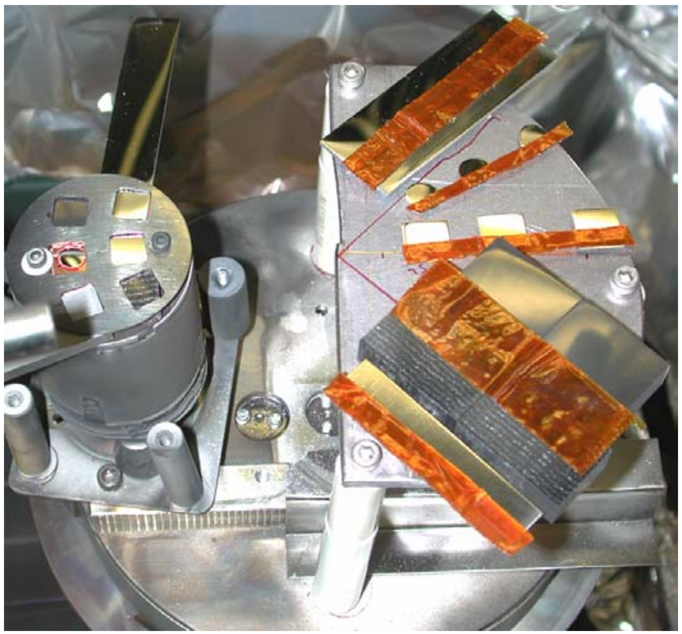
Sandia National Laboratories

Thresholds for Materials exposure to ions on RHEPP

- 6 J/cm^2 — Ablation threshold, W
- 3 J/cm^2 — Ablation threshold, graphites, BUCKY and expt
- 2.0 J/cm^2 — Melting threshold, W, 600C, SIM and expt
- 1.25 J/cm^2 — Roughening threshold, PM W (Schwarzkopf), unheated
- ? Roughening threshold, Graphite
- 0

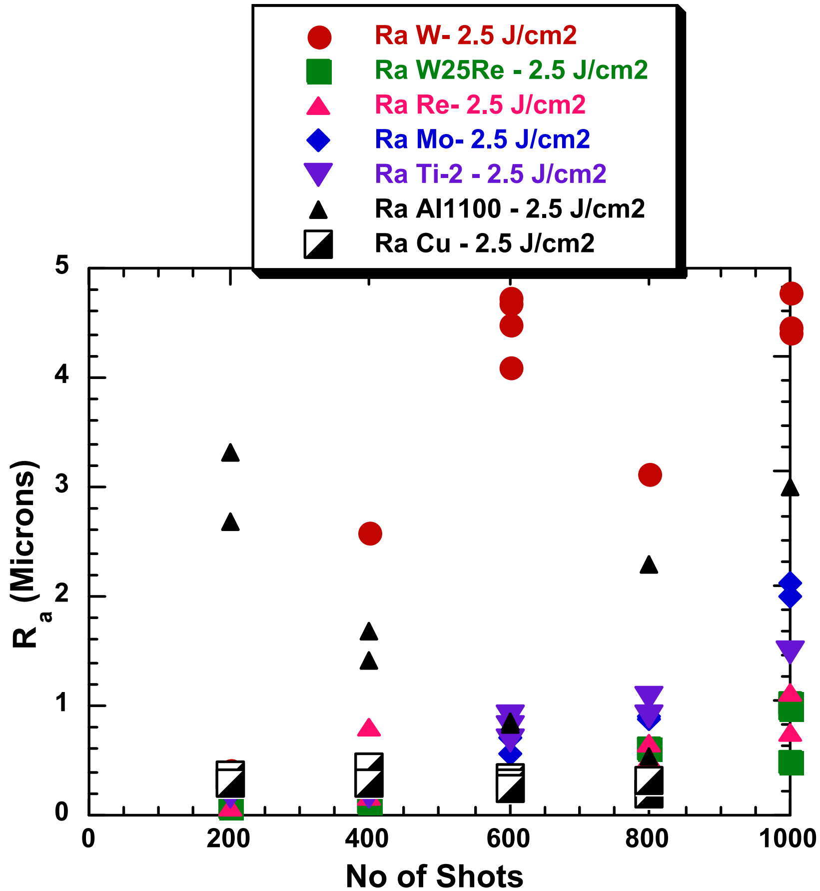
- General exposure conditions: MAP nitrogen beam, 150 ns pulsewidth, single shot.
- Roughening threshold for graphite (matrix) is unknown, but probably below 0.5 J/cm^2
- Roughening threshold for W for He beam is below that for MAP N
- Roughening threshold (Single Pulse), unheated, for
  - W25Re: 3.5 J/cm^2
  - Re: 1 J/cm^2

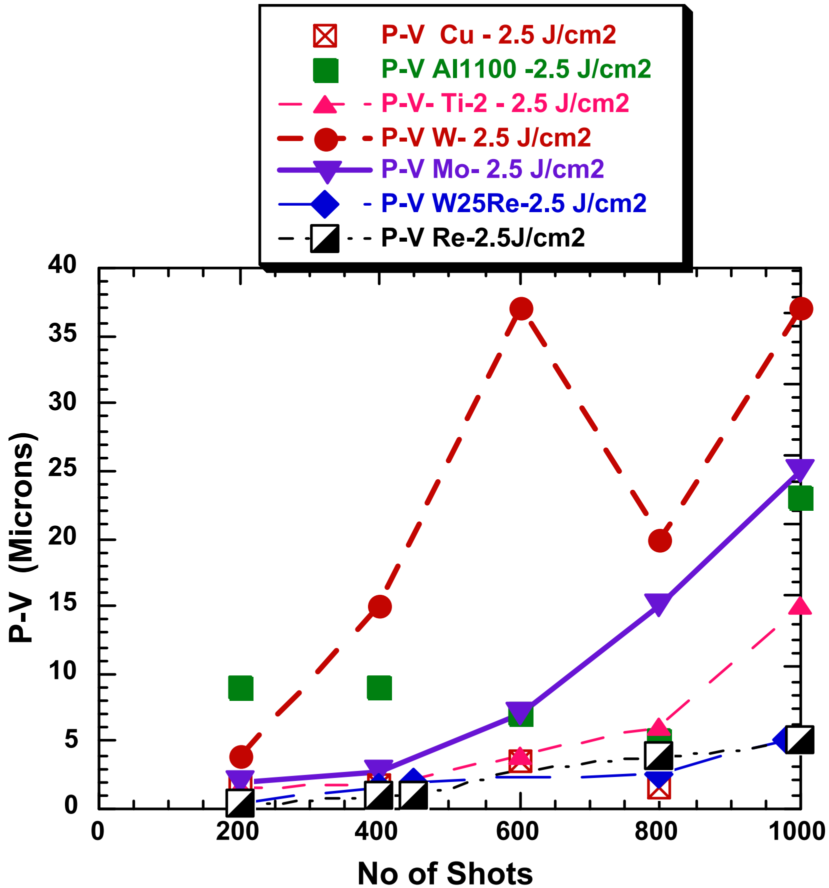
2000 shot ‘SuperKS’ Series: Metals and graphite, RT/520C Roughening and fatigue propagation study



