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### ► **To cite this version:**

C Guillemaut, M Richou, M Diez, S Lisgo, M Cabié, et al.. Thermal shock resistance of a tungsten diamond composite under extreme heat loads. 20th PFMC 2025 - 20th International Conference on Plasma-Facing Materials and Components for Fusion Applications, May 2025, Ljubljana, Slovenia. . <cea-05317907>

**HAL Id: cea-05317907**

**<https://cea.hal.science/cea-05317907v1>**

Submitted on 16 Oct 2025

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# Thermal shock resistance of a tungsten diamond composite under extreme heat loads

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## Limitations of bulk tungsten PFCs

Despite tungsten (W) high melting point and very good tolerance for erosion, its poor thermal properties (thermal conductivity of  $\sim 100 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$  at  $20^\circ\text{C}$  for W) make it prone to very high thermomechanical stresses during thermal shocks in magnetic confinement fusion devices leading to recrystallization, cracking and melting.

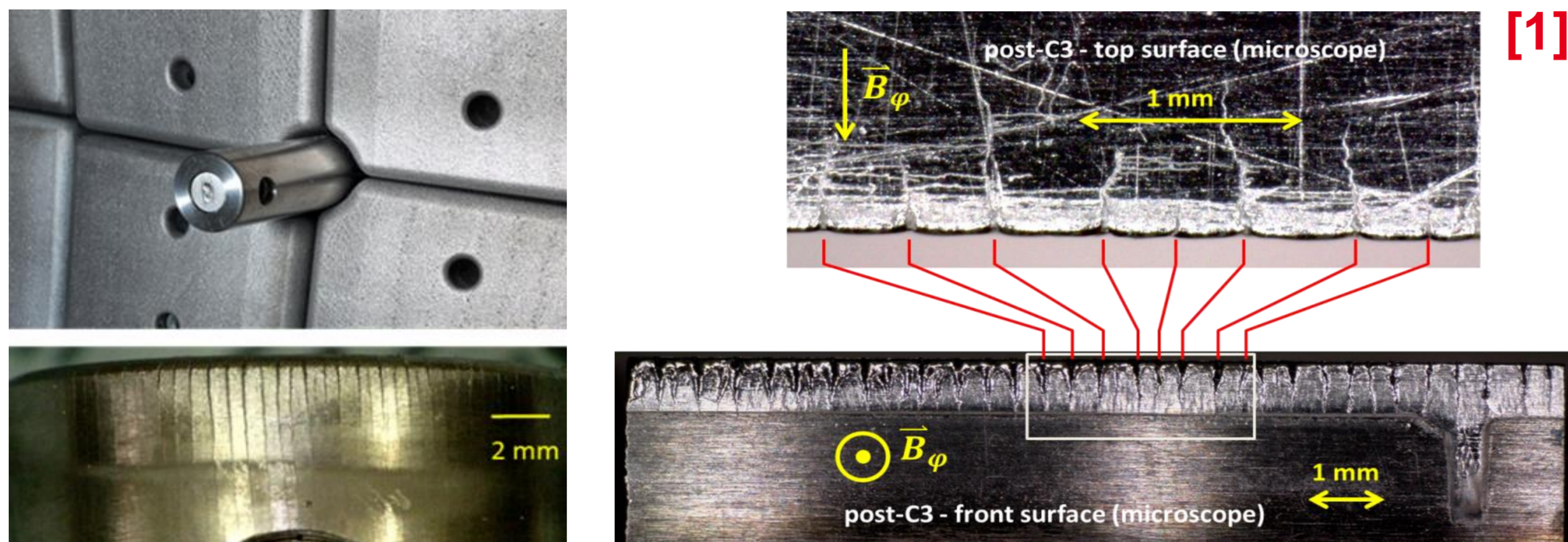


Fig 1. a) Cracks on a WEST bulk W Langmuir « Pecker » Probe after a few transients (disruptions). b) Cracks and melting on ITER-grade W monoblocks leading edges exposed to power densities above  $10 \text{ MW}\cdot\text{m}^{-2}$  in WEST

## Outstanding thermal properties of diamond

The very high thermal conductivity of Chemical Vapor Deposition (CVD) diamond ( $\sim 2000 \text{ W}\cdot\text{m}^{-1}\cdot\text{K}^{-1}$  at  $20^\circ\text{C}$ ) allows outstanding performances under thermal shocks with T retention  $< 1\%$  [2]. Unfortunately, its erosion properties are comparable to graphite [3].

