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Study of Erosion of Ceramic Materials under Transient Thermal Load

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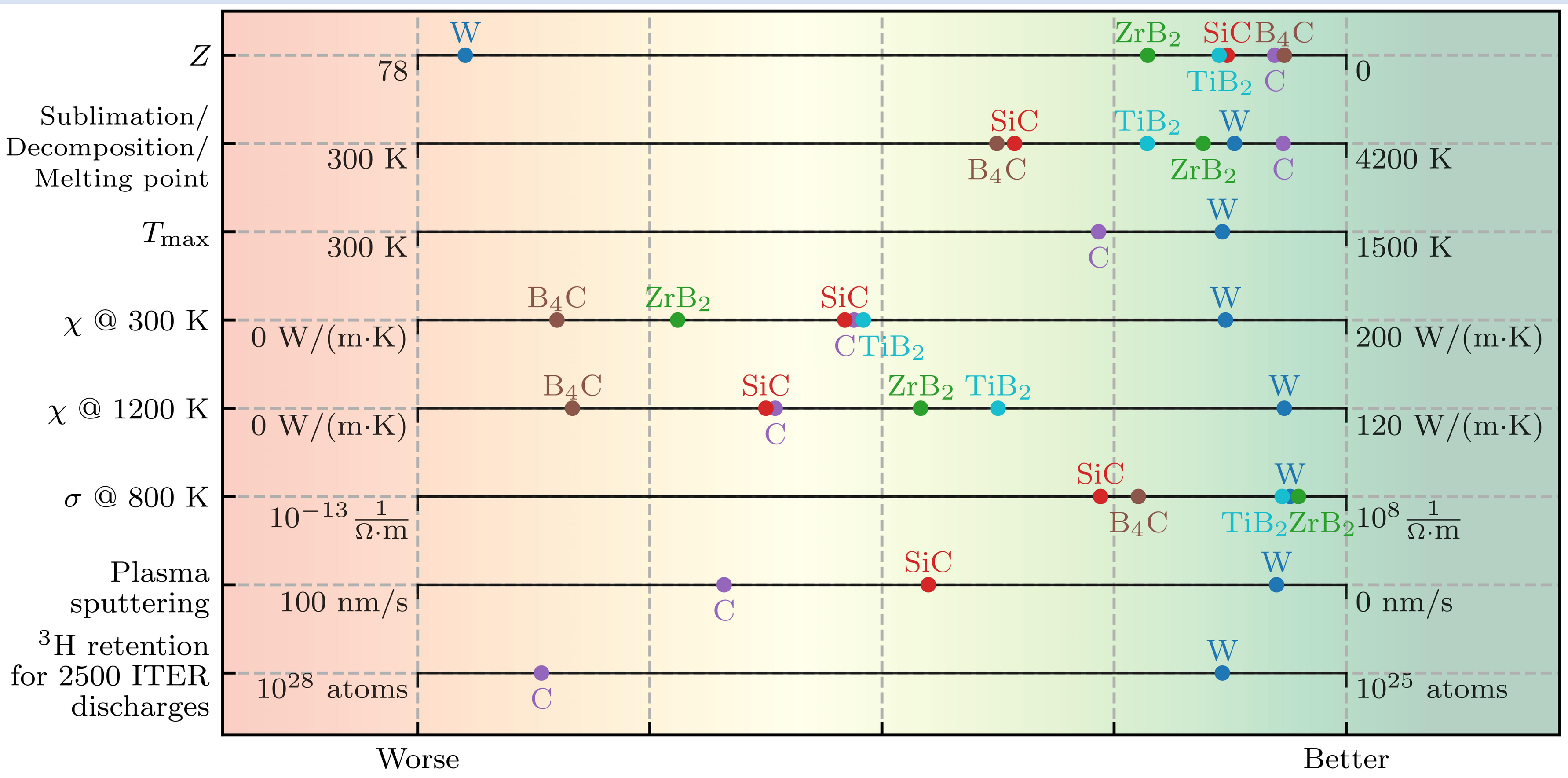
INTRODUCTION

- The interaction of the plasma with the surface of the facing components will have a significant impact on the fusion plasma parameters and will also determine the lifetime of the first wall and diverters/limiters.
- The recent replacement of beryllium by tungsten for the ITER first wall raises anew a number of issues related to plasma-surface interactions, in particular, plasma contamination by high-Z impurities.