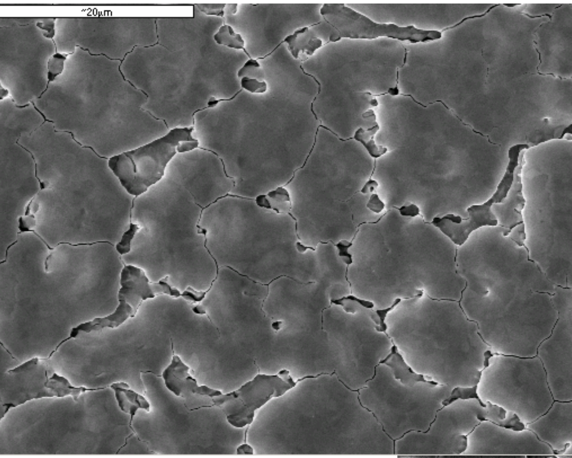
- Goals: Test below-melt response, explore if roughening saturates, study crack propagation, sample separately 400 through 2000 pulses, every 400 pulses
- Upper Photo shows 6-element heated samples (left), RT samples (right). Heated samples below melting, RT below/above
- Lower photo shows Heated samples: CFC NB31, PMW (Snead), W25Re (Rhenium Alloys), graphite R6650, Sing XtalW(Snead), WC. C samples from FZ Julich (Linke)
- Samples shot 400X, then SEM, Dektak (Renk/Tanaka), then reloaded for another 400 shots.
- RT samples: PMW, Sing Xtal W, NB31, R6650, Ti-6Al-4V, W25Re, Re

Evolution of R_a, Peak-Valley Roughness at 2.5 J/cm^2: WPowderMet is worst, then Al1100, Mo and Ti-2

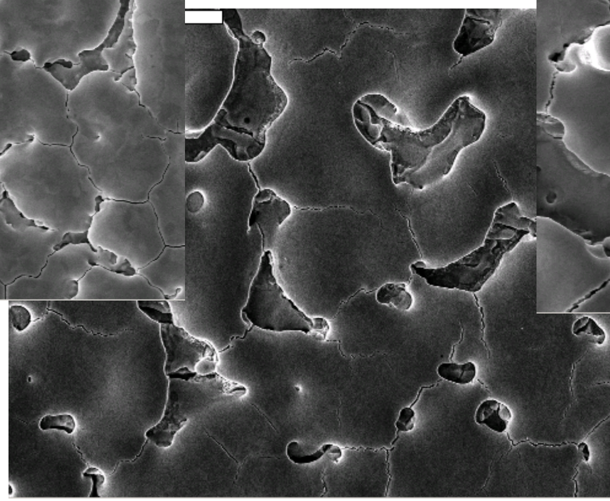




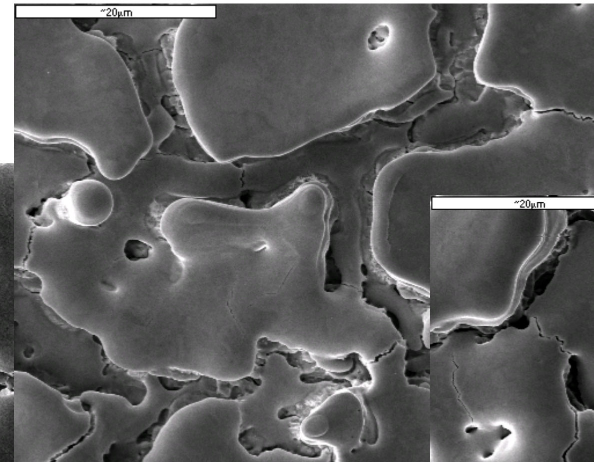
SEMs of PM Tungsten (non-melt): appears stress cracking starts, then exfoliation, forming valleys



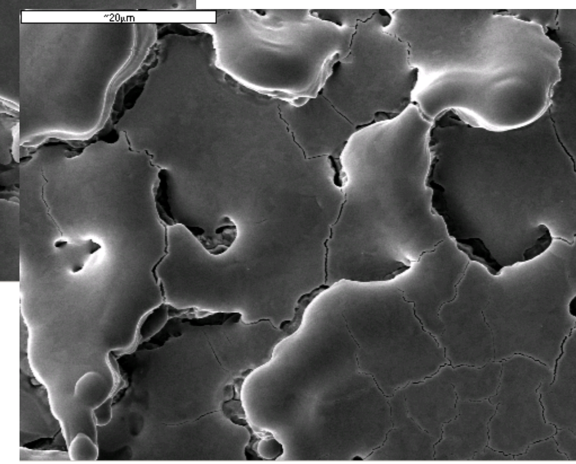
400 pulses



800 pulses



1200 pulses

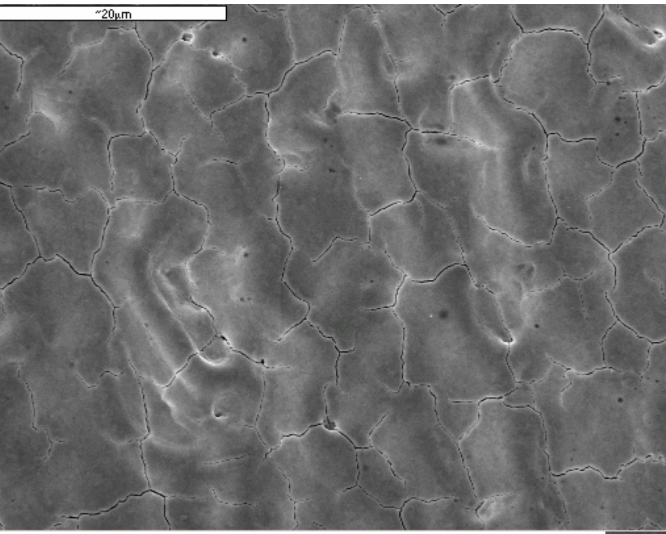


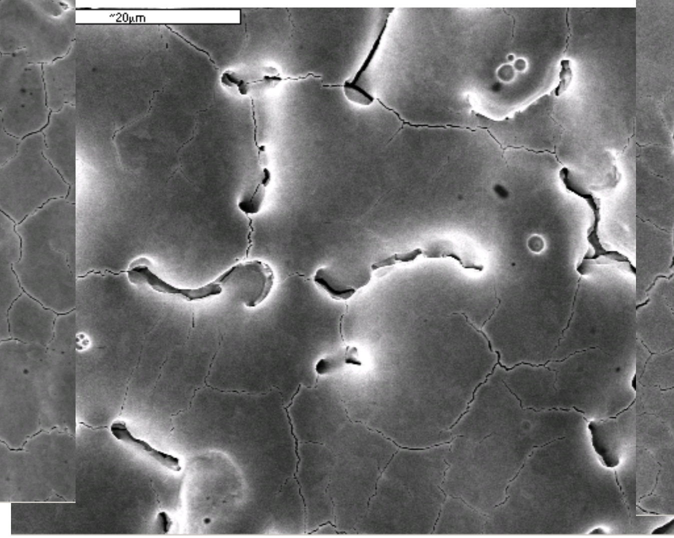
1600 pulses

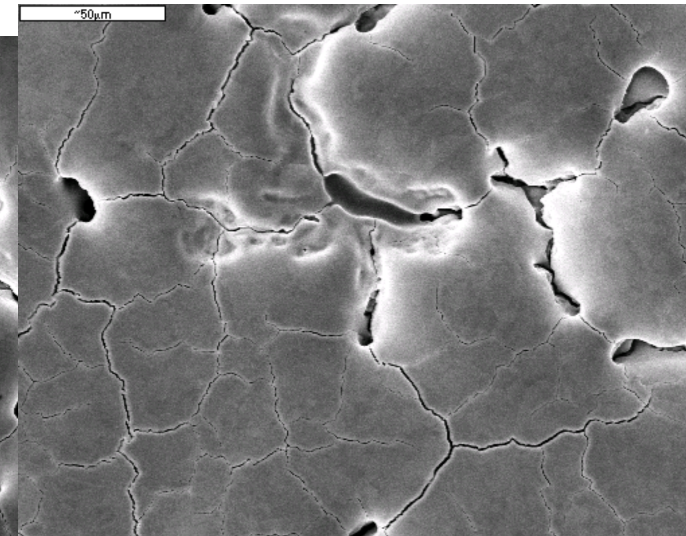
All images 2000X

- Heated PM W (600C) exposed to N beam at ~ 1.5 J/cm^2 - peak temp ~ 3300K
- General height change is UP. W25Re suffers similar but less dramatic effect

W25Re: cracking/valley formation process more muted. But is this enough of a solution?







