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Dependence of deuterium retention and surface morphology on tungsten microstructure after high-flux plasma exposure

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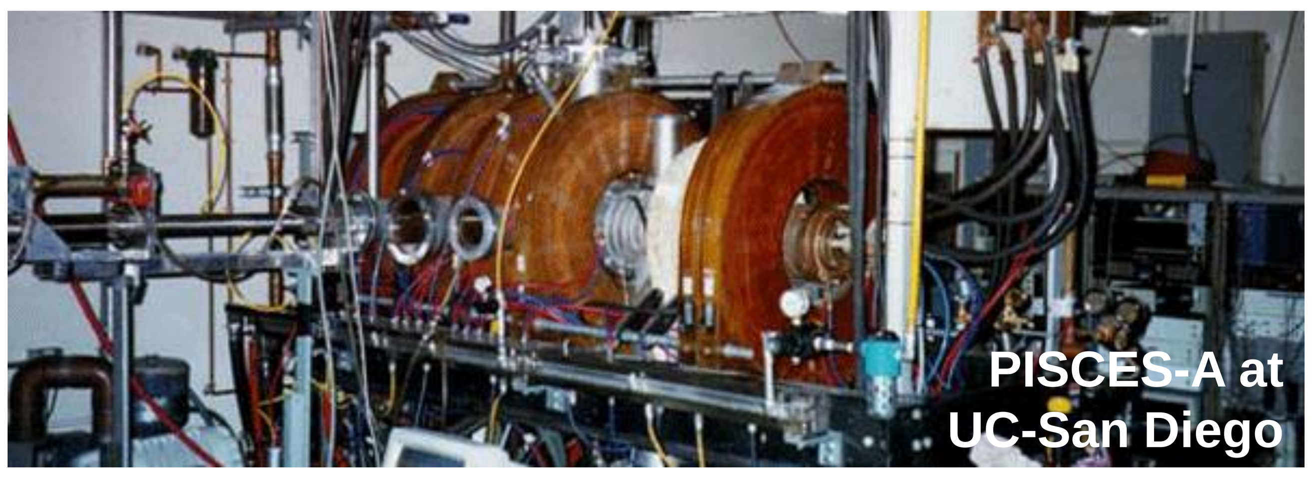
Abstract

In this study, we examine deuterium retention and plasma-induced surface morphology changes in a nanostructured W-Ti alloy recently developed at the University of Utah. The Ti precipitates (1% wt.) within the material act as grain growth inhibitors; average grain dimensions ranged between 200 nm – 1 μm. We exposed samples of this material to high-flux plasmas (E = 100 eV; ϕ = 2×10^{22} D $m^{-2}s^{-1}$; F = 5×10^{25} m^{-2}) in the PISCES-A linear plasma device over a range of temperatures between 200 °C – 500 °C. For comparison, we also exposed samples of warm-rolled (PLANSEE) and ITER-grade (Allied Materials) W at 300 °C. We characterized the post-test surface morphology using scanning probes, as well as optical and electron-based microscopy techniques. This analysis revealed that near-surface bubble formation was absent for the nanostructured tungsten, compared pure-tungsten materials, although small pits in the surface 100 nm in depth were observed. The trapped D was moderately higher than the polycrystalline pure tungsten samples. However, a broader comparison with the published literature database indicates that the retention values are still within the range of variability expected for different pure tungsten grades.

Experiment

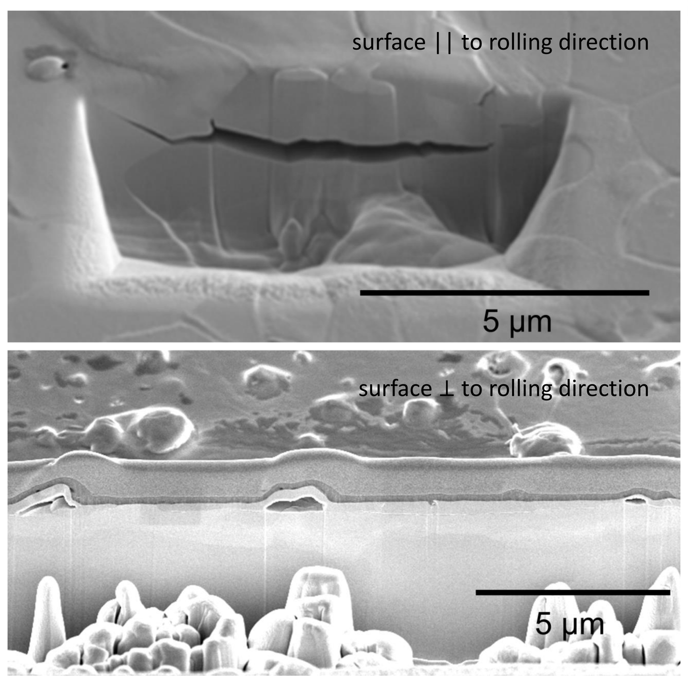
We used the PISCES-A instrument at UC-San Diego to expose the W samples to high-flux plasmas at moderate fluences. (Ion energy: 100 eV)