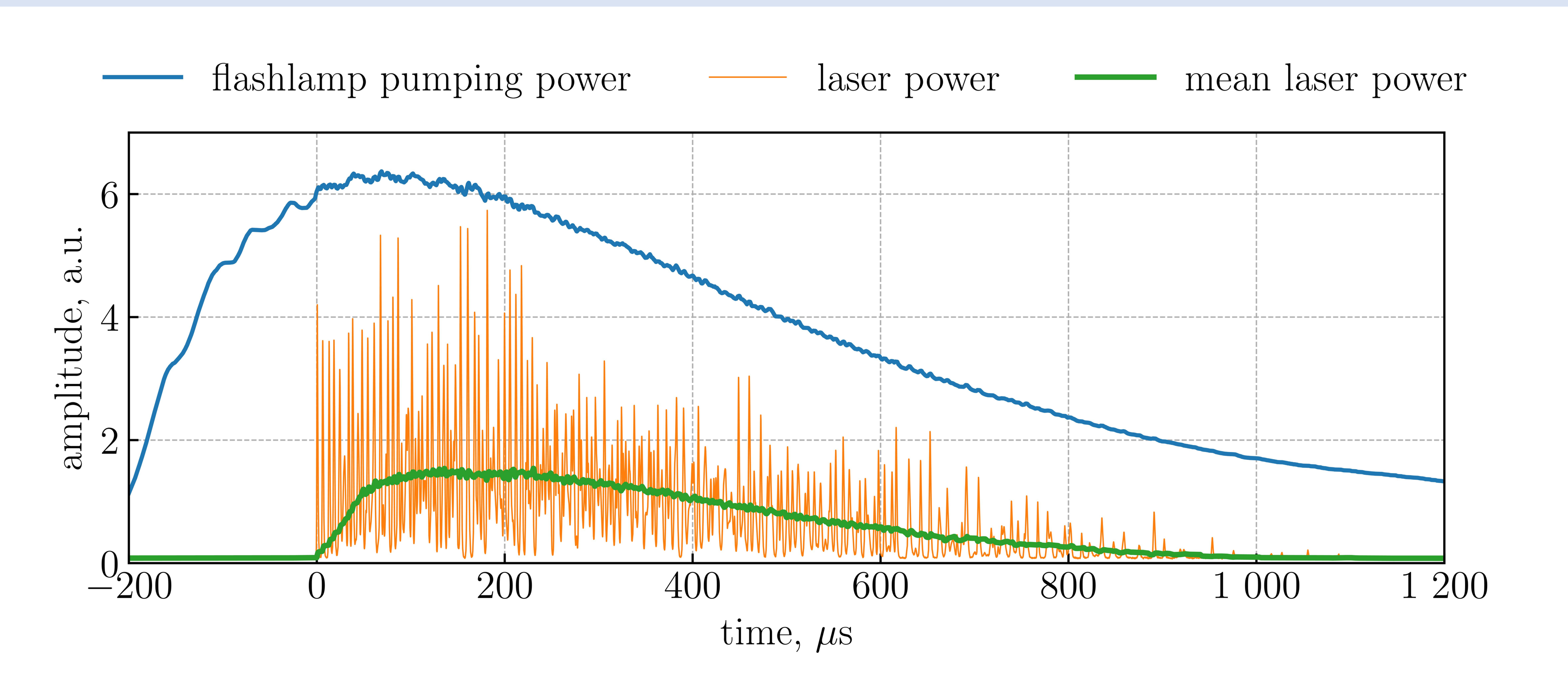


BACKGROUND

- One possible solution to this problem is to coat the tungsten with a layer of a low-Z refractory material or even replace tungsten with more optimal material, such as high-temperature ceramics.
- Experimental studies of ceramic materials promising for coating plasma-facing components (PFC) should first of all include the study of hydrogen isotope retention, as well as erosion processes under transient heat loads.

FACILITIES AT BUDKER INP

- Several experimental facilities have been developed at the Budker Institute of Nuclear Physics to study materials for fusion PFC.
- To study the effects of fusion-relevant thermal exposure on materials, powerful electron beam, continuous infrared fiber laser for pulsed-periodic material impact experiments and pulsed laser on neodymium glass are used.
- The experimental complex setups allow simulating transient heat loads (heat fluxes up to 10 GW/m^2, durations 0.1 – 1 ms).



