SPA Activities DIFFER 2022

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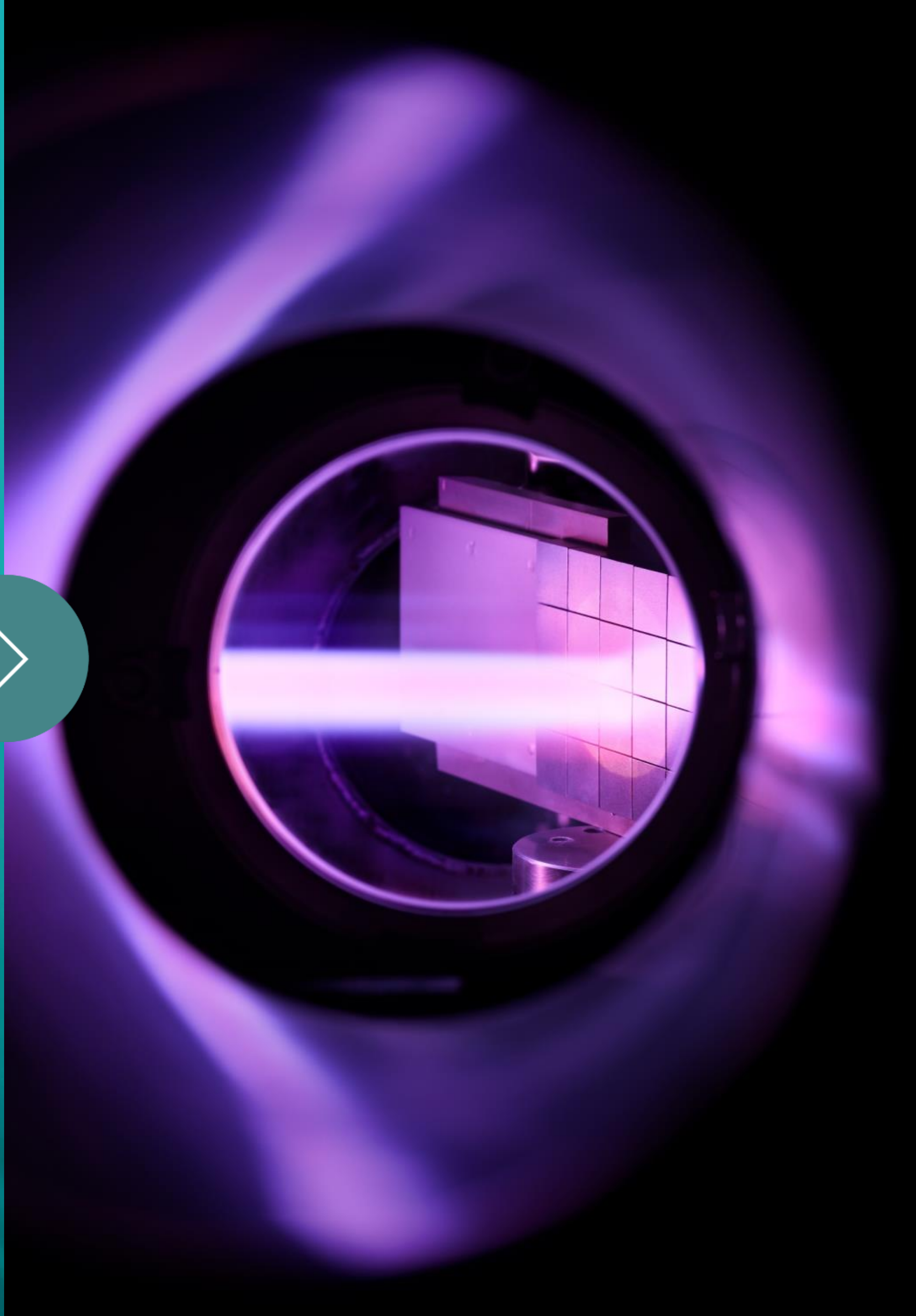


SPA Activities at DIFFER 2022

Activity	Deliverable	Activity description
SP A.1.	D002	Pre-crack damage evolution and erosion under transient loading (2021 work, 2022 shifted to 2023)
SP A.2.	D001	Influence of slow transient plasma loading on tungsten monoblocks
SP A.3.	D005	Retention and erosion of WfW (not reported on here)

Delays for Magnum-PSI operation 2022

Covid-19

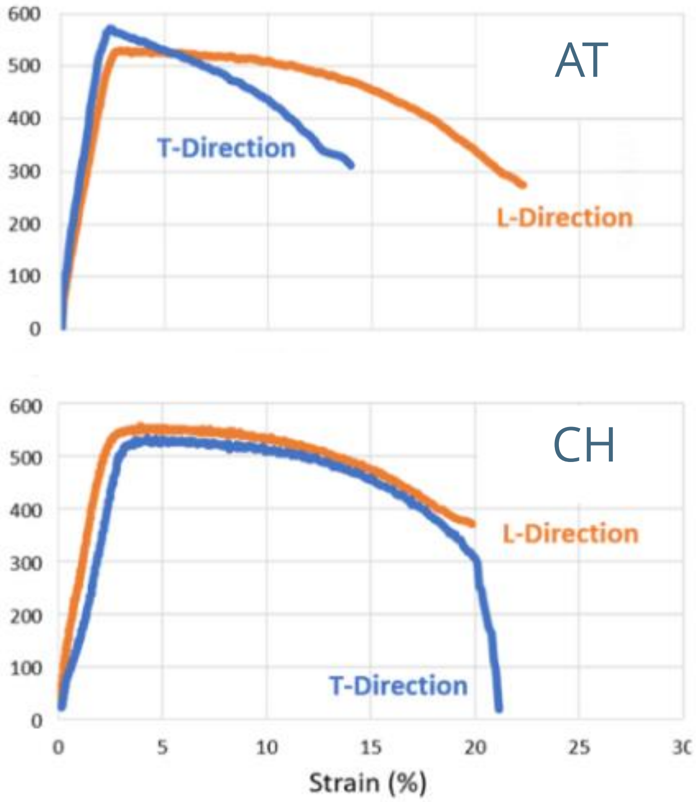
Global parts shortage

Global He shortage

Pre-crack damage evolution and erosion under transient loading

Motivation

- Industrial effort to optimize W production for:
  - Cyclical heat loads
  - Plasma particle loads
  - Fast neutron loads
- Recent industrial developments of “cross rolled tungsten” with potentially superior tensile properties
- Want to compare the performance of three different types of W
  - ITER baseline material ALMT (JW)
  - Cross rolled at high rolling ratio tungsten (CH)
  - Chinese developed ITER grade AT&M (AT)