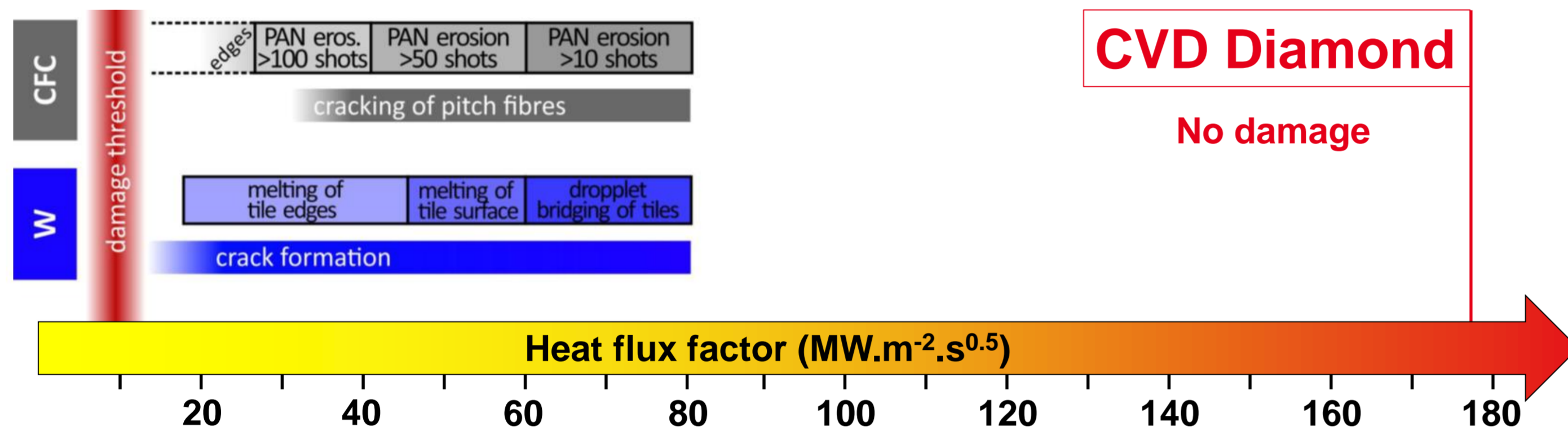


Fig 2. Effects of thermal shocks on CFC, W and CVD diamond

## The W-diamond composite

W-diamond test samples made of a  $\sim \text{mm}$  thick CVD diamond substrate for a uniform and fast distribution of heat with a  $\sim 10 \mu\text{m}$  W coating for protection against erosion were manufactured. The objective was to verify the viability of the metal-diamond interface under fusion relevant thermal shocks. Various options were considered: mono and polycrystal CVD diamond substrates, pure W coatings and a Mo interlayer (C diffusion barrier).

