Contribution ID: **57** Type: **contributed**

Surface Characterization of Advanced Tungsten and Ceramic Plasma-Facing Materials

Wednesday 28 May 2025 11:40 (20 minutes)

This study focuses on using a combination of surface characterization techniques to assess the response of advanced tungsten alloys and ultra-high temperature ceramics (UHTCs) to high-flux plasmas. While these materials are at an early stage of development, they potentially offer superior thermomechanical properties and microstructural stability relative to other existing candidate materials. Our ongoing work focuses on assessing their performance from an erosion, defect nucleation, and hydrogen isotope retention standpoint.

One important diagnostic requirement is the ability to directly detect and quantify how hydrogen isotopes interact with other species present at the exposed surface. Most electron spectroscopy techniques provide only limited sensitivity to hydrogen isotopes. To overcome this challenge, our group employs low energy ion beam techniques that provide direct sensitivity to chemisorbed deuterium through analysis of scattered and recoiled particles. Our basic approach relies on an ultrahigh vacuum system equipped with an electrostatic analyzer, allowing us to perform low energy ion scattering (LEIS), direct recoil spectroscopy (DRS), and x-ray photoelectron spectroscopy (XPS), and thermal desorption spectroscopy (TDS) in one measurement chamber. LEIS and DRS measure the surface chemical composition, including hydrogen isotopes, with sub-monolayer sensitivity. While XPS is not strongly sensitive to D, it provides complementary information on the chemical bonding between species and their electronic structures. Finally, TDS is used to assess surface-to-bulk transport of hydrogen isotopes in these materials.

In this report, we will summarize recent results from applying these techniques to different dispersoid-strengthened W-TiO_2 alloys and K-doped W materials. Incorporation of additive species was found to have a modest effect on hydrogen isotope chemisorption behavior on sputter-cleaned surfaces, since the surface is dominated by W which readily dissociates molecular hydrogen. For most materials, the surface hydrogen concentration diminishes during heating to 500 ℃, following an Arrhenius trend when dosing with a partial pressure of 10^{-6} Torr D_2(g). The presence of O and C impurities, however, has a much more dramatic effect on reducing the chemisorbed H concentration. The effect of the alloy components was found to be more pronounced from a hydrogen retention and sputtering standpoint. Hydrogen retention in W-TiO_2 dispersoid-strengthened material has been observed to be a factor of 2-3 higher than in pure polycrystalline W, and enhanced sputtering of the dispersoid material was also observed relative to the surrounding tungsten matrix. In addition to these measurements, we will also discuss preliminary results for newer ZrC UHTC's and nanostructured W materials as part of a new project focusing on the development of advanced plasma-facing materials.

Sandia National Laboratories is a multi-mission laboratory managed and operated by National Technology & Engineering Solutions of Sandia, LLC (NTESS), a wholly owned subsidiary of Honeywell International Inc., for the U.S. Department of Energy's National Nuclear Security Administration (DOE/NNSA) under contract DE-NA0003525.

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Session Classification: contributed