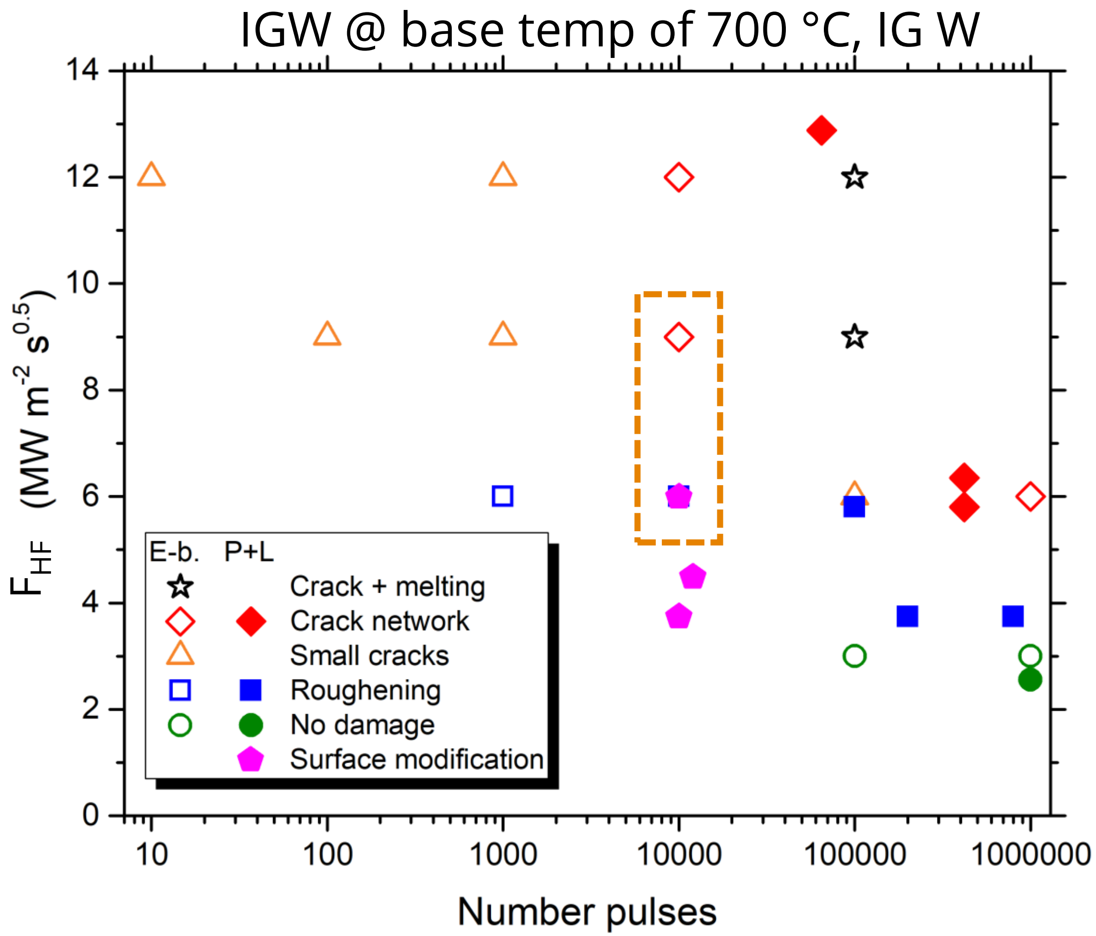


Yu FED 157 (2020)

Background and goal

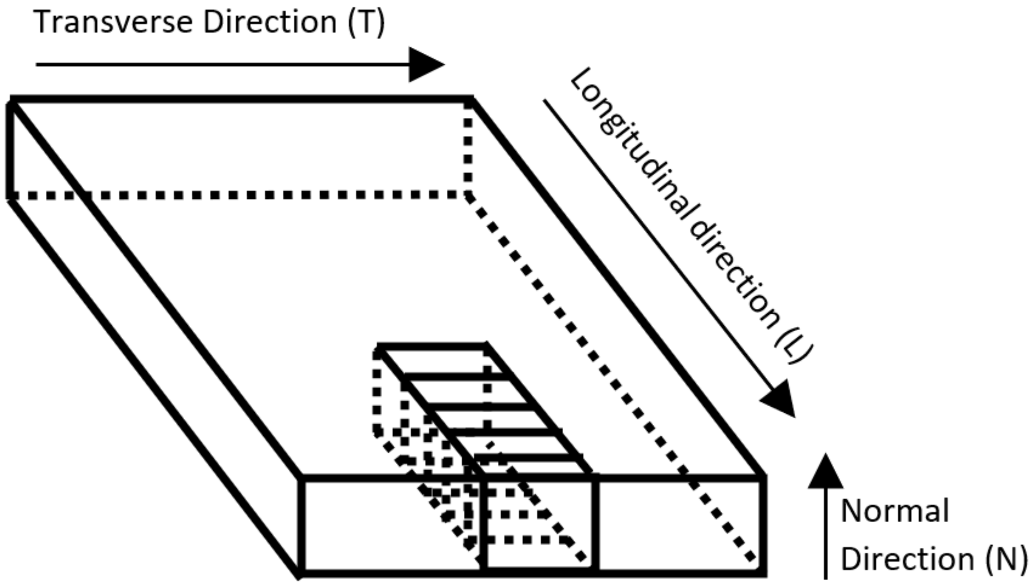
- Small ELM regimes still expected to create roughening and crack networks
- Of concern for effect on
  - Erosion
  - Thermal isolation and melting
  - T retention.
- Large background literature on performance of IGW
- Compare performance under these loading conditions

$$F_{HF} = P\sqrt{t} \propto \Delta T$$



Morgan NF 61 (2021)