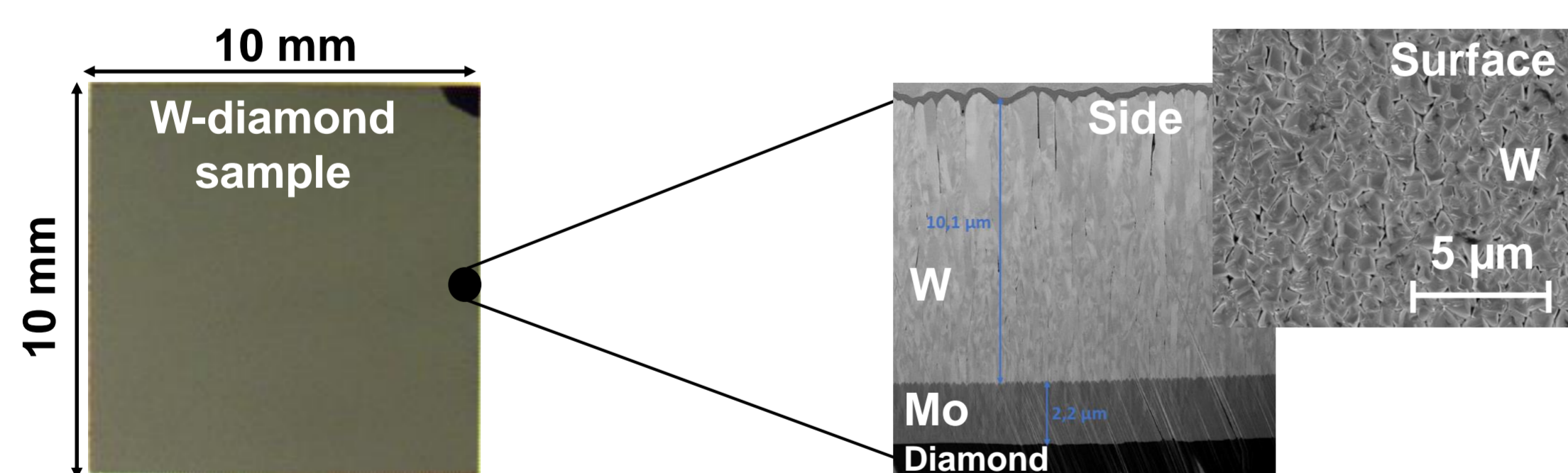


Fig 3. Microscopic view of the top surface and side of a test W-diamond sample.

## Simulations of W-diamond under thermal shocks

COMSOL simulations of an ITER-like ELM yield a surface temperature  $\sim 3$  times higher for bulk W at  $\sim 2100^\circ\text{C}$  than on W-diamond which is at  $\sim 800^\circ\text{C}$ .

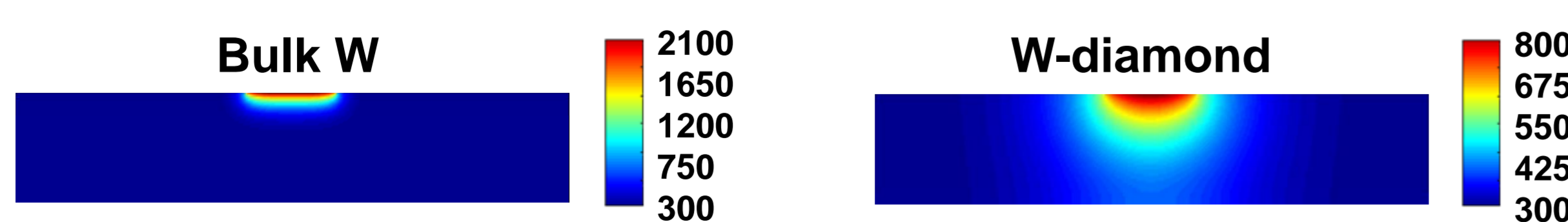


Fig 4. Temperature map simulated by COMSOL for bulk W and W-diamond after 1 ms at  $1 \text{ GW}\cdot\text{m}^{-2}$  ( $32 \text{ MW}\cdot\text{m}^{-2}\cdot\text{s}^{0.5}$ ) on a  $1 \text{ mm}^2$  circular region

Simulations of 1 s transients at  $100 \text{ MW}\cdot\text{m}^{-2}$ , similar to a divertor reattachment in ITER, yield a maximum of  $\sim 800^\circ\text{C}$  on the bulk W surface and  $\sim 300^\circ\text{C}$  on the W-diamond surface. In all cases, the W-diamond never reaches the W recrystallization temperature at  $\sim 1200^\circ\text{C}$  nor the graphitization temperature of the diamond at  $\sim 1100^\circ\text{C}$ .

