Measuring and modeling helium accumulation in single crystal tungsten specimens exposed to He plasma discharges in WEST reciprocating collector probe

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ABSTRACT

- Tungsten single crystals exposed to helium plasma in WEST C4 campaign, using reciprocating collector probe
- Electron microscopy surface characterization reveals formation of nm-sized, low density 'coral' structures and formation of 50-100 nm thick surface oxide 'capping' layer
- Modeling initiated to benchmark to the implanted helium distribution, to be measured in future laser-based surface characterization and thermal desorption spectroscopy.

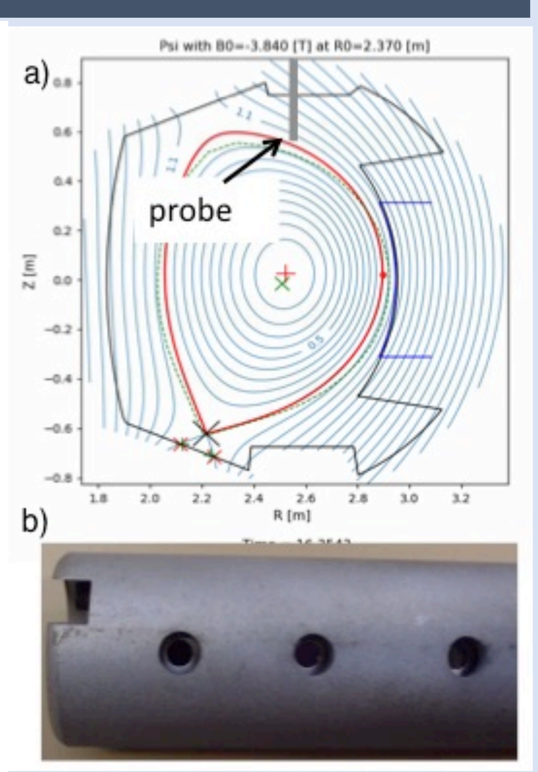
BACKGROUND

- Interfacial region where the edge plasma meets the material surfaces is a crucial scientific issue for the realization of fusion energy.
- Our team has been developing an integrated workflow for modeling plasma surface interactions (PSI) with tungsten divertor materials.
- WEST tokamak and C4 helium campaign provides an opportunity to benchmark and validate our models

RESEARCH APPROACH

RECIPROCATING COLLECTOR PROBE

During C4 He campaign on WEST, the reciprocating collector probe was inserted into the SOL plasma for approximately 20 seconds of cumulative exposure during November 2019, the lower 3 samples on both the ion and electron sides were tungsten single crystals



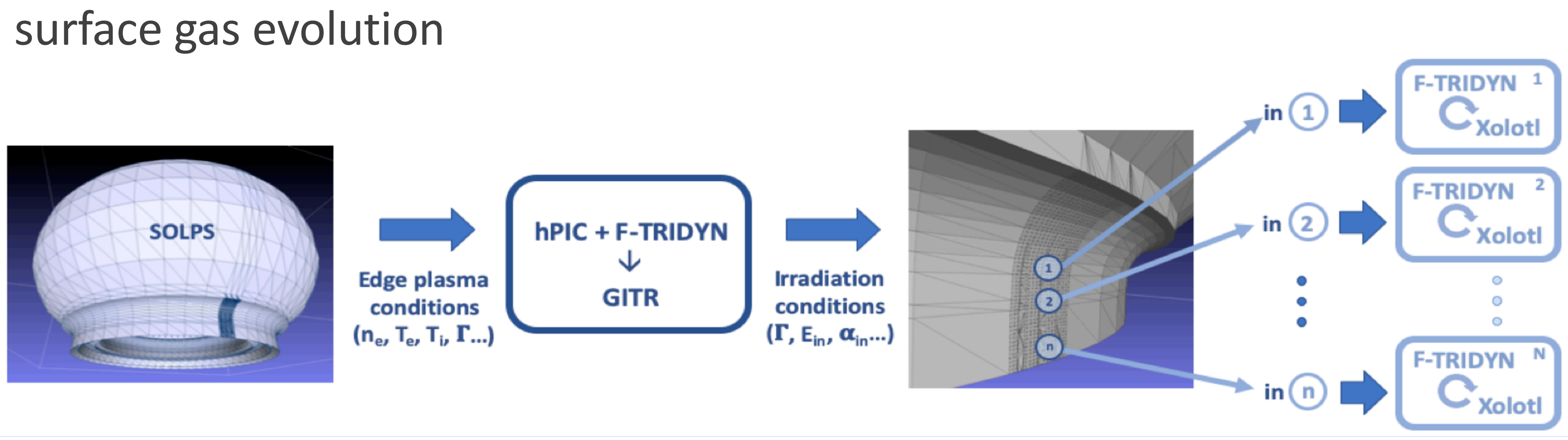
a) Schematic illustration of reciprocating probe location in WEST with magnetic field lines and last closed flux surface (red) and plasma facing surfaces (black). b) Magnified photograph of the WEST collector probe, showing the three lower sample exposure positions of single crystal tungsten.