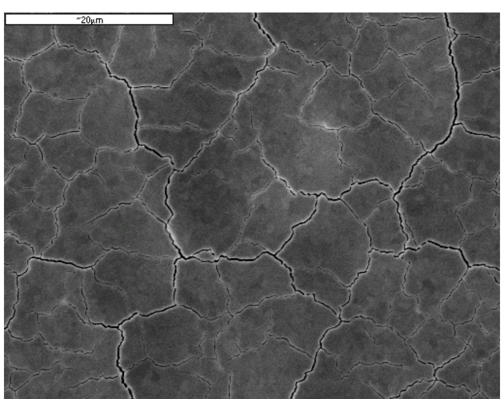
400 pulses

All images 2000X

800 pulses

1200 pulses

- **Depth of cracks in right image unknown.**

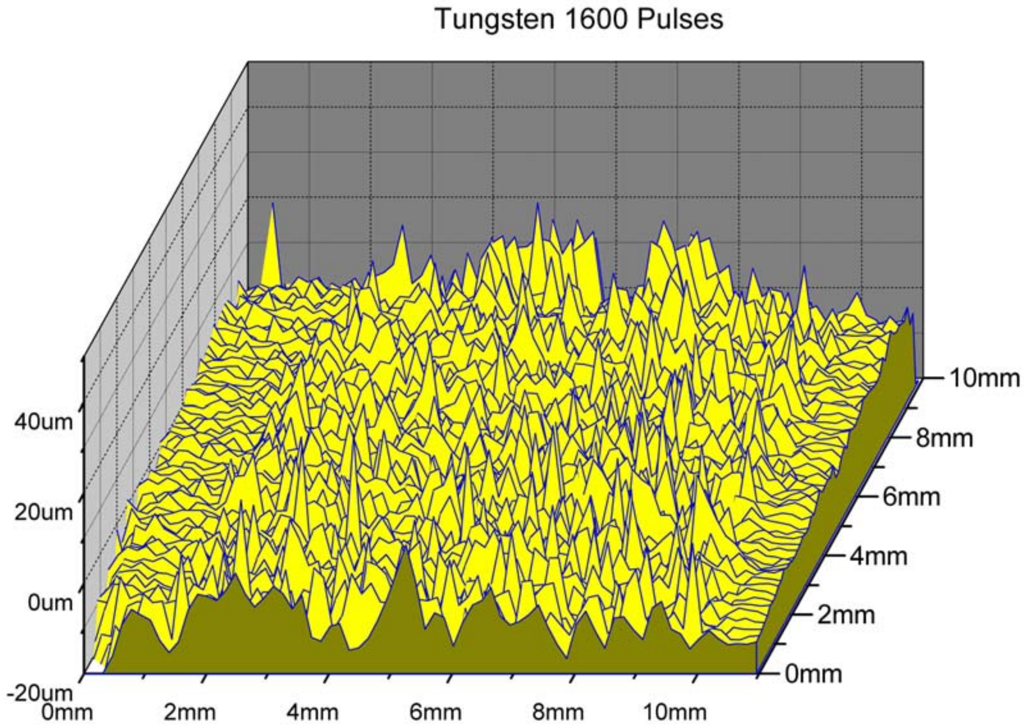


New W25Re @ 400 pulses

Materials Modification Laboratory

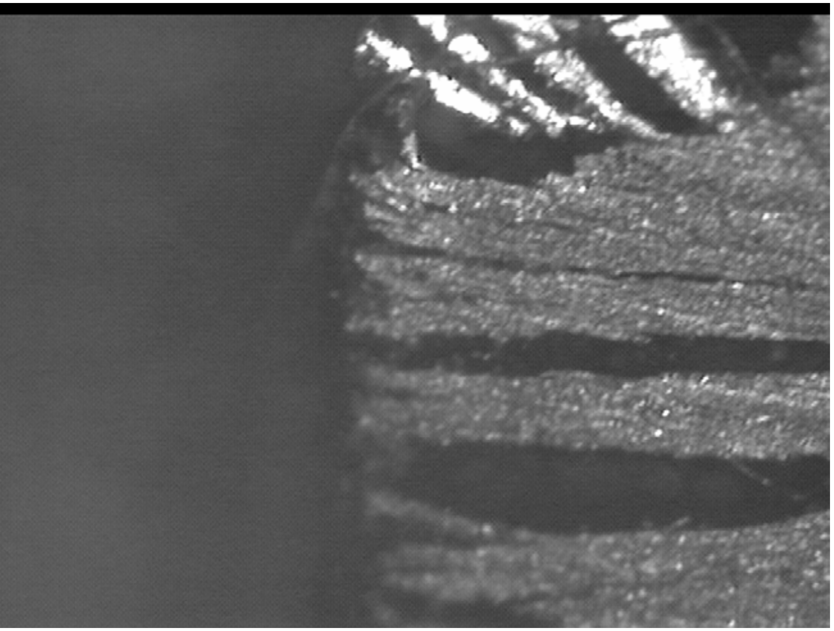
Sandia National Laboratories

PM Tungsten after 1600 pulses (non-melting): Mostly mountains

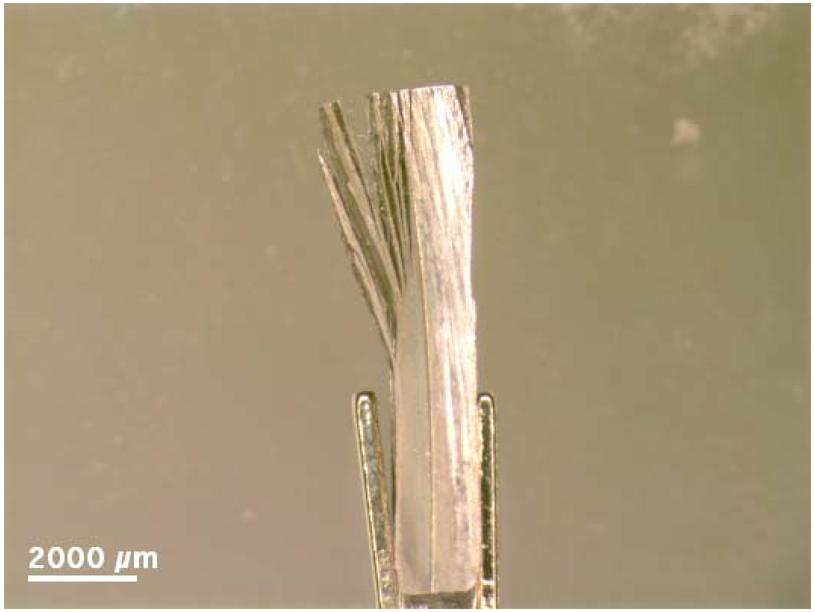


- Heated/treated PM W examined with NEXIV laser interferometry
- Comprehensive line-out scan: max height 30 μm, min height < 10 μm compared to untreated
- There is additional very deep microcracking not visible here

