Investigating Helium-Hydrogen Synergies and Depth Dependent Concentrations in Tungsten Using a Combination of Permeability Measurements, Laser Induced Breakdown Spectroscopy, Laser Ablation Mass Spectroscopy, and Thermal Desorption Spectroscopy

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Tungsten (W) is the leading candidate plasma facing material for future fusion reactors and will be the divertor in ITER. The in-service environment inflicts significant challenges to W due to an intensive flux of particles (i.e. hydrogen (H) isotopes, Helium (He), and 14 MeV neutrons) and high thermal flux. These environmental conditions lead to He bubble formation, displacement damage, W surface erosion, and enhanced H isotope retention. Understanding the synergies between He and H isotopes in W is essential to further the plasma-material-interaction R&D.

Conventional experimental techniques, such as thermal desorption spectroscopy (TDS), ion beam analysis or neutron depth profiling (NDP), used to characterize He and H isotopes in W have limitations in providing a comprehensive surface to bulk characterization and differentiating between elements with similar atomic number. Using a combination of techniques will provide a more comprehensive understanding of complex He-H interactions and synergies as opposed to utilizing a single technique. In this presentation we demonstrate the use of a gas-driven permeability system, TDS, laser induced Breakdown spectroscopy (LIBS) and laser ablation mass spectrometry (LAMS) techniques to perform comprehensive surface-to-bulk depth dependent concentration analysis of He and D in W, in addition to assessing the impact of He on D permeation flux. (111) oriented single-crystalline and polycrystalline (PC) W specimens have been exposed to a mixed He/D plasma at 75 or 250 eV in the UCSD PISCES-A facility at 300 °C and 500 °C to fluences ranging from $4.2 \times 10^{25}$/m\textsuperscript{2} to $2 \times 10^{26}$/m\textsuperscript{2}. Depth dependent concentration profiles of He and D in W are simultaneously measured and characterized using LIBS and LAMS. Post-ablation W crater analysis show a depth-resolution of ~50 nm/ablation and an ablated cross-sectional area of about 55 µm in diameter. Strong agreement between LIBS and LAMS measurements of D and He concentrations, provides confidence in the complementary application of these techniques.

LIBS/LAMS depth dependent concentration measurements are also described for room temperature, 10keV He implanted PC W specimens to a fluence of $1 \times 10^{20}$ He/m\textsuperscript{2} and subsequently annealed to 1000°C for 1 hour. The results are compared to cluster dynamics simulations, NDP measurements, and theoretical SRIM implantation profiles. Additionally, gas-driven D permeability measurements are described for 6 mm x 5mm W disks at temperature from 600°C to 1000°C in increments of 100°C. The results of these measurements will be discussed in the context of prior literature measurements, and how the complementary measurements improve knowledge of complex D-He interactions.