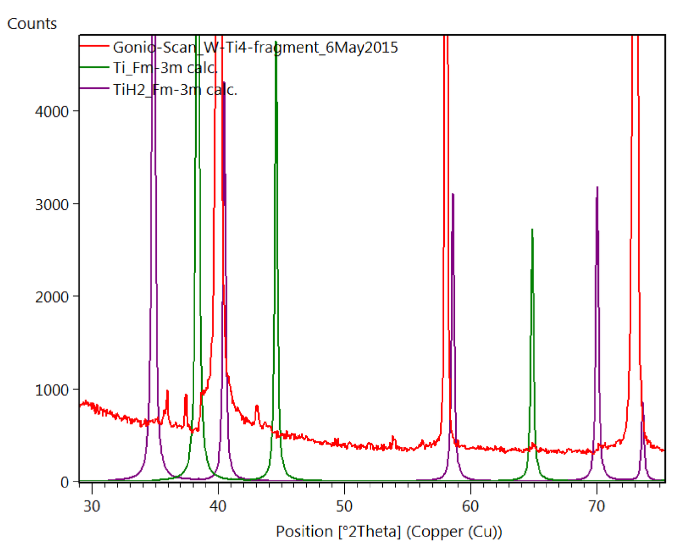


Material type	$T_{exposure}$ [°C]	duration [min]	flux (Γ_i) [m^{-2} s^{-1}]	fluence (Φ) [m^{-2}]
warm-rolled	300	60	9.3×10^{21}	3.7×10^{25}
ITER-grade	300	43	1.5×10^{22}	3.7×10^{25}
W-Ti alloy	200	30	1.7×10^{22}	3.0×10^{25}
W-Ti alloy	300	45	2.2×10^{22}	6.0×10^{25}
W-Ti alloy	500	45	2.1×10^{22}	5.7×10^{25}

Surface morphology changes

Bubble formation depends strongly on microstructure of the material. The nano-structured W shows little evidence of bubble formation.