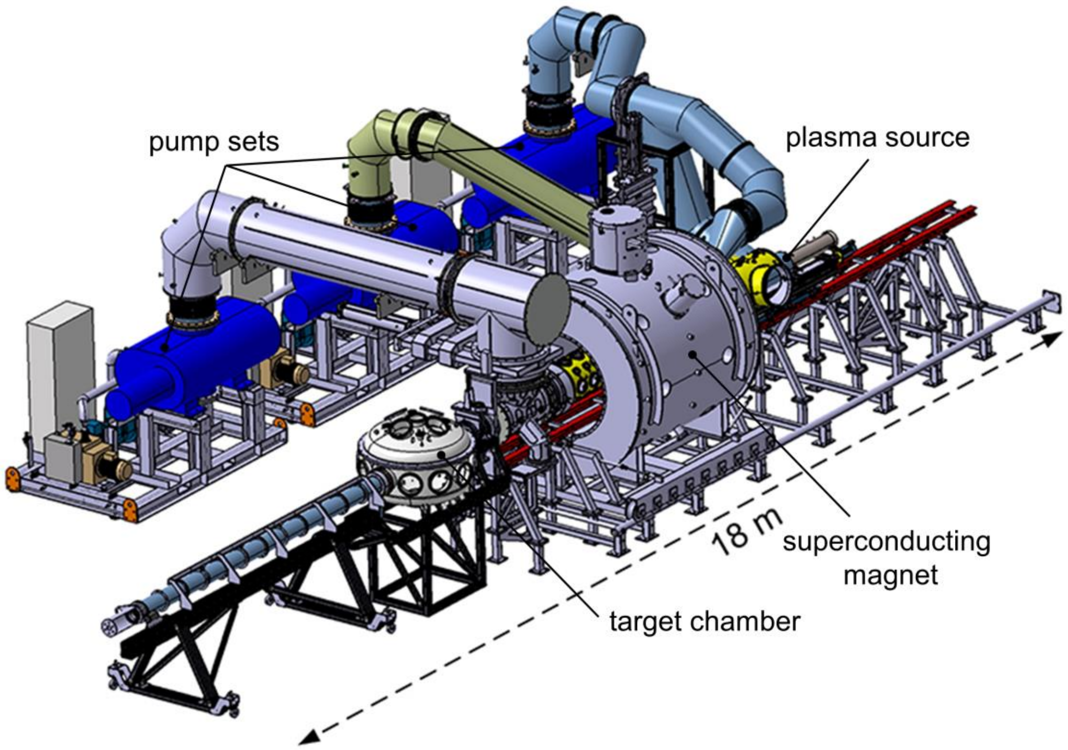
Sample details



Grades

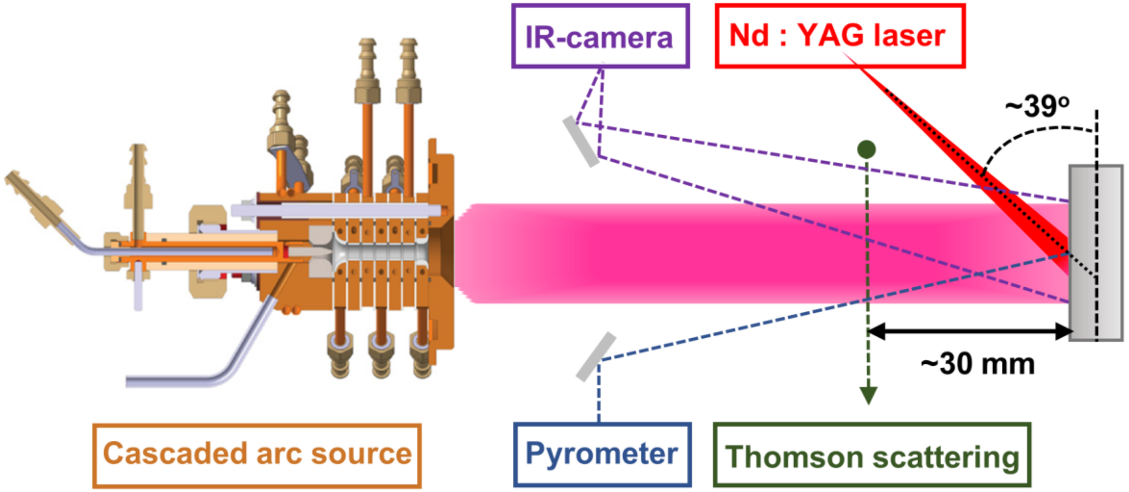
- Dimensions: 12x12x3 or 12x13x3 mm
- JW & AT grades rolled in L direction
- CH grade rolled in L and T directions

Approach



Magnum-PSI

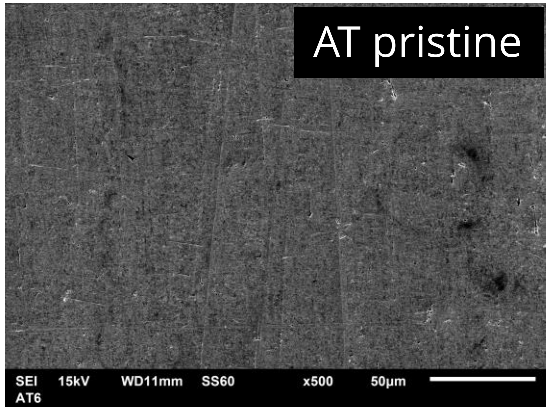
H plasma



$N_{pulses} = 10^4$

T_{base}	F_{HF} (MW m^{-2} $s^{1/2}$)
600	6
800	6
1200	6
600	9

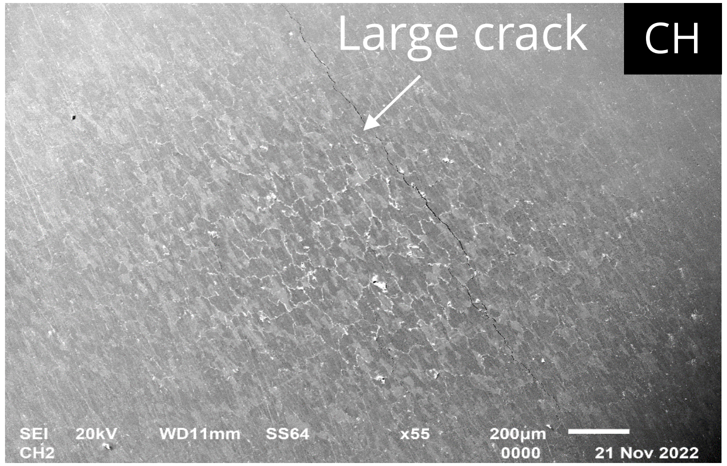
Results: $T_{base} = 600$ °C; F_{HF} 6 MW m^{-2} $s^{0.5}$

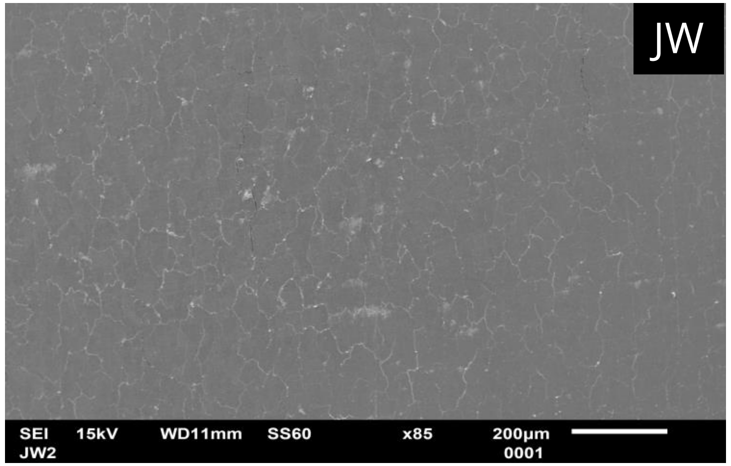


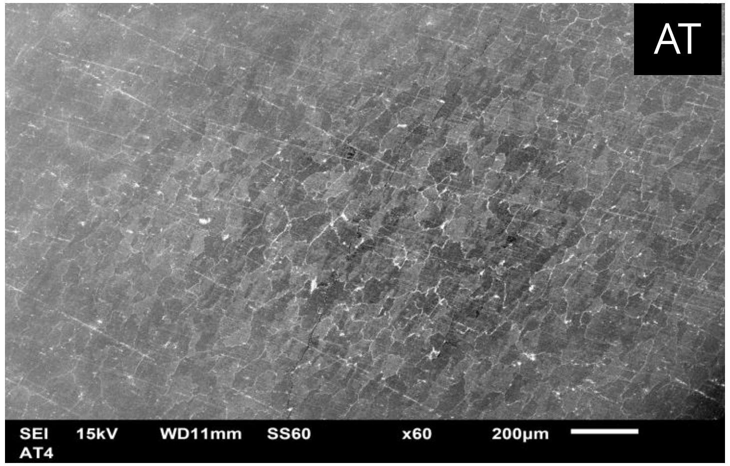
Polished SiC #4000

Similar results for all 3 types

- Large stress relief crack in centre
- Crack network formation seen for all 3 samples

