Advances in Tungsten Ultraviolet Spectroscopy via Improved Atomic Physics Calculations for Erosion Diagnostics in Fusion Plasmas

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Measurements of tungsten (W) gross-erosion and re-deposition rates have been derived from high-resolution ultraviolet (UV) spectroscopy in the lower divertor of the DIII-D tokamak. These results leverage new spectrometric capabilities in the DIII-D device along with improved atomic data for neutral [1] and near neutral charge states of W [2,3] and lead to substantial advances in understanding processes governing W erosion under conditions relevant for future fusion devices. The atomic data consists of R-matrix calculations for the electron-impact excitation [2,3] and exchange classical impact parameter data for ionization [1]. W erosion and transport in future fusion devices could cause unacceptable levels of high-Z impurities in the core, reducing plasma performance by radiation losses. For ionizing conditions ($T_e > 10$ eV), W erosion fluxes can be quantified by atomic line spectroscopy combined with ionization per photon coefficients (S/XBs) obtained from collisional-radiative (CR) atomic physics models [4]. The intensity of the W I emission line at 400.88 nm, commonly used for erosion measurements, can depend on metastable state populations [5]. Conversely, measuring several neutral tungsten emission lines (W I) in the UV wavelength range allows for precise W gross-erosion measurements. In addition, most emission from higher W charge states occurs below 400 nm, enabling W re-deposition measurements.

W-coated graphite samples were exposed over a range of plasma conditions (n_e ~$1 - 2 \times 10^{19}$ m^{-3}, T_e ~15 - 35 eV) using the Divertor Material Evaluation System (DiMES) manipulator. W erosion rates during experiments were of the order of ~1×10^{19} atoms m^{-2} s^{-1}, like previous DIII-D experiments [6]. Emission observed at 255.13 nm is the most intense W I line and is not dependent on metastable levels, while a W I line at 265.65 nm is populated from the same metastable states as the 400.88 nm line. Spectroscopic data from W I emission lines combined with post-mortem Rutherford backscattering measurements of material erosion from W samples yield empirical S/XBs values systematically larger than CR predictions, consistent with underestimated ionization rates [1].

Furthermore, the simultaneous observation of W I and W II emission provides lower bound of W re-deposition estimations, while higher tungsten charge states (W III, …) are needed for more accurate measurements. Post-exposure re-deposition fractions of ~75 – 80% have been measured from W samples of 1.5 cm in diameter. Additionally, pairs of W I emission lines can be used as line ratio diagnostics for T_e in the plasma edge, giving T_e values slightly below Langmuir probe measurements.

References
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