Helium Gas Clustering Dynamics in Tungsten Exposed to Helium Plasmas

Brian D. Wirth, and the SciDAC-PSI team
Department of Nuclear Engineering, University of Tennessee

Abstract

The plasma facing components, first wall and blanket systems of future tokamak-based fusion power plants arguably represent the single greatest materials engineering challenge of all time. Indeed, the United States National Academy of Engineering has recently ranked the quest for fusion as one of the top grand challenges for engineering in the 21st Century. These challenges are even more pronounced by the lack of experimental testing facilities that replicate the extreme operating environment involving simultaneous high heat and particle fluxes, large time varying stresses, corrosive chemical environments, and large fluxes of 14-MeV peaked fusion neutrons. Fortunately, recent innovations in computational modeling techniques, increasingly powerful high performance and massively parallel computing platforms, and improved analytical experimental characterization tools provide the means to develop self-consistent, experimentally validated models of materials performance and degradation in the fusion energy environment. This presentation will describe the challenges associated with modeling the performance of plasma facing component and structural materials in a fusion materials environment, the opportunities to utilize high performance computing and then focus on recent progress to investigate the dramatic surface evolution of tungsten exposed to low-energy He plasmas. More specifically, multiscale modeling results will be presented to identify the mechanisms of tungsten surface morphology changes when exposed to 100 eV He plasma conditions as a function of temperature and initial tungsten microstructure. The results demonstrate that during the bubble formation process, He clusters create self-interstitial defect clusters in W by a trap mutation process, followed by the migration of these defects to the surface that leads to the formation of layers of adatom islands on the tungsten surface. As the helium clusters grow into nanometer sized bubbles, their proximity to the surface and extremely high gas pressures leads them to rupture the surface thus enabling helium release. Helium bubble bursting induces additional surface damage and tungsten mass loss, which varies depending on the nature of the surface. However, these computational results also clearly identify the importance of rate effects associated with the implantation flux (plasma current) on the quantity of retained helium and the gas bubble populations, and the impact of this rate effect will be discussed in relation to ITER operation and beyond.