Heating laser power dynamics

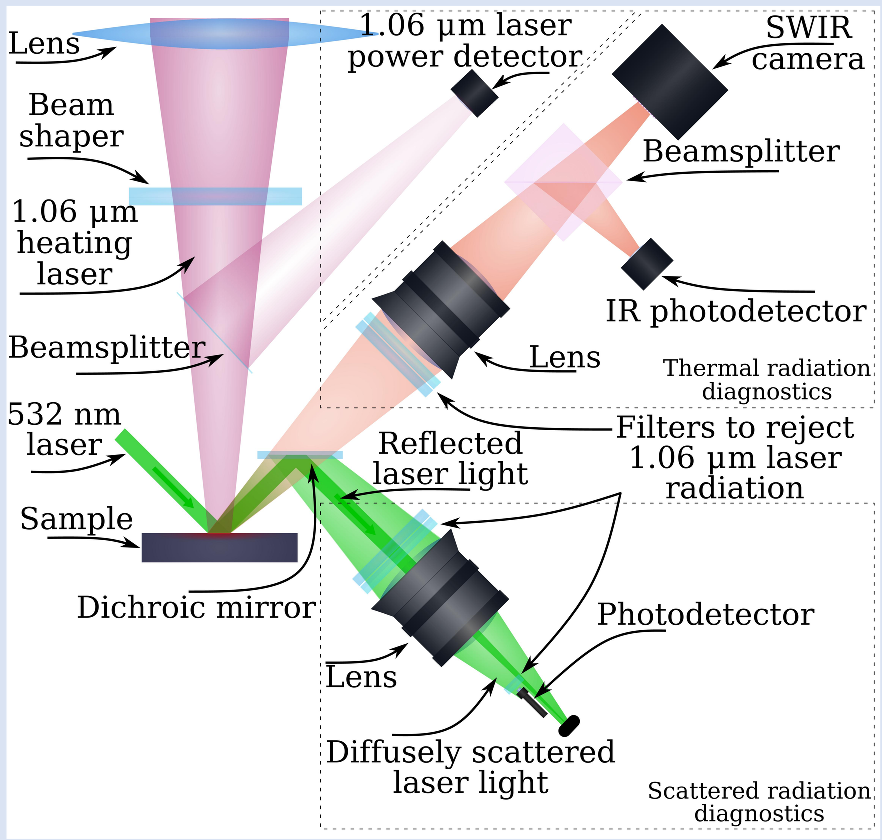
LASER HEATING

The use of laser heating enables the study of dielectric samples, as well as samples placed in a magnetic field, regardless of its strength and direction.

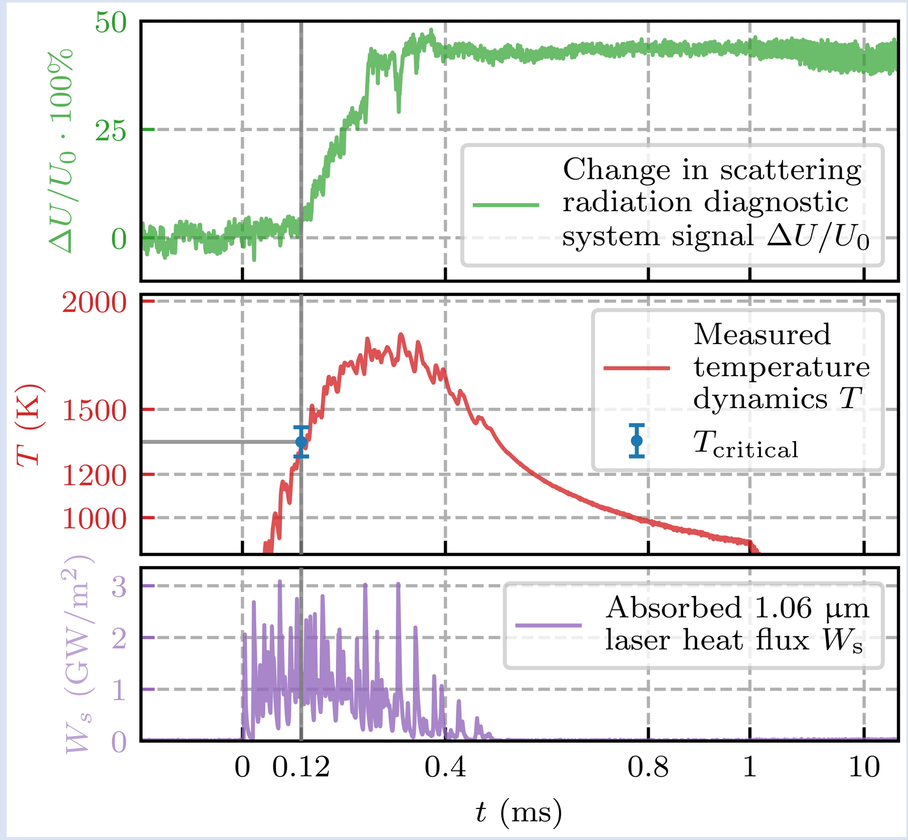
- Wavelength 1.06 um; Pulse energy up to 200 J;
- Pulse duration 500 – 800 us; Irradiated area 0.1 – 10 cm²;

DIAGNOSTICS

- The facilities are equipped with optical in situ diagnostics that allow monitoring of samples surface temperature and studying erosion processes directly during impact.



