Contribution ID: **505** Type: **Oral**

Model validation on EAST and DIII-D experiments towards understanding of high-Z material erosion and migration in a mixed materials environment

Friday 26 October 2018 11:05 (20 minutes)

The 3D Monte Carlo code ERO taking into account a material mixing surface model has been used to simulate tungsten (W) erosion and migration on EAST with an upper full W divertor and DIII-D with toroidally continuous W rings embedded in the divertor target. Modeling shows that the transport of carbon (C) impurities not only dominates the W sputtering source but also determines the overall erosion and deposition balance in the mixed materials surface. With a self-consistent calculation of transport of C impurities and taking into account the re-erosion of W by returned eroded particles, W gross erosion rates measured by WI spectroscopy can be well reproduced by the modeling for both devices. The ExB drift and lower electron temperature at the radial outboard side lead to a net deposition zone where W and C are accumulated, which is consistent with the measurements with several changeable inserts in a specially designed collector probe at the DiMES system in DIII-D. In the net erosion zone closer to the outer strike point, the W coverage on C is very low and saturated independent of exposure time, agreeing with the measurements by collector probes. Strong sheath effects on material erosion rates have also been observed using external biasing samples. The particle flux and material erosion as a function of biasing voltage have been analyzed by the SPICE2 and the ERO code. Both the PIC simulation and the Dα emission measured by a fast camera reveal that with increasing biasing voltage the ion flux decreases at the biased area while increases at the adjacent downstream tile, although the biased sample potential is far below the plasma potential. Detailed modeling shows that the ion flux variation at different area is due to the strong gradient of the electric field in the sheath, which results in different magnitude of the polarization drift above the biased and non-biased surface. The reduced ion flux and incident energy are responsible for more than an order of magnitude reduction of erosion with slight positive voltage biasing in the experiments. The critical role of C impurities and the sheath in determining high-Z material erosion and migration have been revealed. This understanding indicates promising methods for erosion control, which is critical for material lifetime, plasma impurity content, and tritium retention in future fusion reactors.

Country or International Organization

China, People's Republic of

Paper Number

MPT/2-2

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Session Classification: MPT/2, FNS/1, SEE/2 Materials, Fusion Nuclear Science, Environmental

Track Classification: MPT - Materials Physics and Technology