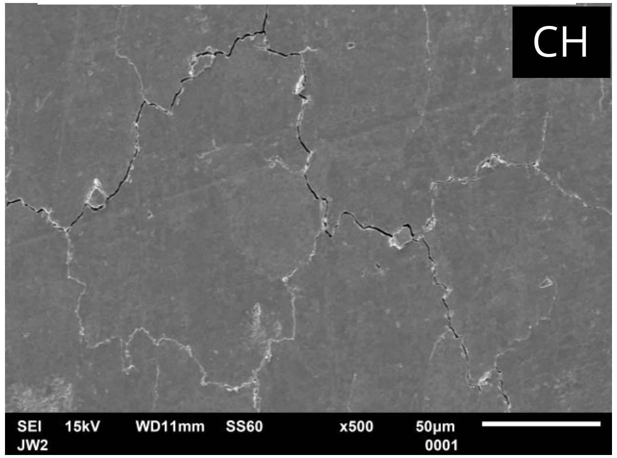






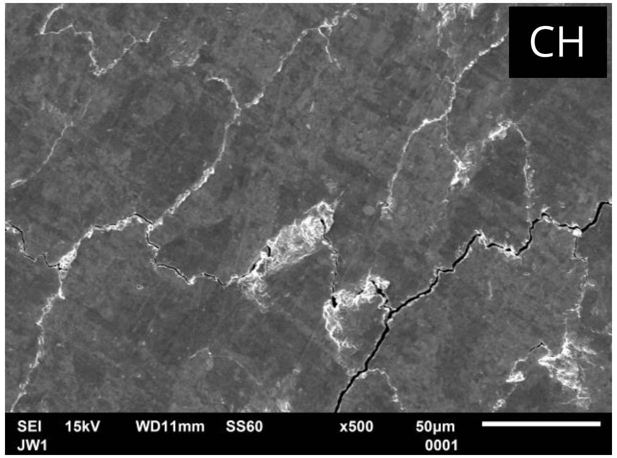
Summary of results: surface topology changes

600 °C | 6 MW m^{-2} $s^{0.5}$



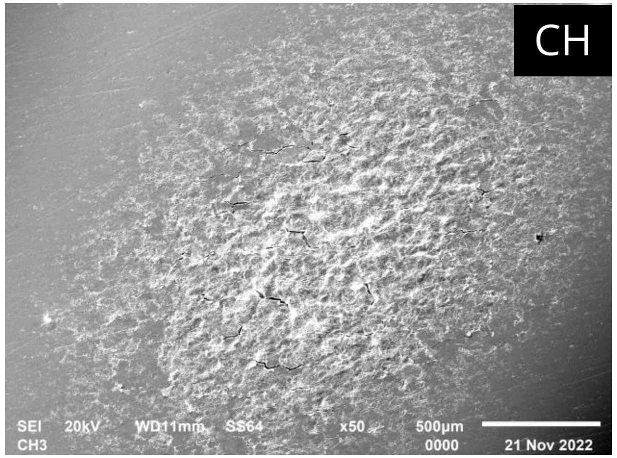
Observed changes
Crack network
No roughening

800 °C | 6 MW m^{-2} $s^{0.5}$



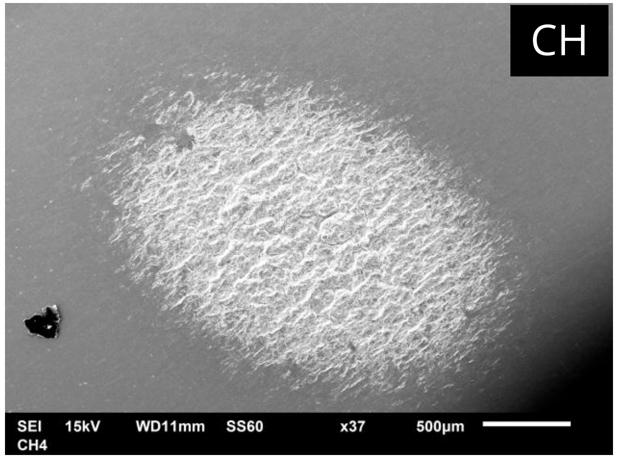
Observed changes
Crack network
Local roughening