## Tests under extreme heat loads

Thermal shocks were performed on the samples with the ChauCoLase laser facility [4]:

- up to  $10^4$  cycles of 1 ms at  $0.5\text{-}3 \text{ GW}\cdot\text{m}^{-2}$  of absorbed power density ( $19\text{-}95 \text{ MW}\cdot\text{m}^{-2}\cdot\text{s}^{0.5}$ ) to simulate ITER-relevant fast transients like ELMs, disruptions and runaways,
- up to 20 cycles of 1 s at  $100 \text{ MW}\cdot\text{m}^{-2}$  to simulate reattachment in the ITER divertor.

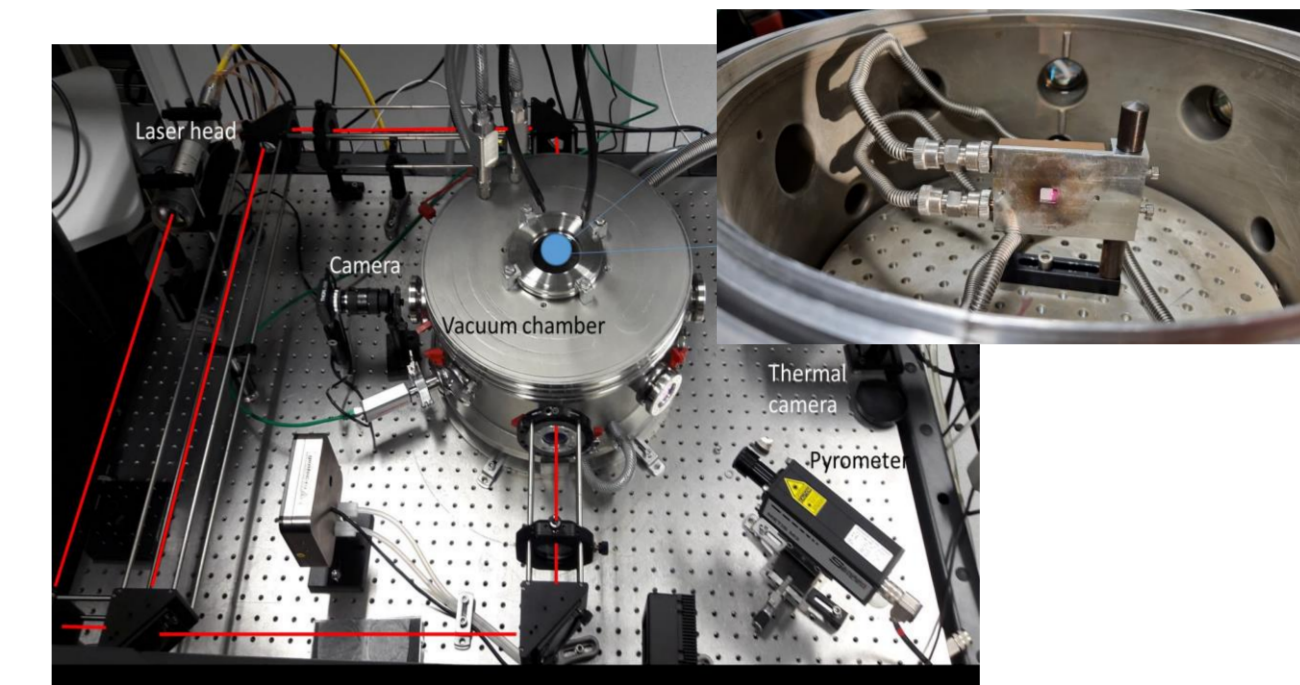


Fig 5. The ChauCoLase laser installation at Fresnel Institute, Aix-Marseille University

Microscopic and focused ion beam analysis showed pristine W coatings and W-diamond interfaces for all samples under fast transients up to  $1.7\text{-}2 \text{ GW}\cdot\text{m}^{-2}$  ( $54\text{-}63 \text{ MW}\cdot\text{m}^{-2}\cdot\text{s}^{0.5}$ )