SURFACE CHARACTERIZATION

Scanning electron microscopy (SEM) was used to provide a top down image of the surface features formed during exposure, and scanning transmission electron microscope (STEM) was used to image the surface cross-section to provide characterization as a function of depth. Future characterization will involve laser ablation based spectroscopy and thermal desorption spectroscopy.

MODELING WORKFLOW

As shown below, our integrated PSI modeling involves SOLPS simulations of the background plasma, coupled to hPIC for assessing sheath effects and F-TRIDYN/XOLOTL to model the ion-surface interactions and implanted, sub-surface gas evolution

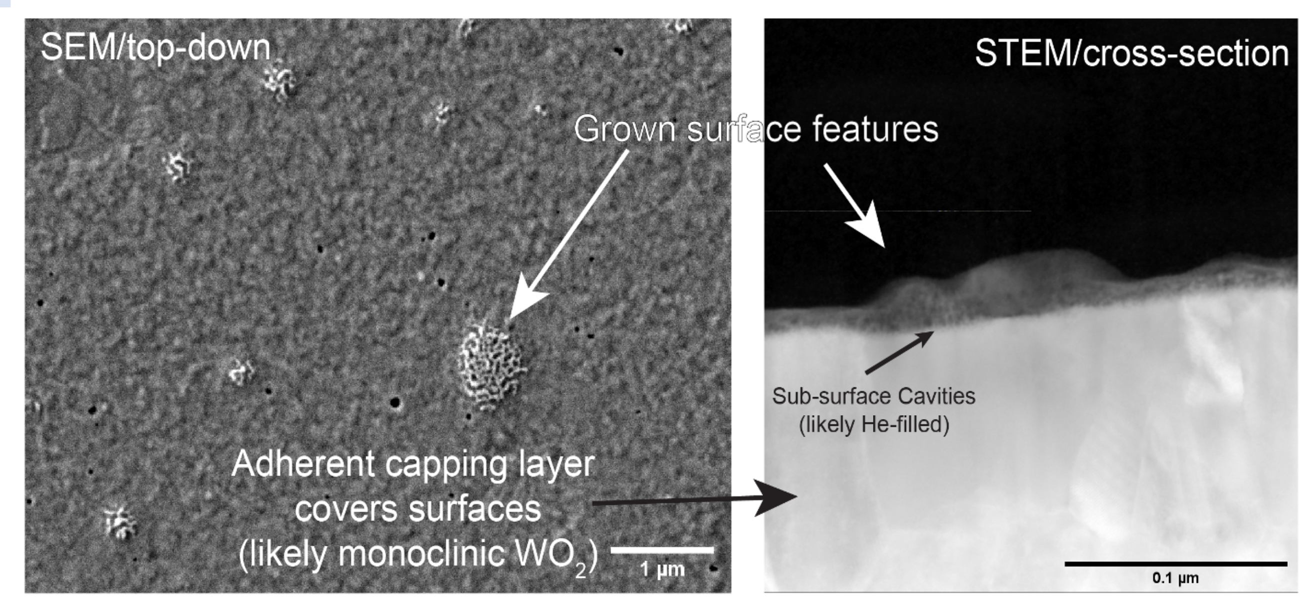


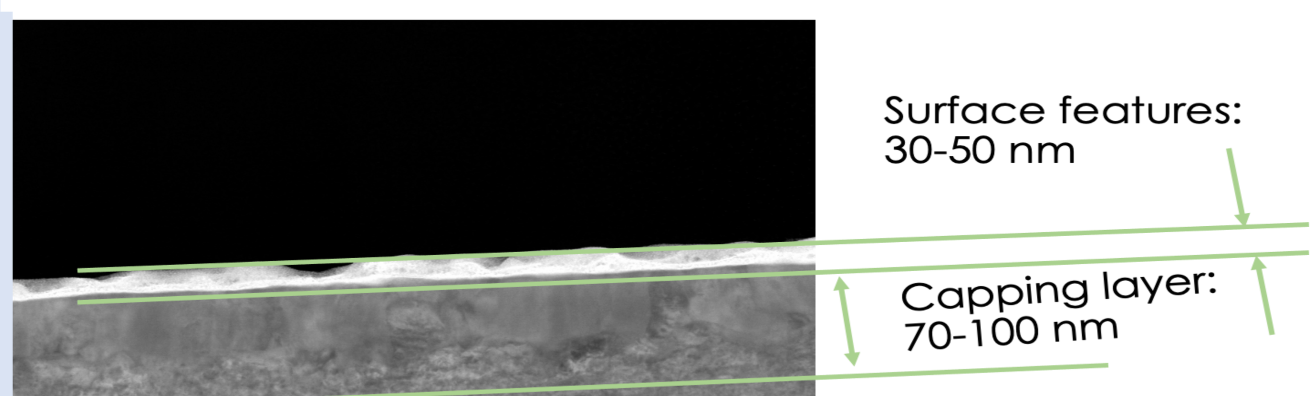
OUTCOME

OBSERVED SURFACE FEATURES AND OXIDE DEPOSITION

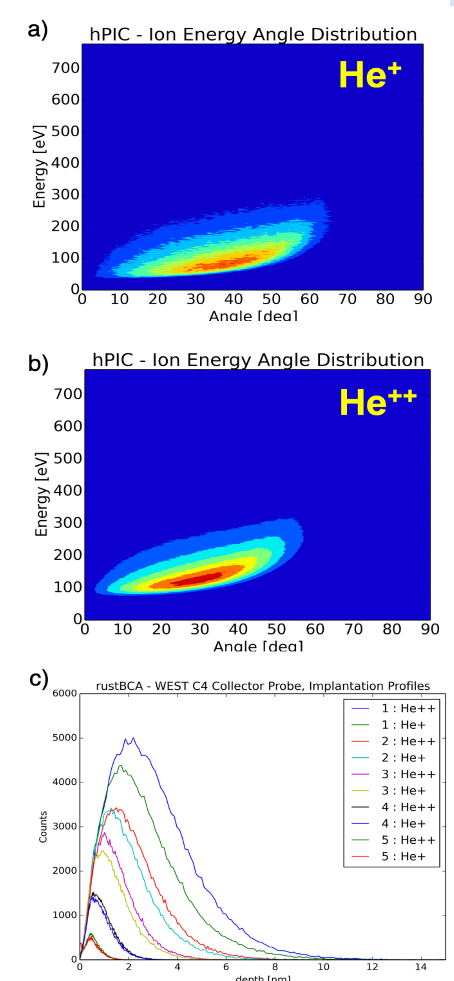
50-100 nm diameter surface protrusions, consisting of low-density, 'coral' type structures were observed on the W(111) single crystal exposed to ≈7×10^{23} He m^{-2}, and those features appear to contain cavities, which we presume are helium-filled.

As well, a surface oxide layer of approximately 70-100 nm in thickness was observed across the entirety of the tungsten sample.





SEM and STEM images of the W(111) single crystal exposed to the WEST C4 He plasma, showing surface features and a 70-100 nm oxide thickness



a) and b) ion energy angle distributions for He+ and He++ at the ion side lowest W(111) sample in the WEST reciprocating probe (R1), and c) corresponding ion implantation depth profile for ion side collector probe positions 1 through 5.

PSI MODELING

Helium ion energy angular distributions at the W(111) sample in the collector probe, and the implanted He depth distribution are shown to the right.

CONCLUSION

- Surface features, consisting of low-density, coral-like deposits and an approximately 50 to 100 nm thick oxide layer are observed by electron microscopy. Further characterization has been delayed by the Covid-19 pandemic, but will be reported in the future to assess and quantify the depth dependent helium and oxygen concentration
- These data will provide opportunities to benchmark our integrated PSI modeling, which is underway and ongoing

ACKNOWLEDGEMENTS / REFERENCES

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