1200 °C | 6 MW m^{-2} $s^{0.5}$



Observed changes
Crack network
Strong roughening

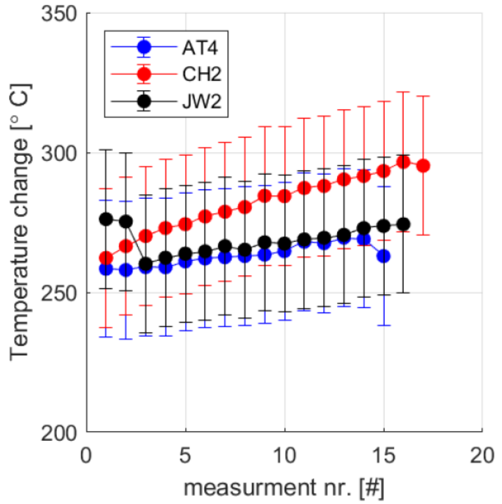
600 °C | 9 MW m^{-2} $s^{0.5}$



Observed changes
Crack network
Strong roughening

Runaway temperature increase for roughened samples

600 °C | **6 MW m^{-2} s$^{0.5}$**

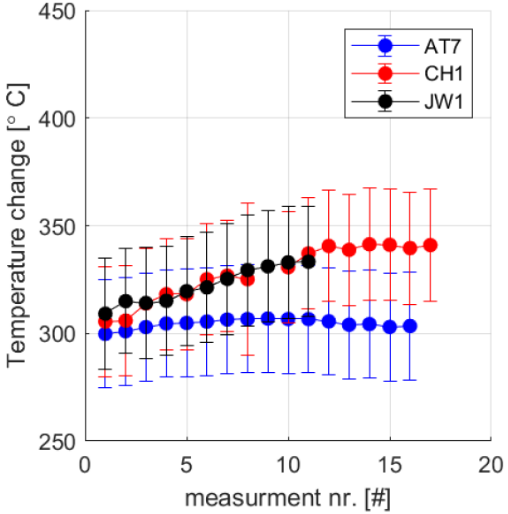


Observed changes

No emissivity change

Max $\Delta T_f/\Delta T_0$ =13%

800 °C | **6 MW m^{-2} s$^{0.5}$**

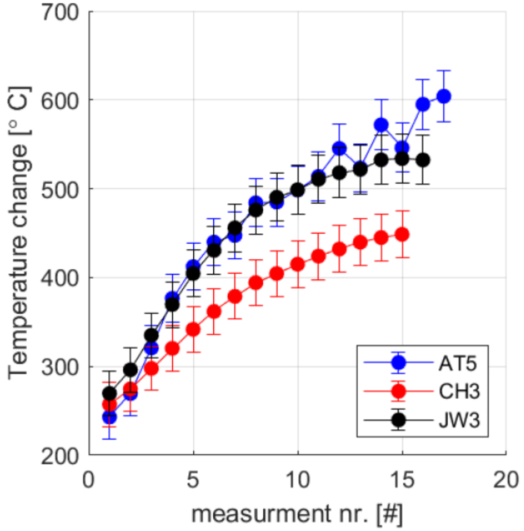


Observed changes

No emissivity change

Max $\Delta T_f/\Delta T_0$ =12%

1200 °C | **6 MW m^{-2} s$^{0.5}$**

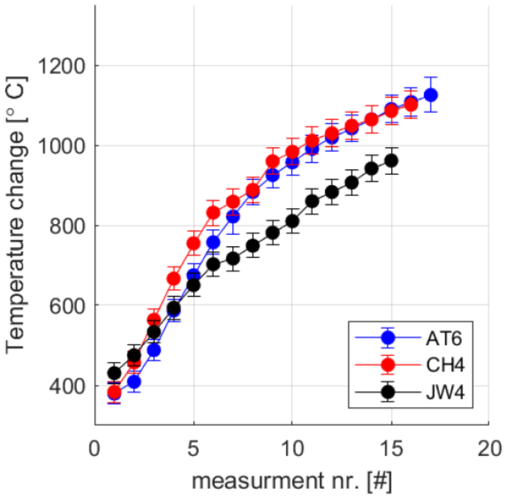


Observed changes

No emissivity change

Max $\Delta T_f/\Delta T_0$ =150%

600 °C | **9 MW m^{-2} s$^{0.5}$**

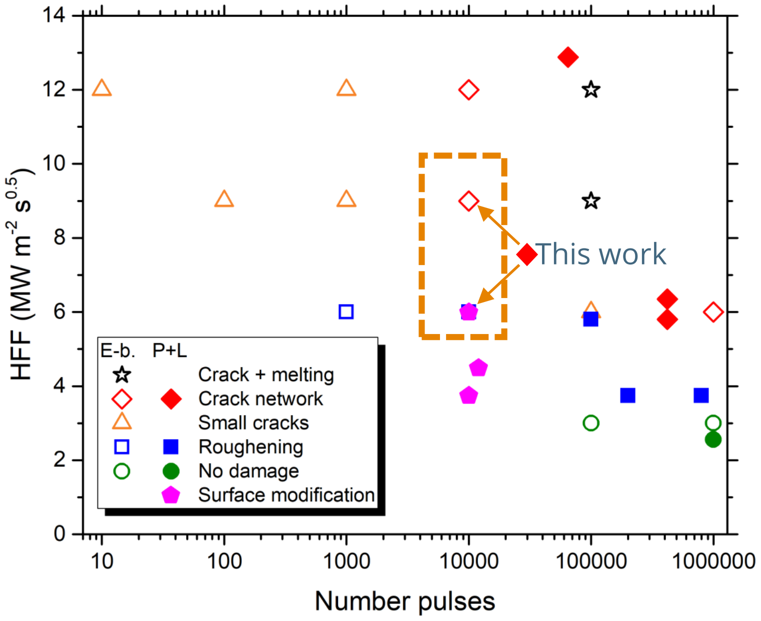


Observed changes

No emissivity change

Max $\Delta T_f/\Delta T_0$ =200%

Discussion



Surface damage effect

- Cracking seen at lower F_{HF} and N_{pulses} than previous experiments:
  - Roughening only for e-beam at similar settings [Loewenhoff *Fusion Eng. Des.* (2012)]
  - Surface modifications only for plasma + laser on monoblocks [Morgan *Nucl. Fusion* **61** (2021)]
- Surface finish? -> Synergy plasma + ELMs?
- Slight differences in experimental approach (close to cracking threshold)?

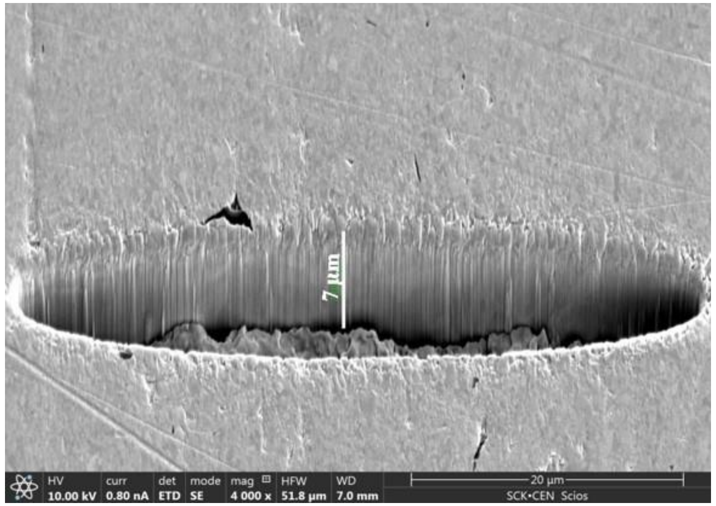
Temperature response during pulses

- Runaway effect correlates to increased roughening
- Control for emissivity/laser absorption effects
- Increased delta-T due to thermal isolation of near surface region grains (local hotspots?).

Conclusions and next steps

- No significant differences between 3 grades of W
  - No advantage for cross-rolling
  - AT&M and ALMT IGW similar to each other in thermal shock performance

- Plans 2023:
  - Further investigate cracking threshold and isolation effect
  - Study effect of pre-cracking on crack growth mechanisms
  - Effect of pre-cracking on edge erosion



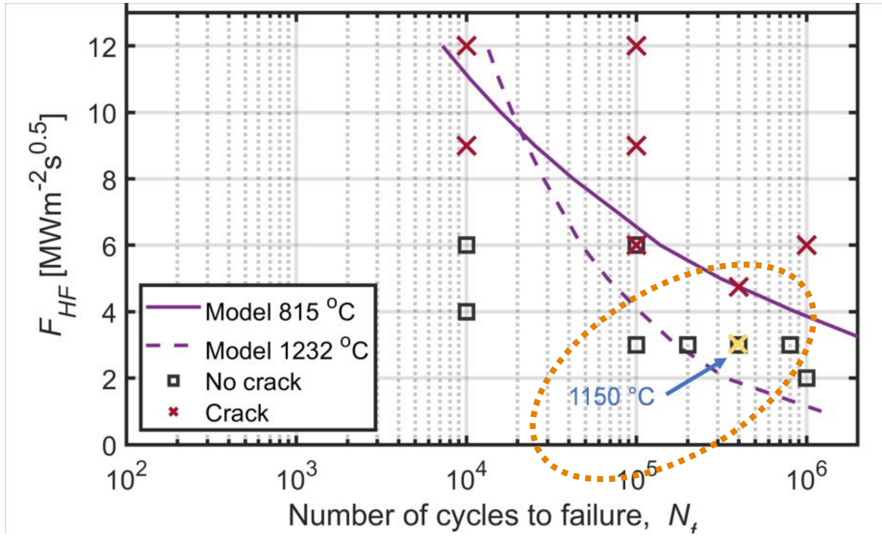
Influence of slow transient plasma loading on tungsten monoblocks

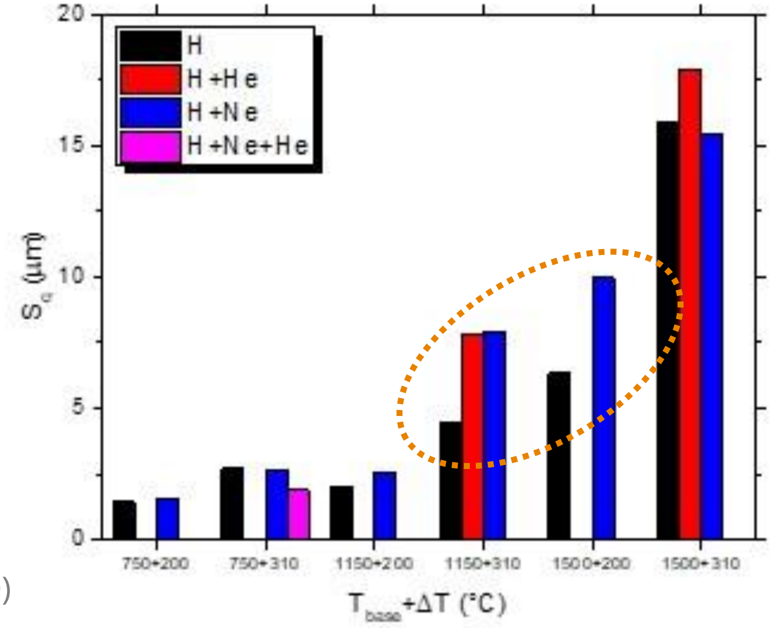
Motivation

Previous studies (nominal operating conditions)

- Long fluence up to 10^{30} m^{-2} fluence at >10 MW m-2 shows no severe consequences for divertor [Morgan *Phys. Scr.* T171 (2020)]
- Influence of ELM-loading with seeding impurities previously done at nominal conditions up to 15 MW m-2 equivalent [Morgan *Nucl. Fusion* 61 (2021)]:
  - Increase T_{base} →Lower resistence to fatigue cracking
  - Seeding impurities show increase in ELM-like loading damage with seeding impurities
  - Ion energy was low so sputtering near negligible

What happens beyond nominal conditions?





