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Recent progress in understanding of high-Z material erosion and re-deposition in tokamaks with a mixed materials environment

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Modeling of recent experiments on EAST and DIII-D tokamaks reveals the critical role of background low-Z impurities and the sheath in determining high-Z material erosion and re-deposition in a mixed materials environment. This understanding leads to promising methods for erosion control, which is critical for material lifetime, plasma impurity content, and tritium retention in fusion reactors.

The 3D Monte Carlo code ERO taking into account a material mixing surface model has been used to simulate tungsten (W) erosion and re-deposition 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 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 the distribution of background carbon (C) impurities in different charge states, W gross erosion rates measured by WI spectroscopy diagnostics can be well reproduced by the modeling. The ExB drift and lower electron temperature at the radial outboard side lead to a net deposition zone where W and C are accumulated. 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 been observed using external biasing samples. The particle flux and material erosion as a function of biasing voltage have been simulated by the 2D Particle-In-Cell (PIC) code SPICE2 and the ERO code. Both the PIC simulation and the D_α 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.

References

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