'Baklava': Horizontal laminar separation of treated PM W that extends far beyond heat-affected zone (~ 10 μm)

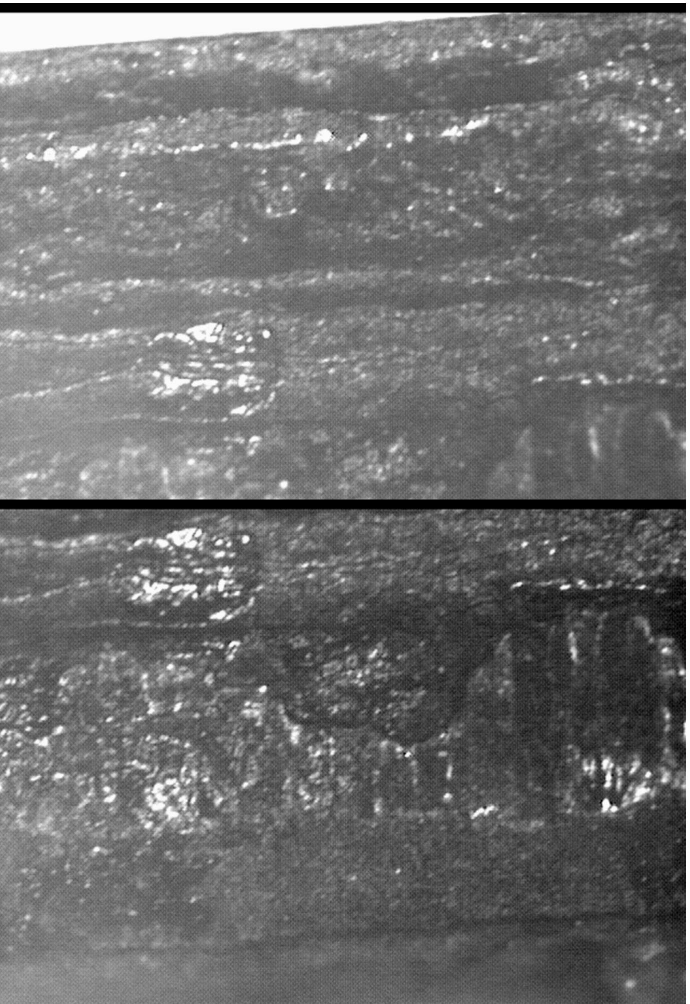


Photomicrograph, side view, PM W (Schwarzkopf), 1600 pulses, surface temp to near-melt. Vertical height ~ 1.2 mm



Side-image, PM W Schwarzkopf, 125 pulses above melt. Clip holds untreated area

Comparison, treated PMW and W25Re, side view (Uncut), 1600 pulses: 'Laminated' structure to 1mm depth on W, missing in W25Re



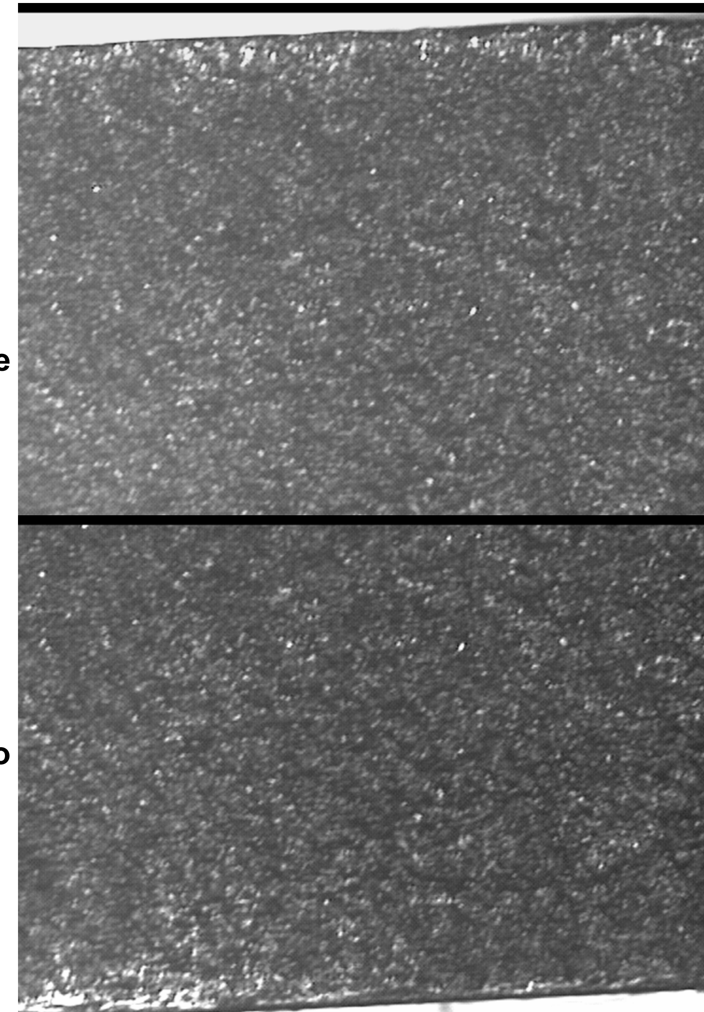
Photomicrographs, side view, 1600 pulses, surface temp to near-melt

Surface to near-middle (~ 0.8 mm)

0.8 mm to ~ 1.5 mm

Surface to near-middle (~ 0.6 mm)

0.6 mm to ~ 1.2 mm

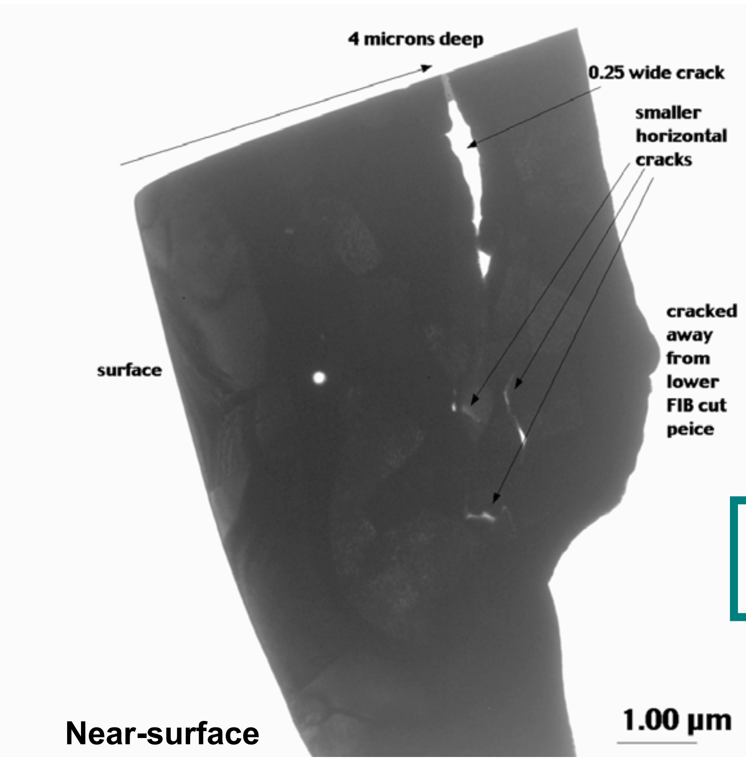


PM Tungsten: 'Baklava' effect'