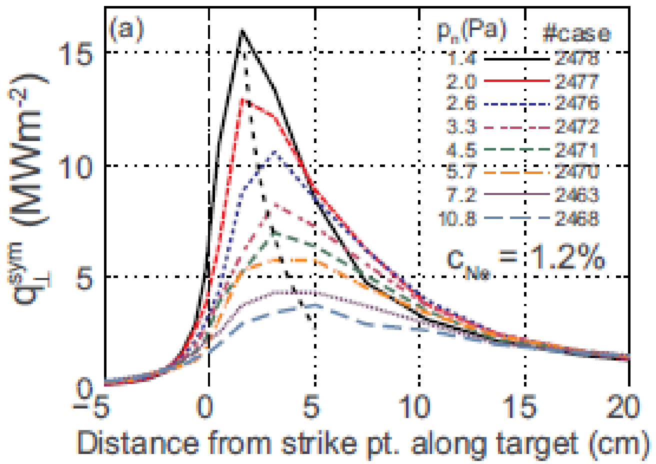
Morgan *Phys. Scr.* T171 (2020)

What is the effect of slow transients?

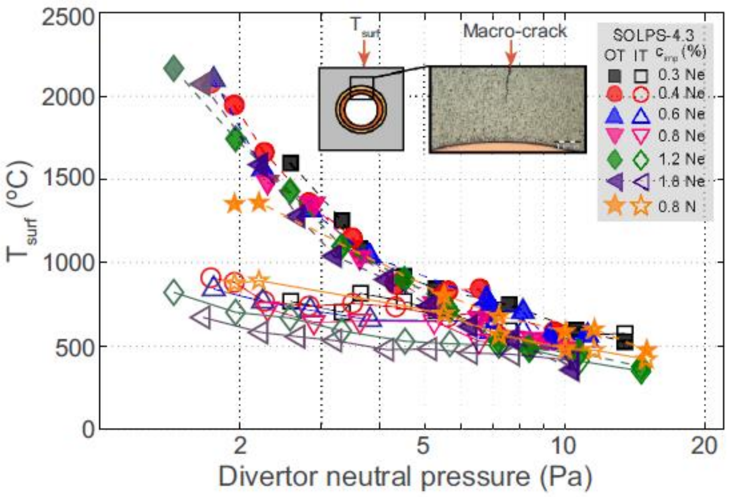
What happens during slow transients?

Slow transients: heat flux increase at divertor (10-20 MW m^{-2}) due to loss of detachment

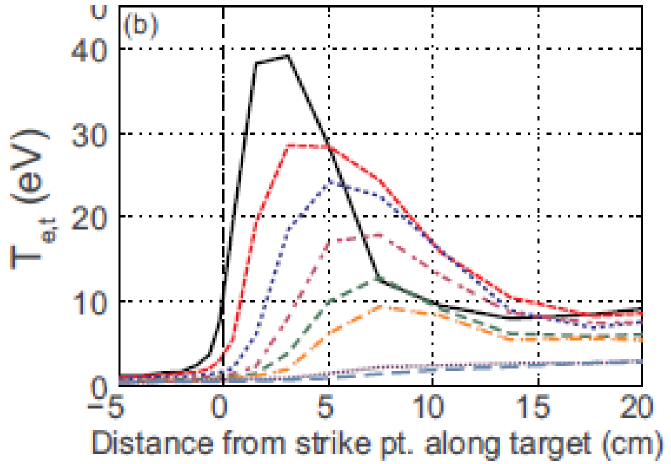
- T_{surf} > 2000 °C, R_x to 2mm deep in 1 hour, lose yield strength, cracking
- T_e increases, sputtering due to entrained impurities



$p_n \downarrow$ » $q_\perp \uparrow$



$q_\perp \uparrow$ » $T_{surf} \uparrow$



$p_n \downarrow$ » $T_{e,t} \uparrow$

Pitts *Nucl. Mat. Energy* 20 (2019)

Approach part 1

Extend temperature scan of ELMs+impurities to slow transient temperatures

High T_{surf} + ELMs + no/low sputtering (seeding impurities)

Plasma Species	<Tsurf> (degC)	Bias (V)	Npulses	<Delta-T> (degC)
H	2090	Floating	1e5	200
H+He	2040	Floating	1e5	320
H+Ne	2080	Floating	1e5	340
H+Ar	2060	Floating	1e5	380
H	2000	-40	X	X
H+He	2080	-25	1e5	200
H+Ne	1700	-40	X	X