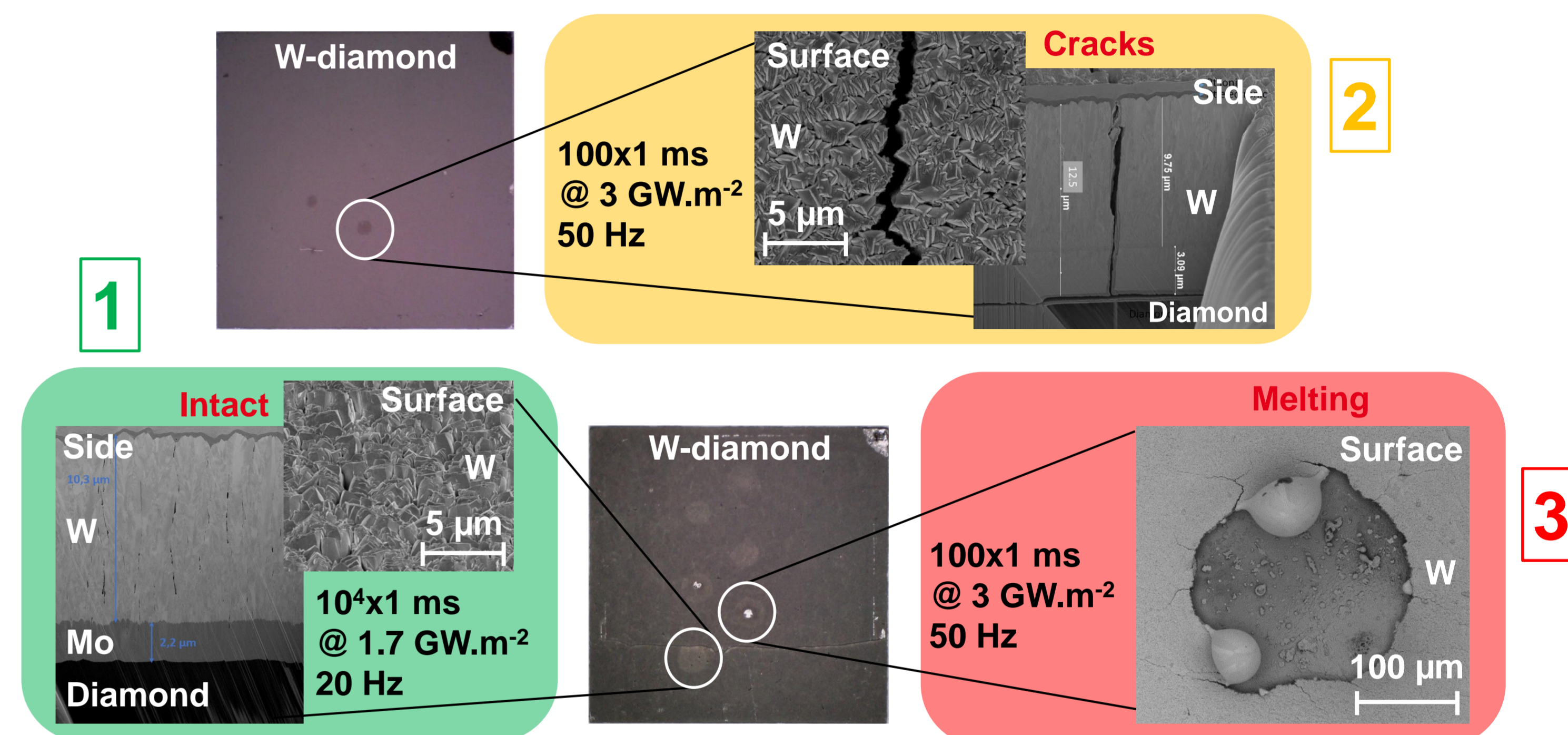


Fig 6. Steps to failure of the W-diamond samples under fast transients

Test bulk W samples of the same dimensions cut from ITER-grade W monoblocks [5] already showed cracked and melted surfaces at the lowest thermal loads.