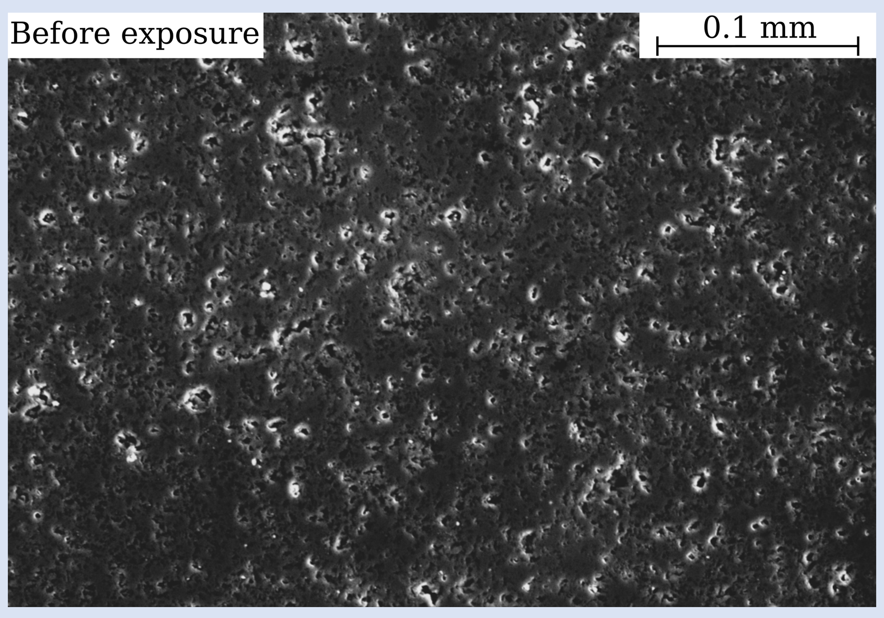
Schematic of the setup featuring the 1.06 µm heating laser path, IR power detector, thermal radiation diagnostic system, and 532 nm scattering-based erosion monitor

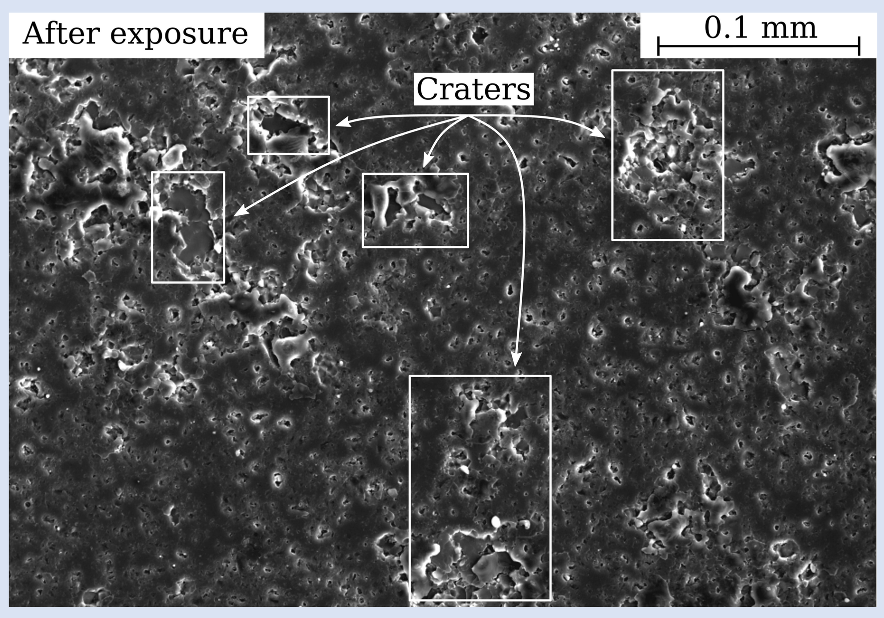


Experimental data obtained during the experiments with B_4C. From 0 ms to 1 ms, the data is plotted on a linear timescale; beyond 1 ms, a logarithmic timescale