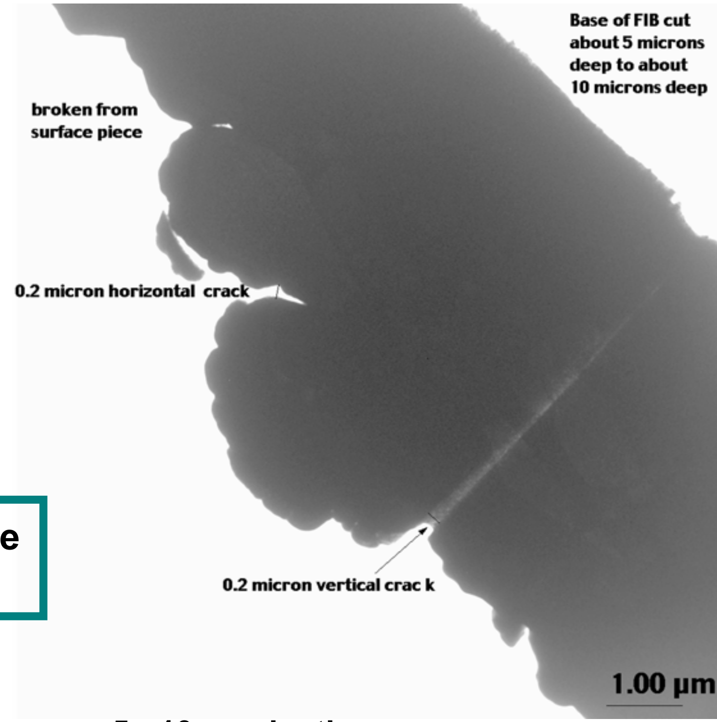
(Left): Dark horizontal lines represent possible delam areas

W25Re

FIB-XTEM of 1000-pulse W at 2.25 J/cm^2 (ave): Deep horizontal/vertical cracking without melt



Near-surface

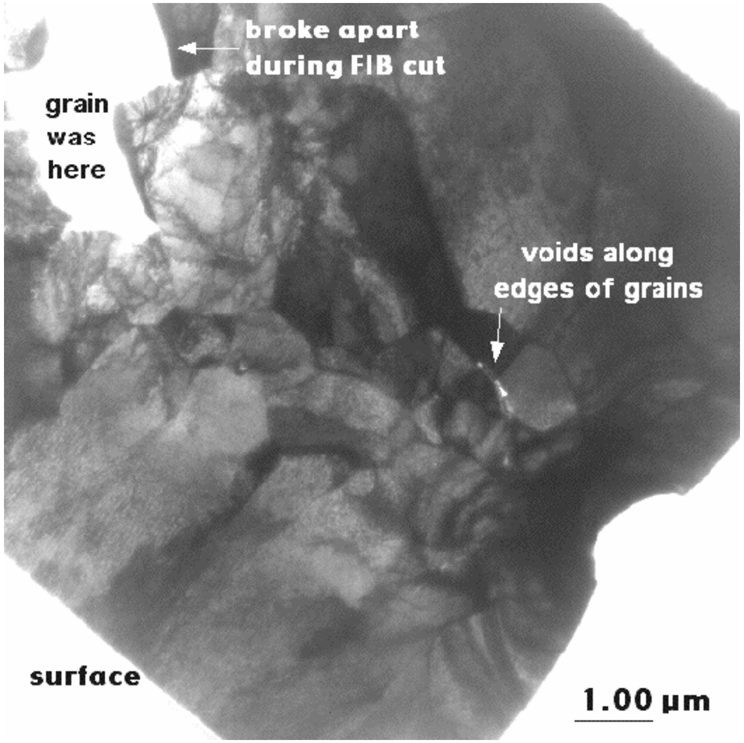


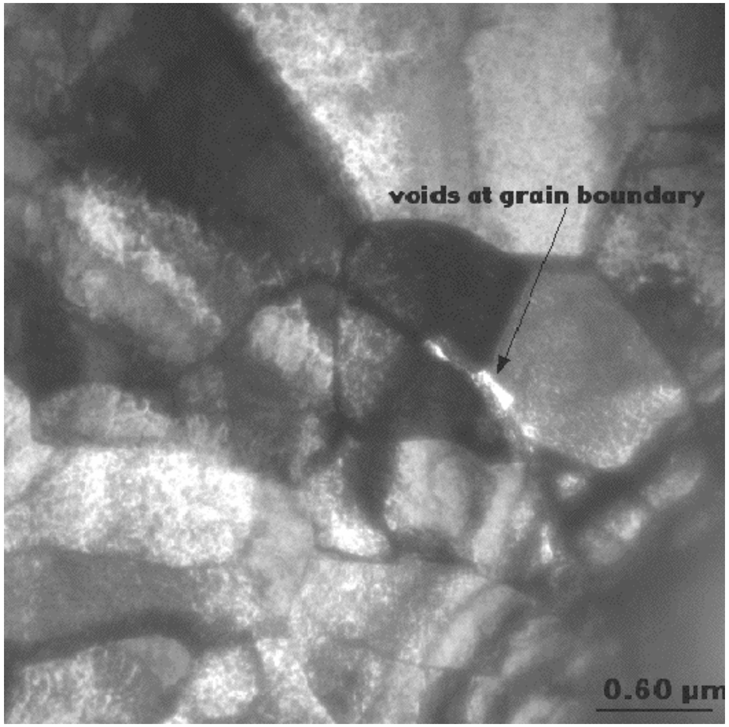
5 - 10 µm depth

Note: this FIB Sample Fell apart

- **Polished Powder Met W exposed to 100 shots N beam @ 2.25 J/cm^2 ave /pulse, ~ melting temperature at surface. No melt layer observed.**
- **600°C exposure**
- **Sample cracking horizontally/vertically down to 10 µm depth**
- **Suspect fatigue-cracking**

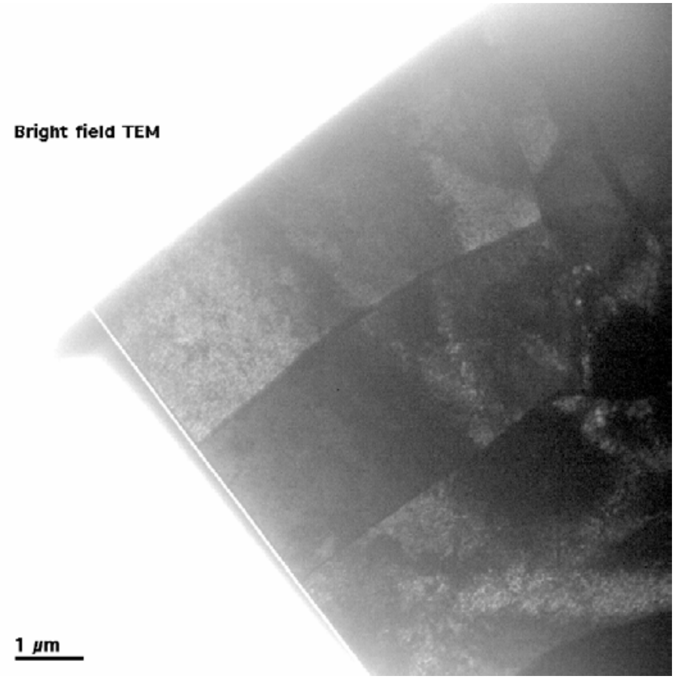
FIB-XTEM of 600-pulse Mo at 4.5 J/cm² (ave): Voids at grain boundaries, but no Baklava/falling apart