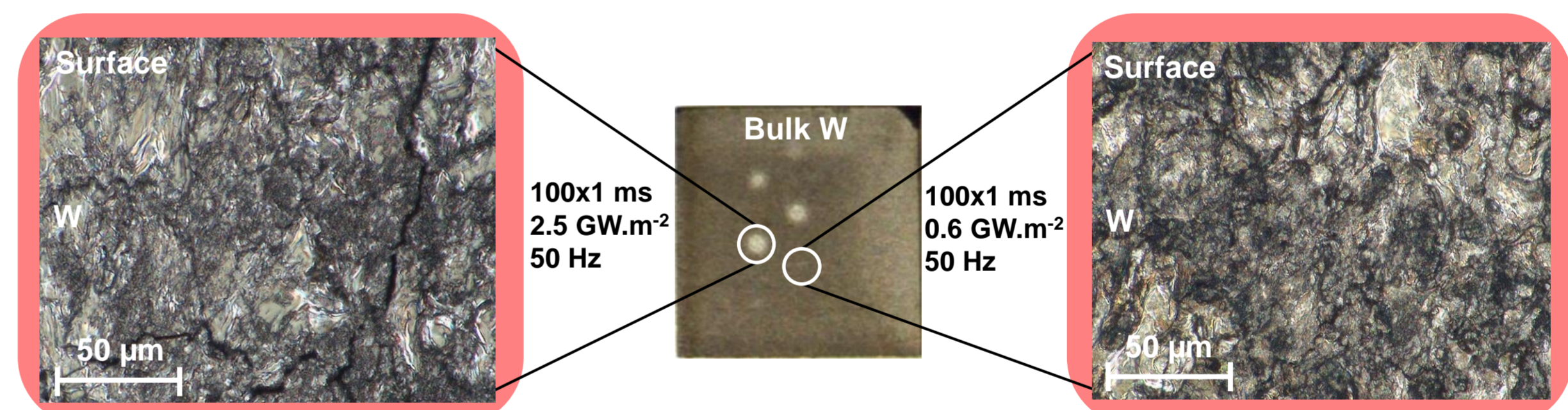


Fig 7. Melted surfaces on the ITER-grade bulk W sample under fast transients

All W-diamond samples tested under slow transients (up to 20 consecutive 1 s events) at  $100 \text{ MW}\cdot\text{m}^{-2}$  are intact while bulk W surface cracks and melts after 1 slow transient.

