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

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We report the results of experimental characterization of the depth dependent helium concentration in single crystal tungsten specimens, as compared to modeling predictions, following repeated helium plasma exposures in the reciprocating collector probe in WEST during the C4 helium campaign. This study was motivated by the opportunity to experimentally validate modeling predictions of the helium retention and sub-surface helium spatial profiles and bubble concentrations following helium plasma exposure conditions in WEST, which is an all tungsten metal long pulse tokamak. WEST has a reciprocating collector probe that can be inserted into the far scrape off layer plasma (Fig. 1a) and provides repeatable exposure conditions during reproducible plasma discharges that limit sample heating and yet still provide significant helium plasma exposure that is above experimental detection thresholds. This enables experimental validation in well controlled conditions of a high fidelity, integrated modeling capability for plasma surface interactions that has recently predicted the performance of the ITER tungsten divertor to initial operation conditions relevant to helium plasma operation as well as for burning plasma conditions 1.

Six single crystal tungsten samples were loaded in the reciprocating collector probe and exposed to repeated plasma discharges in November 2019 to reach an accumulated helium fluence ranging from approximately 2 to 7x1023 m-2. Figure 1 shows a schematic illustration of the probe location in the WEST tokamak with the magnetic field lines and plasma facing surfaces, respectively, along with a photograph of the three lower slots containing tungsten single crystal samples in the collector probe. Two different tungsten single crystal orientations, either (100) or (111), were used in this experiment, in order to test modeling predictions that (111) oriented surfaces retain significantly more helium than (100) oriented tungsten surfaces 2.

These exposure conditions have been modeled using our coupled, high-fidelity plasma-surface interaction codes, including the evolution of the plasma-facing component (PFC) surface layer that is continually modified by contact with the fusion plasma. This approach to modeling plasma surface interactions is shown in Figure 2, and involves a wide range of physical phenomena: our current model includes components for a) the scrape-off layer plasma including helium and extrinsic impurities (using SOLPS[3]), b) the implantation of plasma ions into the material, including electromagnetic sheath affects, and subsequent wall erosion (using hPIC [4] and F-TRIDYN, and extension of TRIDYN [5]), and c) the dynamics of the subsurface (Xolotl, a continuum cluster dynamics code 2). These components are integrated to yield predictive capability for the changes in surface morphology in addition to the sub-surface helium retention and spatially dependent concentrations. The SOLPS modeling predictions of the background plasma conditions during the WEST helium plasma discharges have been benchmarked to Langmuir probe data obtained by the collector probe, and provide input to hPIC, F-TRIDYN and Xolotl on the helium implantation conditions (flux, ion energy).

The experimental measurements include laser ablation based techniques to quantify the depth dependence of the helium, using laser induced breakdown spectroscopy and laser ablation mass spectrometry. These laser based measurements build upon prior measurements of the helium and deuterium spatial distributions following low-energy plasma exposure in PISCES/A [6]. Additionally, thermal desorption measurements are performed to quantify the helium release kinetics and to provide additional experimental data to compare with the coupled plasma surface interaction modeling predictions of Xolotl. This presentation will discuss the agreement between the modeling predictions and experimental observations, possible reasons for any discrepancies, and plans for future experiments.

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Country or International Organization

United States

Affiliation

University of Tennessee, Knoxville

Authors: Prof. WIRTH, Brian (University of Tennessee, Knoxville); Dr BERNARD, Elodie (CEA, IRFM); Dr BLONDEL, Sophie (University of Tennessee, Knoxville); CANIK, John (Oak Ridge National Laboratory); Dr CIRAOLO, Guido (CEA IRFM); Prof. CURRELI, Davide (University of Illinois, Urbana-Champaign); Mr DROBNY, Jon (University of Illinois, Urbana-Champaign); Ms GARCIA, Wendy (University of Tennessee, Knoxville); Dr GUNN, Jamie (CEA, IRFM); Ms HAYES, Alyssa (University of Tennessee, Knxoville); Dr HU, Xunxiang (Oak Ridge National Laboratory); Dr LASA, Ane (University of Tennessee, Knoxville); Dr LORE, Jeremy (Oak Ridge National Laboratory); Dr PARISH, Chad (Oak Ridge National Laboratory); Mr PASCAL, Jean-Yves (CEA IRFM); Dr PEGOURIE, Bernard (CEA IRFM); Dr TSITRONE, Emmanuelle (CEA IRFM); Dr UNTERBERG, Ezekial (Oak Ridge National Laboratory); Dr YOUNKIN, Tim (Oak Ridge National Laboratory)

Presenter: Prof. WIRTH, Brian (University of Tennessee, Knoxville)

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