ENEA-58 mounted on holder for Auriga

Photo after exposure with conditions

H, fl
☺

H, -40V
→ arcing

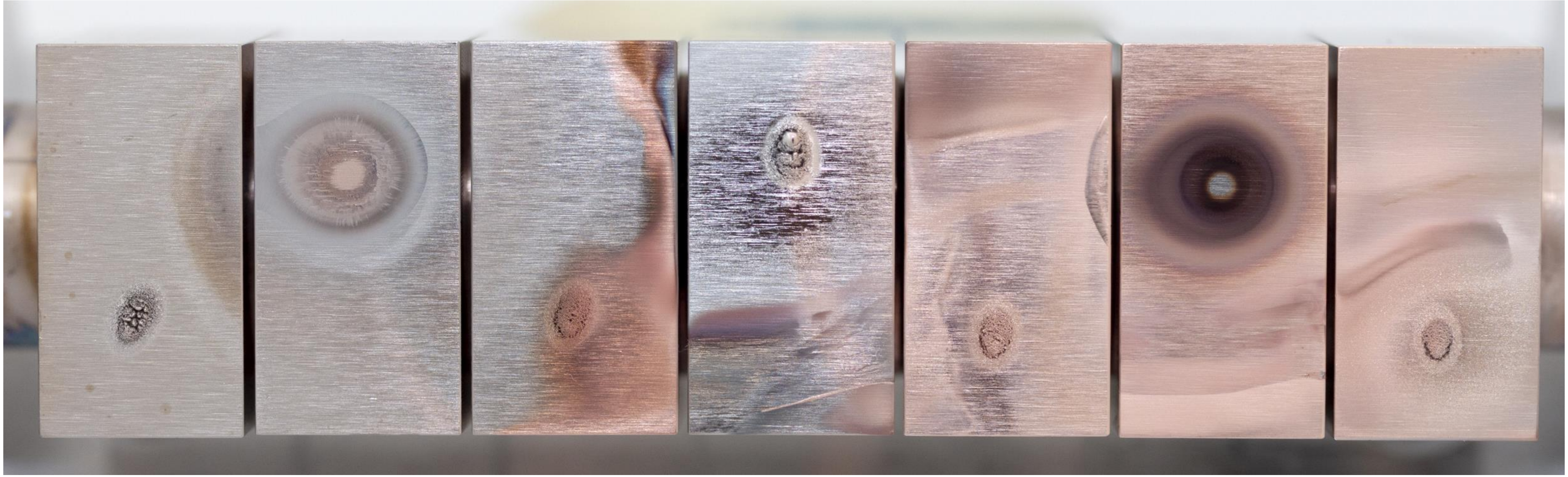
H+He, fl
☺

H+He,-25V
☺

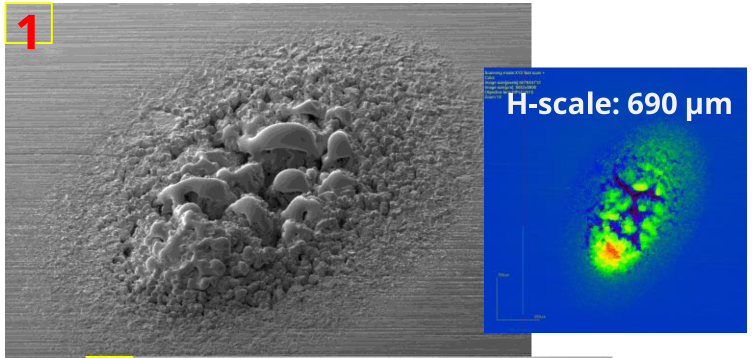
H+Ne, fl
→ Cu

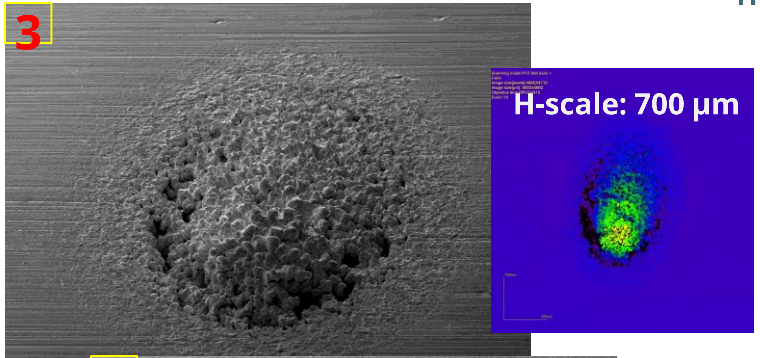
H-Ne,-40
→ failure

1H+Ar, flo
☺



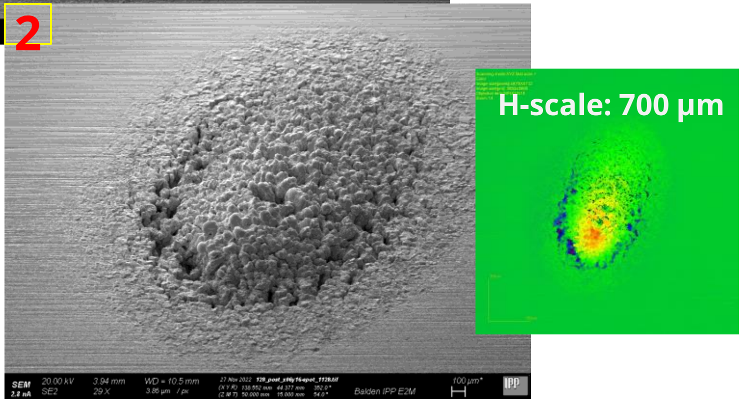
Laser spots: roughness

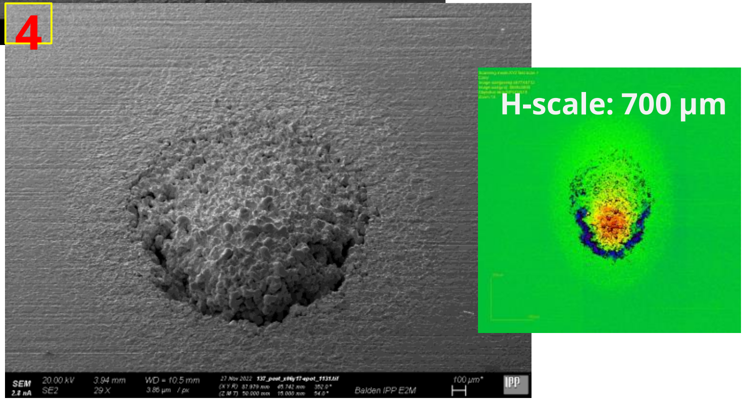


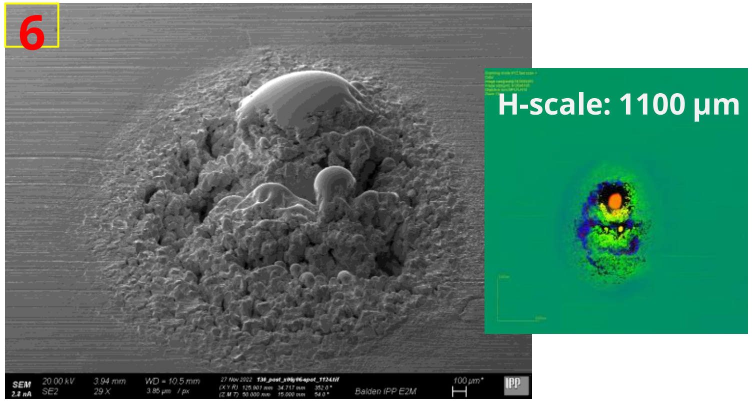


Extremely roughened/cracked laser spots

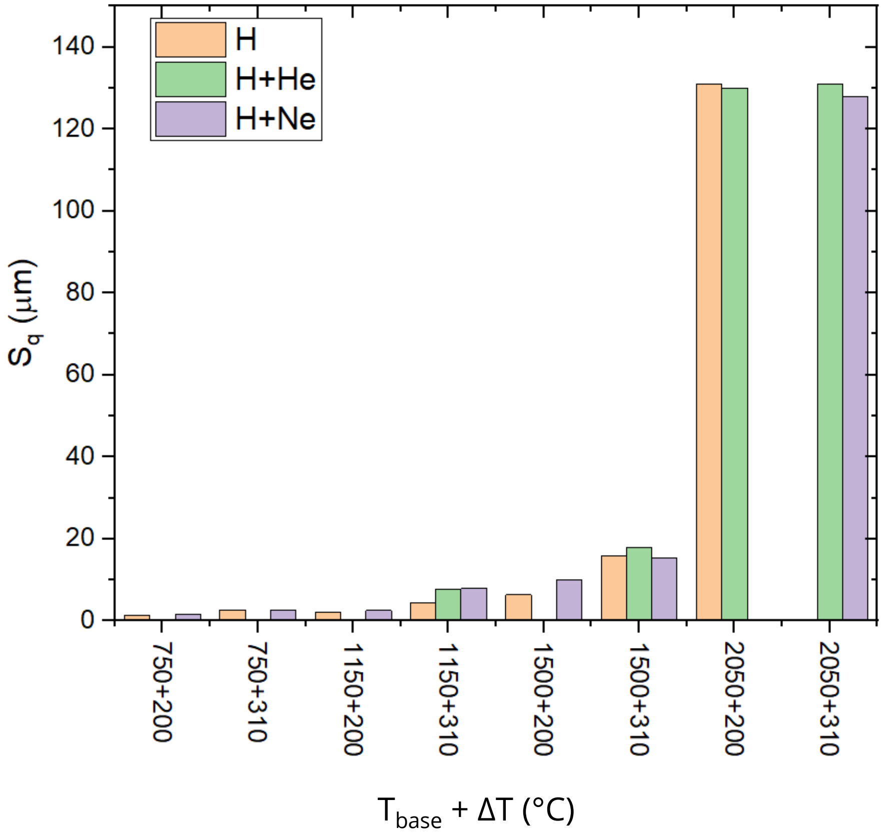
Localized melting







Roughness comparison



Severe deformation for very small ELM-like loads (F_{HF}~4 MW m$^{-2\ 0.5}$)

Strikepoint protrusion = erosion risk?