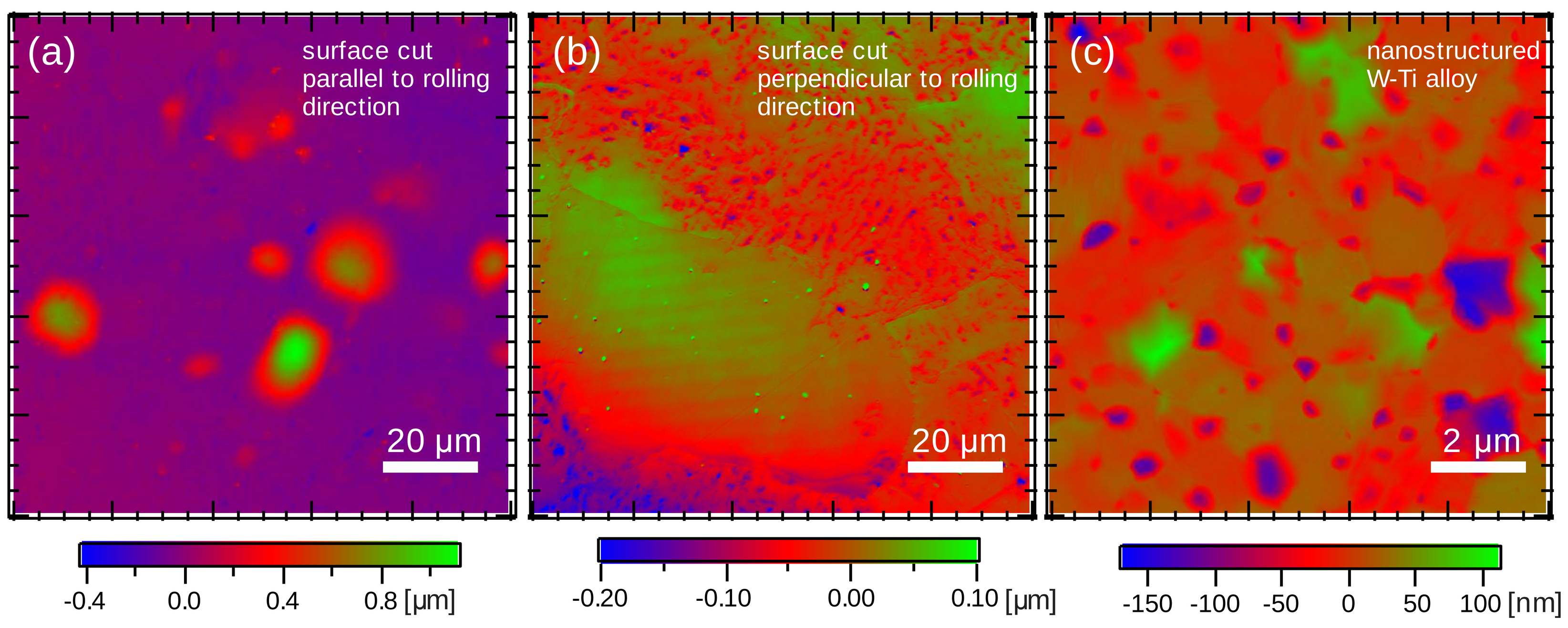




Left: X-ray diffraction of W-Ti alloy sample exposed at 200 °C. An additional phase was observed in addition to W, but was not consistent with Ti or Ti-H phases.

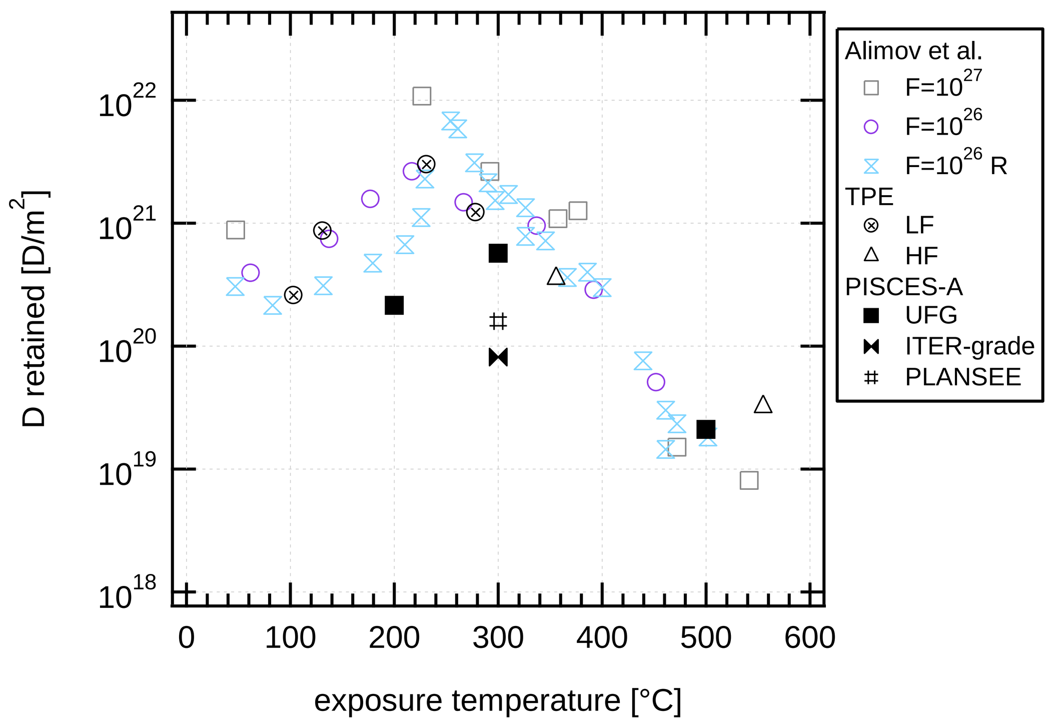
In this work we considered a new nanostructured W-Ti alloy developed at the University of Utah. The fabrication process involved:

- High-energy planetary ball milling to generate fine tungsten powder (10-30 nm diameter particles.)
- Warm compaction, and low-temperature, high-pressure sintering in an H_2 environment.
- Rapid heating during an omni-directional compaction process.
- Ti was incorporated as a grain growth inhibitor and exists as a precipitate within the W matrix (1% wt.) The resulting material has a very fine grain size (~200 nm) and minimal porosity.