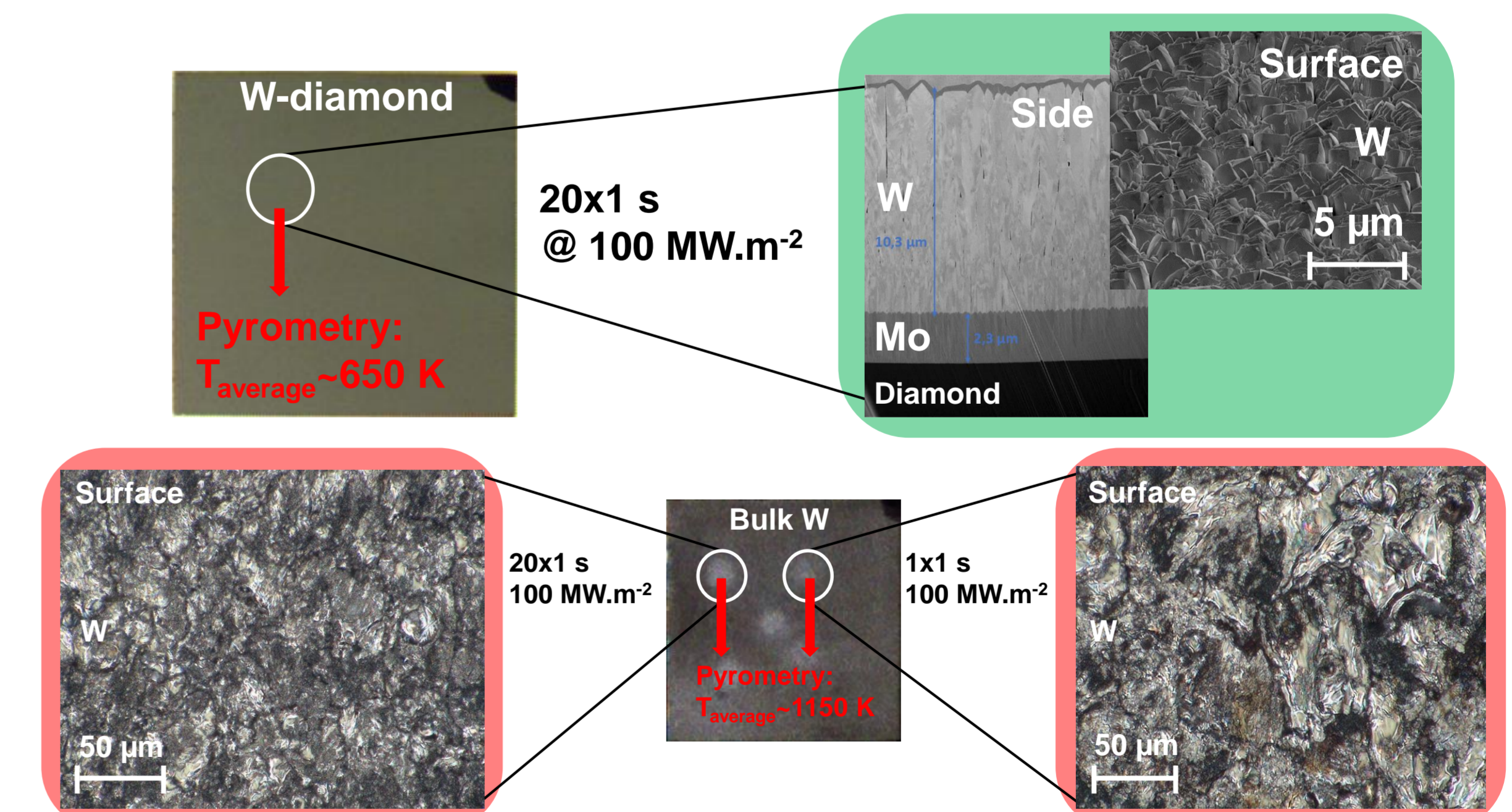


Fig 8. W-diamond and ITER-grade bulk-W samples after slow transients at  $100 \text{ MW}\cdot\text{m}^{-2}$

Systematic melting of the ITER-grade bulk W surface under thermal shocks maybe related to the reduction of its thermal conductivity by the development of cracks.

## Conclusions

Transients	Fast transients (1 ms à 50 Hz)						Slow transients (20x1 s)
	0.5 GW.m <sup>-2</sup> (16 MW.m <sup>-2</sup> .s <sup>0.5</sup> )	1 GW.m <sup>-2</sup> (32 MW.m <sup>-2</sup> .s <sup>0.5</sup> )	1.5 GW.m <sup>-2</sup> (47 MW.m <sup>-2</sup> .s <sup>0.5</sup> )	2 GW.m <sup>-2</sup> (63 MW.m <sup>-2</sup> .s <sup>0.5</sup> )	2.5 GW.m <sup>-2</sup> (79 MW.m <sup>-2</sup> .s <sup>0.5</sup> )	3 GW.m <sup>-2</sup> (95 MW.m <sup>-2</sup> .s <sup>0.5</sup> )	
W/monocrystal	OK	OK	OK	OK	Cracks	Cracks	OK
W+Mo/monocrystal	OK	OK	OK	OK	OK	Melting	OK
W/polycrystal	OK	OK	OK	OK	Melting	Melting	OK
W+Mo/polycrystal	OK	OK	OK	OK	Melting	Melting	OK
Bulk W	Melting	Melting	Melting	Melting	Melting	Melting	Melting

### References

- [1] J.P. Gunn et al., Nuclear Materials and Energy 27 (2021) 100920  
[2] G. de Temmerman et al., Nucl. Fusion 51 (2011) 052001  
[3] G. de Temmerman et al., Phys. Scr. T138 (2009) 014013  
[4] M. Minissale et al., Rev. Sci. Instrum. 91 (2020) 035102  
[5] T. Hirai et al., Journal of Nuclear Materials 463 (2015) 1248–1251