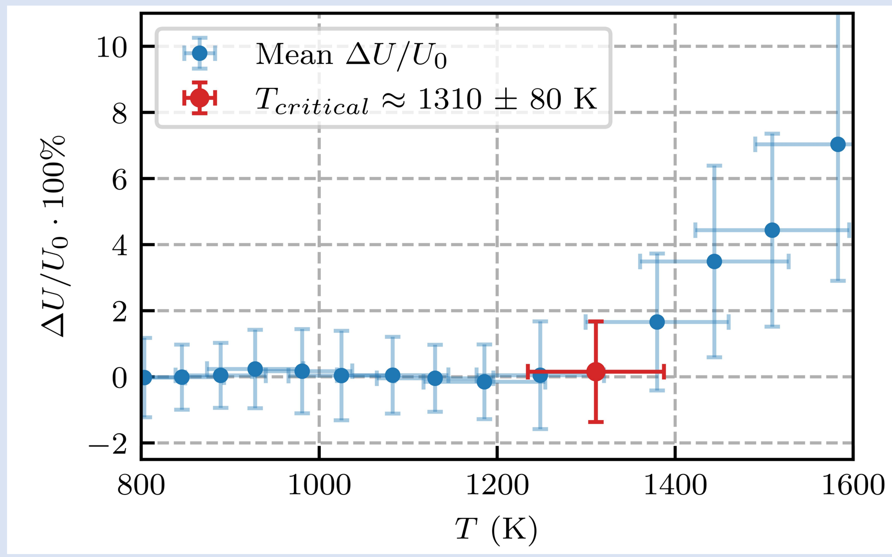
RESULTS

- The damage thresholds for a series of ceramics under transient heat loads have been determined.
- Craters formation resulting from material spallation are clearly visible.

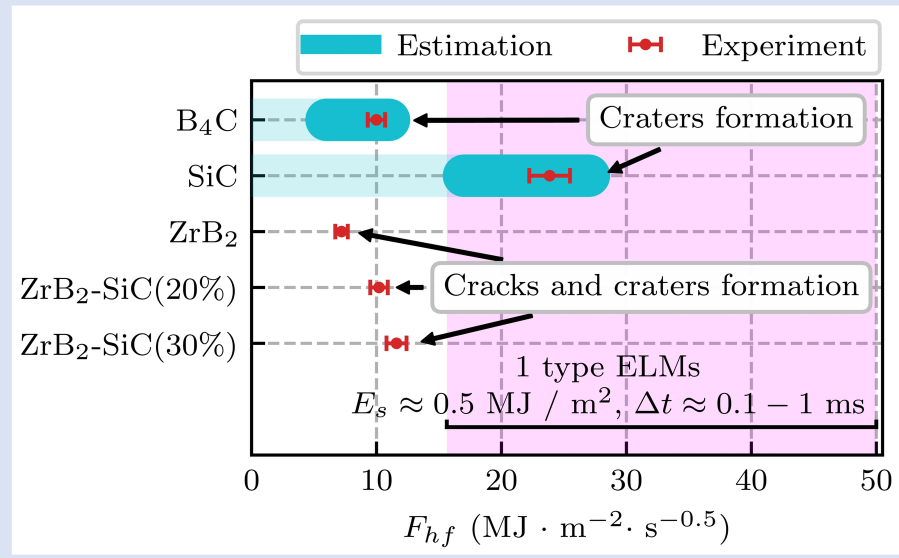




SEM images of hot-pressed B_4C



The dependence of the signal recorded by a laser scattering diagnostic. The red dot indicates the temperature corresponding to the onset of spallation.



The heat flux factors corresponding to the erosion beginning on the surfaces of boron carbide (B_4C), silicon carbide (SiC) and zirconium diboride (ZrB_2).

CONCLUSION AND PROSPECTS

- Plans for a further experimental campaign include exploring new ceramic materials, specifically diborides such as titanium diboride, as potential replacements for carbides. Carbon-free materials appear more promising due to their expected lower hydrogen retention rate.
- The nearest plans include testing samples using a stationary plasma source based on helicon discharge in magnetic field and periodic pulse electron beam.
- New sources of exposure will make it possible to study the hydrogen retention problem and phenomena associated with thermal fatigue of materials (up to 10^7 pulses and more).