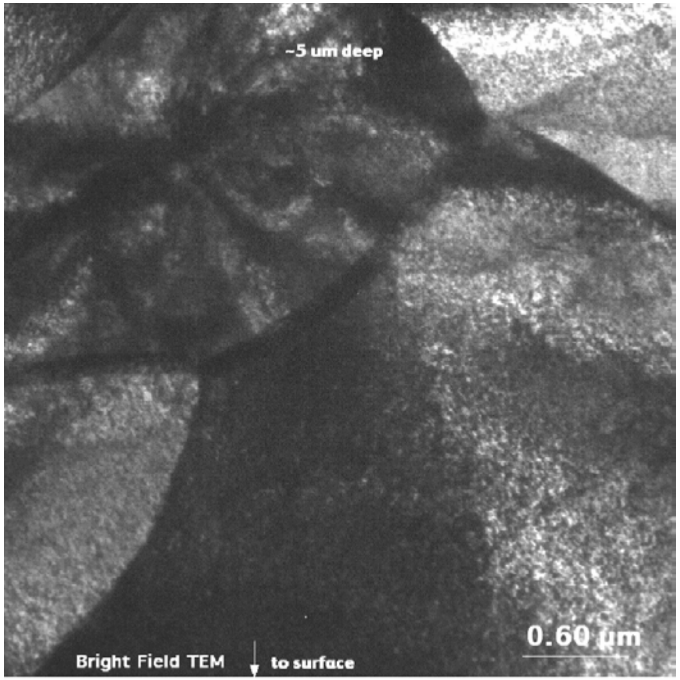


Note: this FIB Sample
Did not fall apart

XTEM of 60X-treated PM W (right) show no cracking in depth



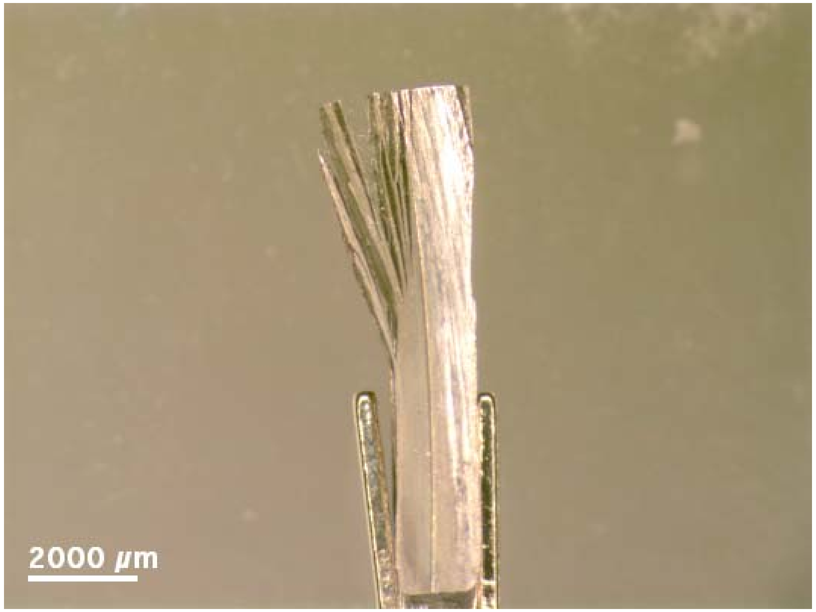
Bright-Field TEM image



TEM image from 5 μm depth

Note: This PM W at 60 pulses does NOT exhibit Baklava

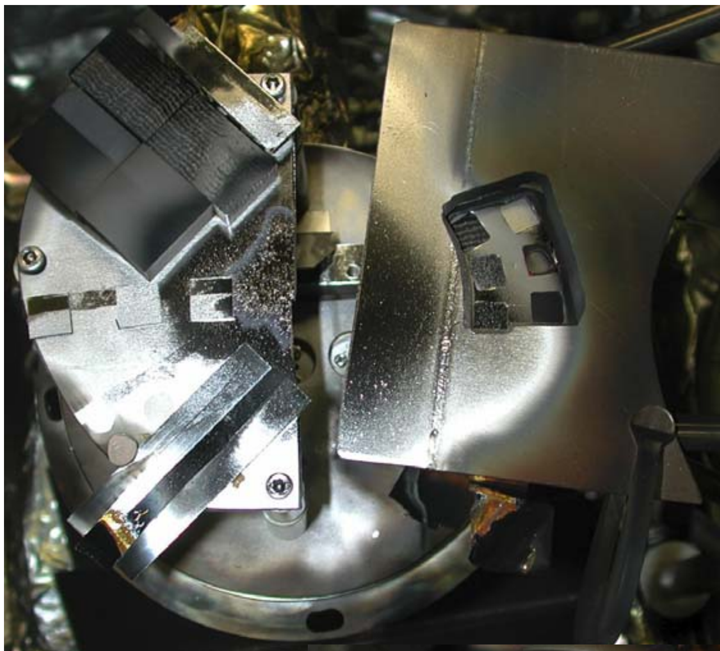
'Baklava' - Summary



Side-image, PM W Schwarzkopf, 125 pulses above melt. Clip holds untreated area

- **Laminar separation occurs on PMW Schwarzkopf, either FIB or saw-cut. Material is hot-rolled 50% deformed, similar to Snead W (Alfa Aesar)**
- **Length scale (500-1200 μ) way beyond ion range**
- **Lesser fluence/lesser pulse number produces less thickness**
- **Untreated W - striated structure, but does not delam**
- **W25Re does not striate or delam**

SuperKS: Appearance after 400 pulses

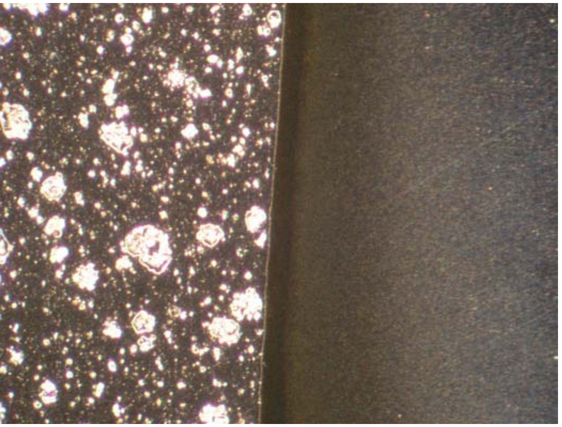


- Tape removed
- RT Sing Xtal samples blown off plate
- Inner Carbon blocks eroded heavily
- Samples shot 400X, then SEM (Renk/Tanaka), Dektak, then reloaded for another 400 shots. Continue till 2000 shots total
- Next time: Remove inner C blocks, use metal masks