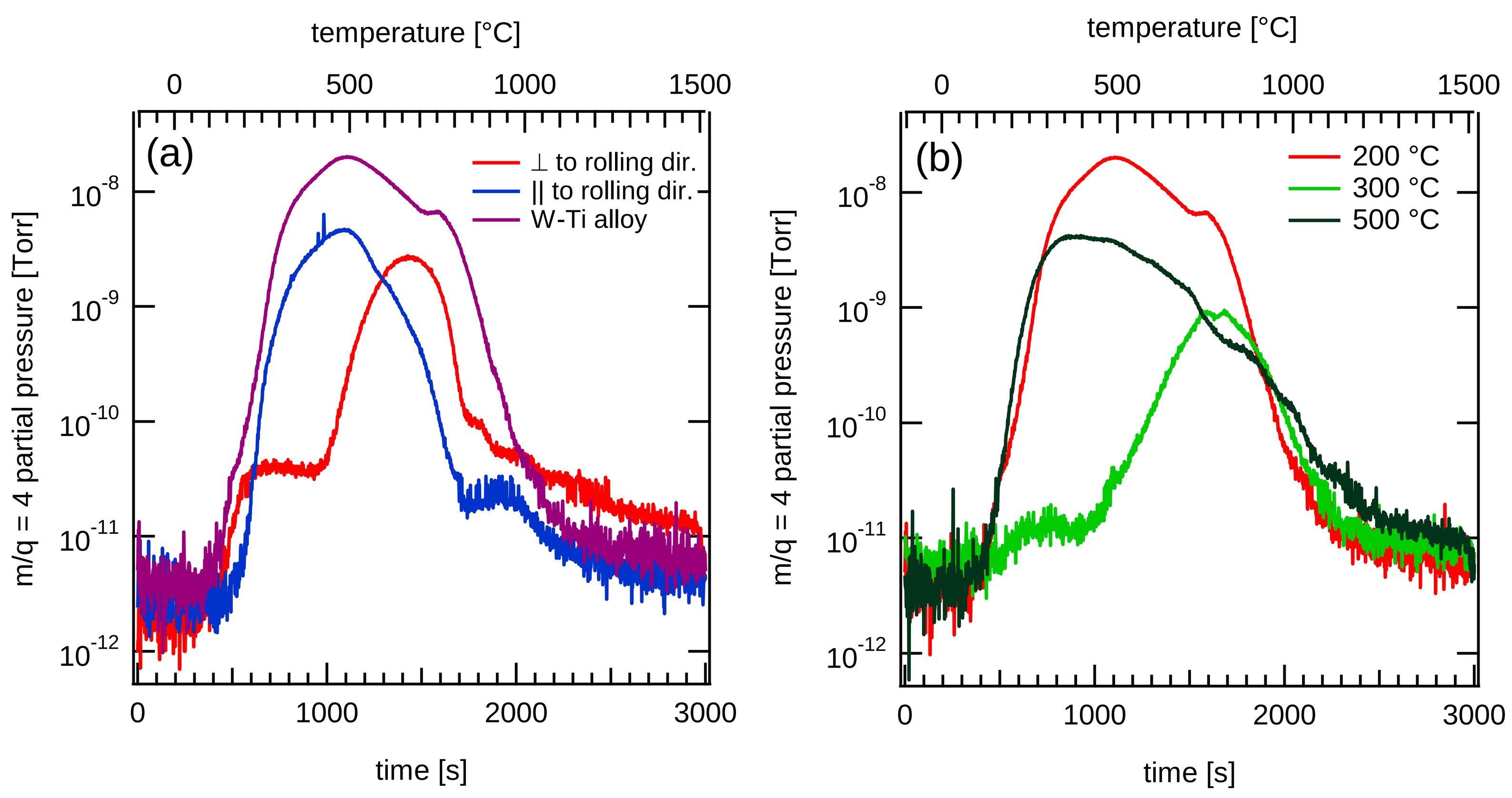


Above: Surface topography of tungsten samples after plasma exposure at 300 °C. Case (a) shows large blisters on a polycrystalline rolled tungsten (PLANSEE); (b) shows smaller blisters arising on ITER grade W; (c) illustrates the morphology of nanostructured W.

Assessment of D retention



Above: D retained in W samples as a function of temperature. Results from this work are compared with prior results from Alimov (Toyama Univ. / IPP-Garching) as well as TPE (INL). Retention in the W-Ti alloy samples as approximately 5x higher than in the reference materials, although still within the range expected for different grades of polycrystalline W.



Above: Thermal desorption spectra showing D release from the surfaces during heating (30 min ramp to 1000 °C). Panel (a) shows a comparison with reference W materials, whereas panel (b) shows desorption spectra from W-Ti alloy specimens at different temperatures.

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