High-resolution laboratory measurements of tungsten M-shell x-ray spectra for burning plasma diagnostics in SPARC and ITER

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High-resolution x-ray crystal spectroscopy (XRCS) is routinely used on tokamaks to measure the ion temperature and toroidal rotation profiles by monitoring the Doppler broadening and Doppler line shifts, respectively, of intrinsic or seeded impurity line emission. The SPARC tokamak, currently under construction, will similarly employ this diagnostic method. The designed XRCS system is optimized to view the Ne-like Xe 3D line (3d-2p, 2.72 Å, 4.5 keV) for low-temperature operations (Te(0)~4-10 keV) and the He-like Kr w resonance line (2p-1s, 0.945 Å, 13.1 keV) for high-temperature operations (Te(0)>10 keV) [1]. A low-resolution survey spectrometer is also being designed to monitor L-shell W emission from 8-10 keV (1.6-1.2 Å). However, similar XRCS systems have shown that high-Z impurity emission (Mo, W) can contaminate the spectrum leading to errors in the inferred plasma parameters [2,3]. As SPARC will feature an all-tungsten wall design, it is crucial to fully characterize the tungsten emission spectrum within the spectral ranges relevant to SPARC's XRCS system.

OpenADAS and FLYCHK indicate W lines nearly degenerate with the Ne-like Xe 3D line, but these sources do not always provide accurate wavelengths or complete line lists. To address this, we have performed high-resolution W measurements at the electron beam ion trap (EBIT-I) facility at Lawrence Livermore National Laboratory (LLNL) using the EBIT Calorimeter Spectrometer (ECS). These measurements were done by systematically varying the electron beam energy to isolate and associate emission lines with the emitting charge state. Using the EBIT-I data to identify the brightest lines in this spectral range, we preformed high-fidelity simulations using the SCRAM, FAC and ColRadPy codes to deduce the transitions as well as generate emissivity data. Wavelengths were measured using the SPECTRALLY spectral fitting code and reported here. We then apply these data for throughput modeling using the ToFu and XICSRT ray-tracing codes to scope the impact of the relative W-to-Xe concentration on inferred ion temperature. We will use these lines, along with the survey spectrometer, for W density measurements and transport studies, such as profile peaking.

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