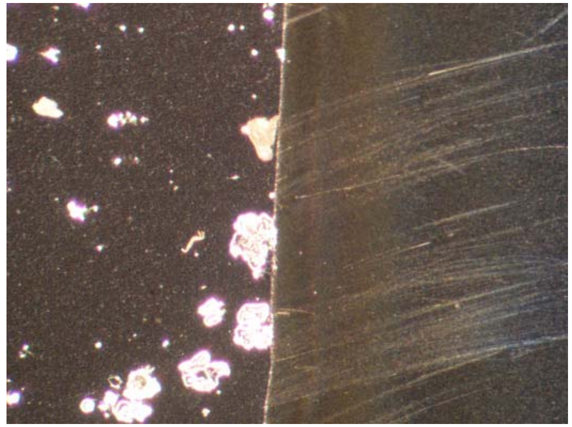
Materials Modification Laboratory

Sandia National Laboratories

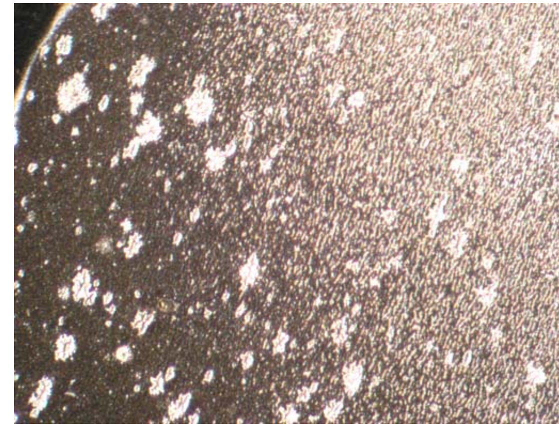
Optical Micrographs, surfaces after 400 pulses (nitrogen)



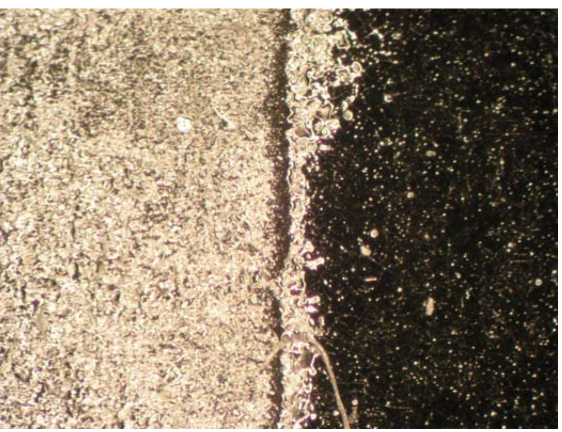
PMW, 1.5 J/cm2 (3000K), 520C



W25Re, 1.5 J/cm2, 520C



SingXtal W, 1.1 J/cm2 (2450K), 520C

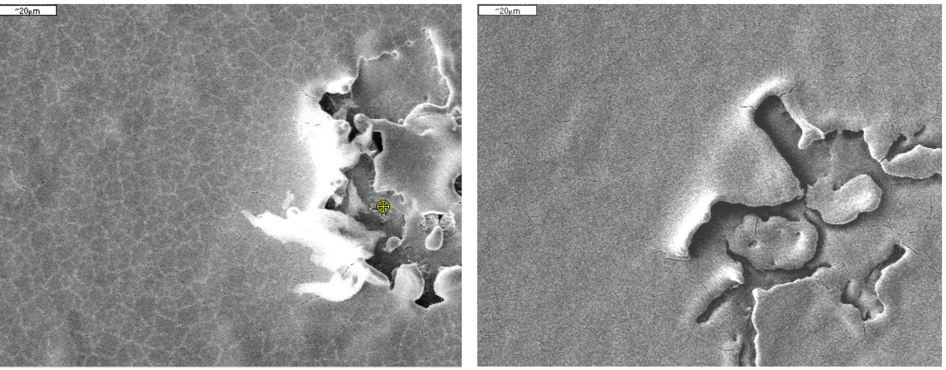


PMW, 1.1 J/cm2 (1700K), RT

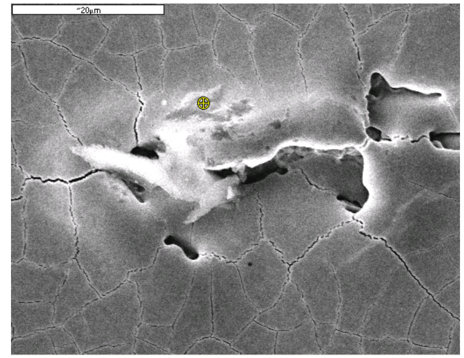
Re, 1.2 J/cm2 (1800K), RT

R6650 Graphite, 1.2 J/cm2, 520C

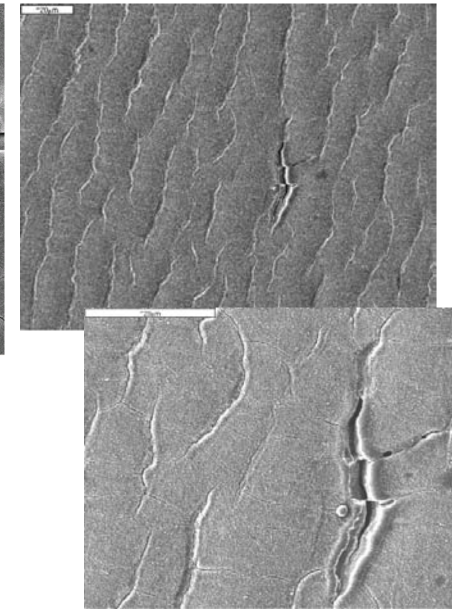
Heated W, W25Re, SingXtal smooth except for ‘exfoliation cracks’