Approach part 2

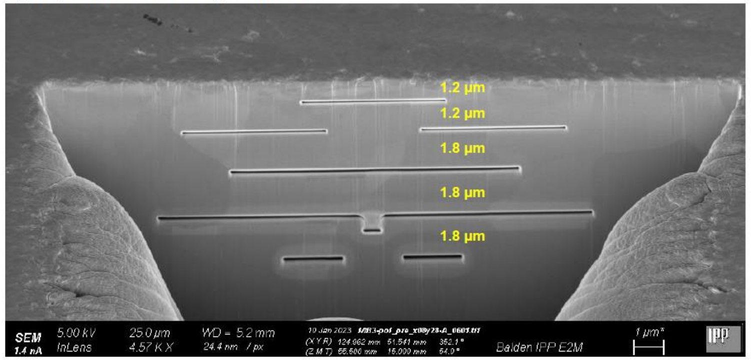
Sputtering and re-deposition under high-flux conditions

Low T_{surf} + ELMs + sputtering (Ar plasma)

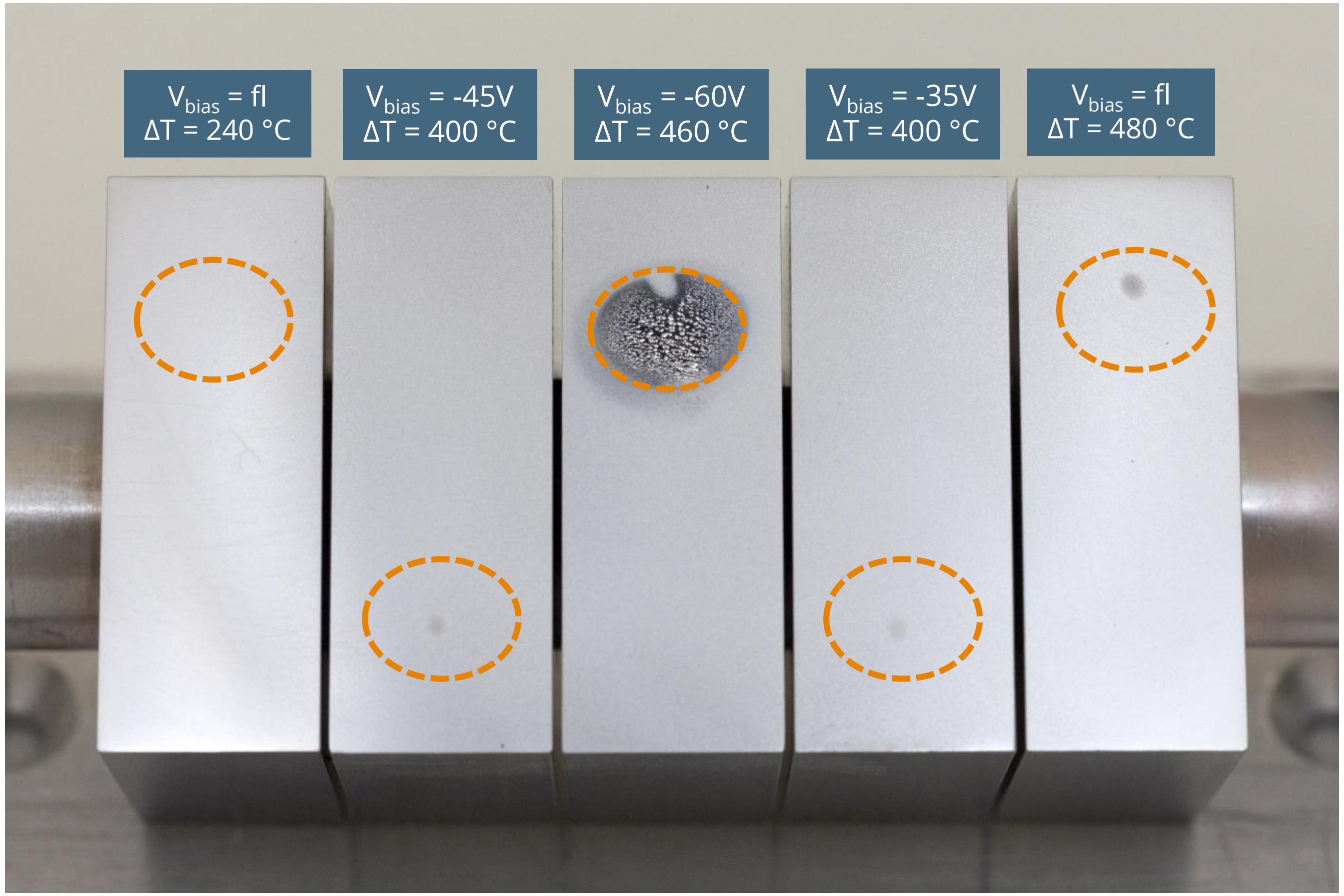
Plasma Species	$<T_{surf}>$ (°C)	Bias (V)	Npulses	$<\Delta T>$ (degC)	Gross erosion (µm)	Net erosion (µm)
Ar	550	Floating	1×10^4	480	0	0
Ar	550	-35	1×10^4	400	47	2.3
Ar	550	-60	1×10^4	460	382	19.1
Ar	550	-45	1×10^4	400	134	6.7
Ar	550	Floating	1×10^4	240	0	0

- Aim for no-impurity conditions
- Vary bias to get different sputtering
- Large gross erosion due to high flux ($\sim2\times10^{24}$ m^{-2} s^{-1})/fluence ($\sim1\times10^{27}$ m^{-2})
- Expect large re-deposition rate from plasma entrainment due to high density $\sim1.2\times10^{21}$ m^{-3}. Measure with micrometer rulers
- Investigate effect of ELMs during strong sputtering conditions on W

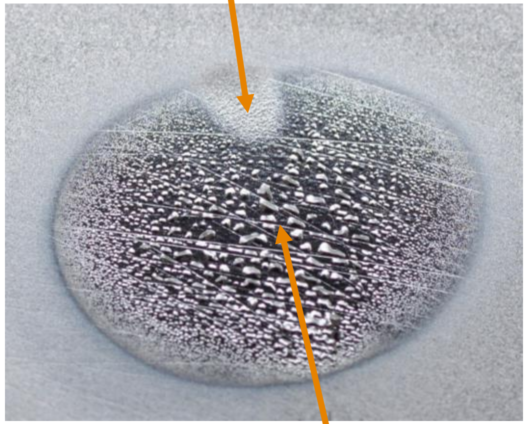
Typical µm-ruler trench for "high" erosion



Initial results (last week's experiments)



Laser spot



Smooth and crystallite regions of increasing size towards centre

Next steps surface analysis IPP Garching

Summary

SPA.1

Thermal shock performance of three W grades compared

- Lower crack threshold than literature in all cases -> plasma effect?
- No significant improvement in fatigue resistance for cross-rolling of W

SPA.2

Performance of W monoblocks under slow transient conditions investigated

- Very strong increase in roughness in laser-spot location -> thermal isolation and erosion/droplet risk?
- Sputtering and re-deposition leads to strong surface morphology changes -> further investigation

Both topics to be further investigated in 2023