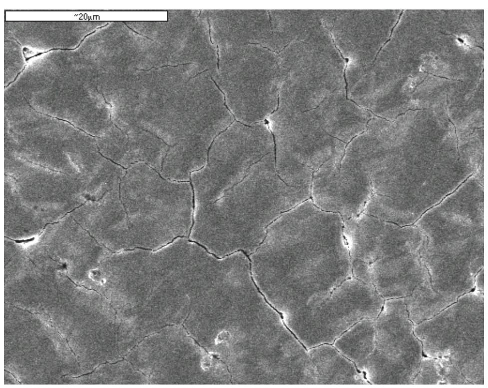
PMW, 1.2 J/cm2, 520C, 750Mag



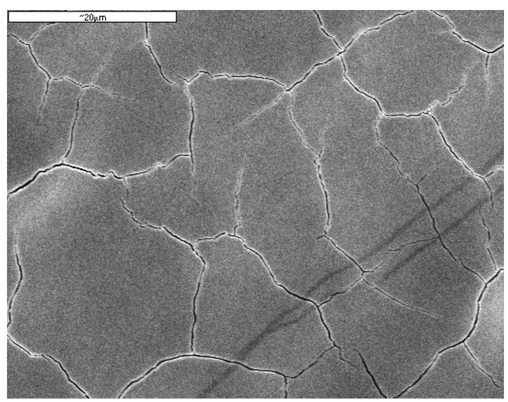
W25Re, 1.2 J/cm2, 520C, 2000Mag



SingXtal W, 1.2 J/cm2, 520C. 750Mag and 2000Mag



(Comparison) Re, 1.2 J/cm2, RT



Re, 2 J/cm2, RT, 2000MAG

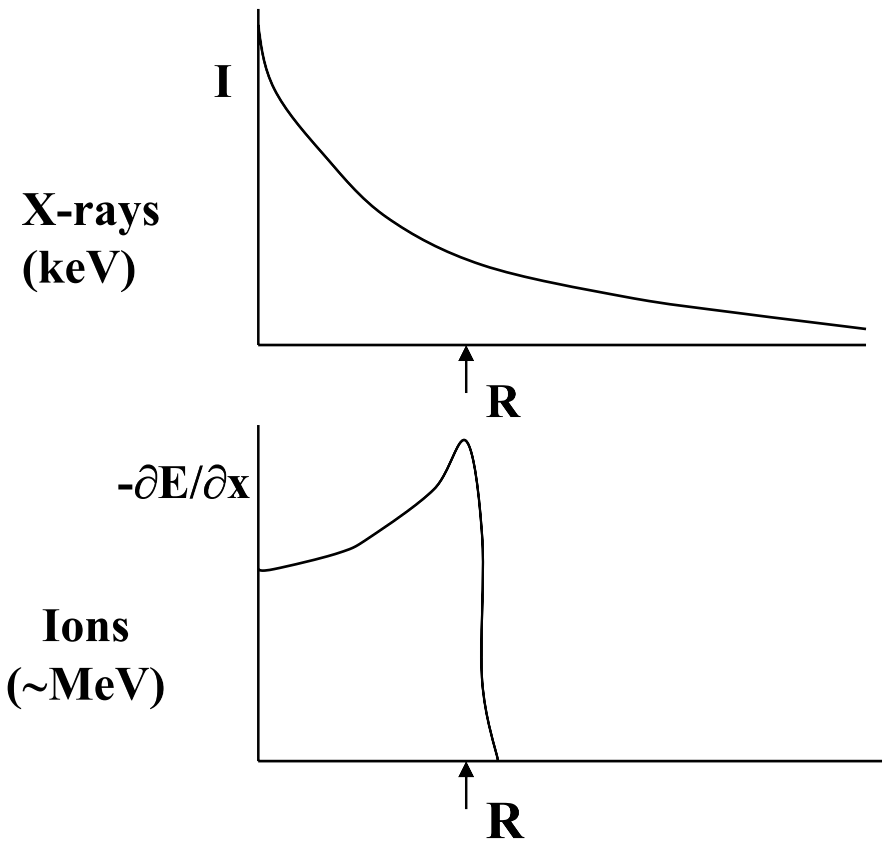
EDS in all cracks shows no contamination

SuperKS after 400 pulses - Summary

SEM, WC, Interface (treated below), 520C, 1 J/cm2)

- PMW continues to set pace for roughness. Heating to 520C makes big difference
- Crater/Cracks on surface appear almost certainly to induce exfoliation. Worst for PMW, but present for W25Re, SingTal as well. Morphology is then very smooth surface with ~ 10 μ lumps (Shiny ‘cratering’ on photomicrographs)
- Melting of the RT PMW reduces roughness dramatically
- Materials ‘almost’ unaffected at ~ 1 J/cm2 - Graphite R6650, CFC, WC, Re (?)

X-rays and ions deposit energy with different spatial profiles



photoelectric absorption of photons

photons removed from flux

I <u>decreases</u> exponentially

absorption length R = $(\mu\rho)^{-1}$

penetrates beyond R

ion collisions with electrons

ions slow down continuously

$|-\partial E/\partial x|$ <u>increases</u> to Bragg peak

range is R

essentially no penetration beyond R

Materials response testing should accurately reproduce specific energy deposition in candidate materials

Need to reproduce:

(1) specific energy deposition $S = \Delta E/\Delta V \sim F(J/cm^2)/R(g/cm^2)$

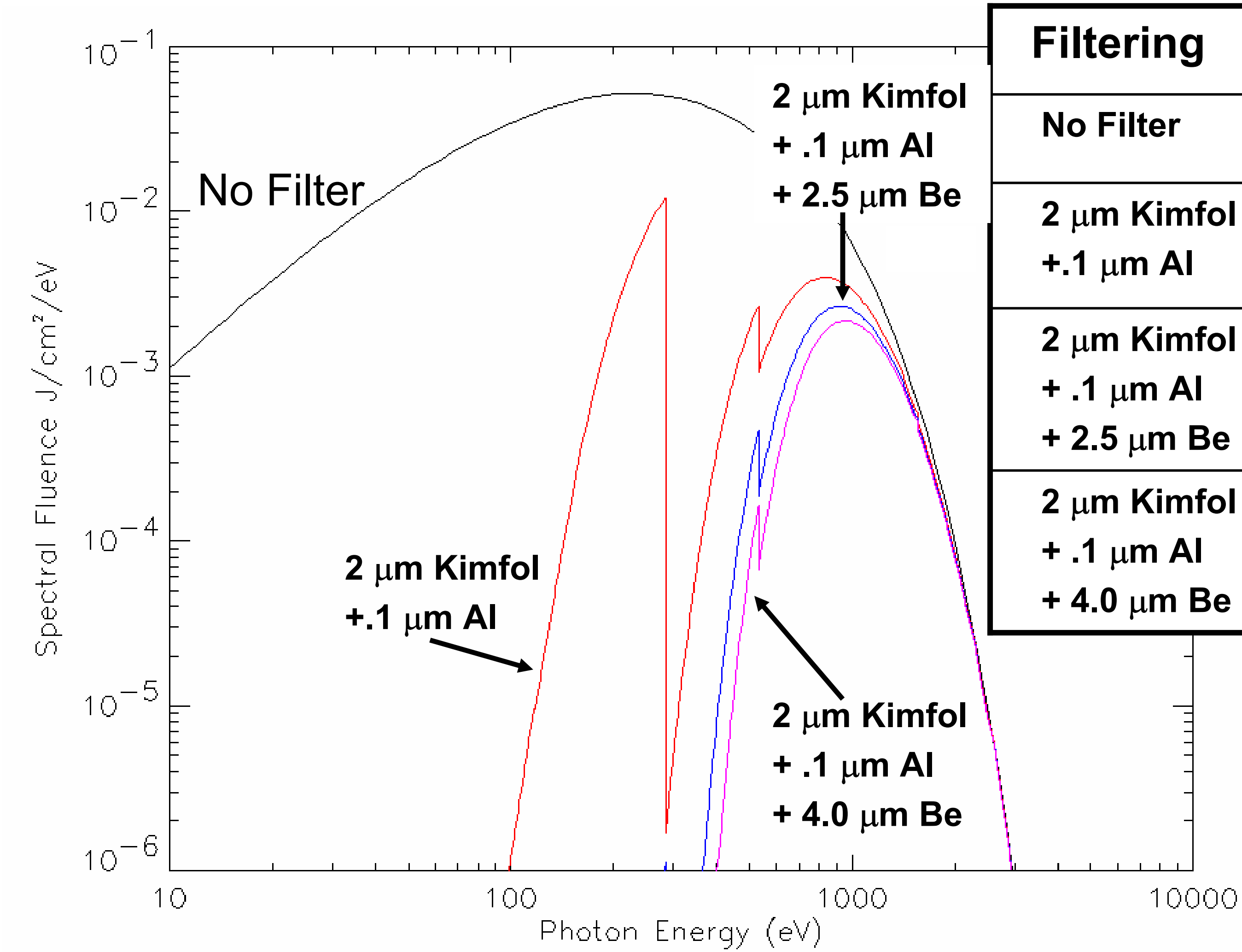
(2) temporal profile S(t) [$\partial S/\partial t$, pulse width,…)
rate of rise competes with thermal conductivity

(3) spatial profile S(x) [deposition profile,…]
deposition scale length compared to
grain size, impurity scale size,…
temperature gradients in deposition region

<u>Z and RHEPP can replicate the conditions in IFE chamber walls</u>

- **Though there are some differences between IFE target spectra and Z and RHEPP, the experiments study the most important issues**
- **The surface temperature histories and temperature profiles are similar**

X-Ray Spectrum and Fluence With Various Filters on Z



Filtering	Fluence	<E>
No Filter	19 J/cm²	443 eV
2 μm Kimfol +.1 μm Al	2.3 J/cm²	830 eV
2 μm Kimfol + .1 μm Al + 2.5 μm Be	1.3 J/cm²	1050 eV
2 μm Kimfol + .1 μm Al + 4.0 μm Be	.98/cm²	1100 eV