Space-charge limited sheaths in magnetized fusion plasmas

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In contemporary fusion devices, thermionic emission (TE) is the dominant electron emission process from W surfaces transiently molten by ELMs. ITER predictions even reveal that the surface temperatures in some divertor regions approach the W melting point also during normal operations [1]. The Richardson-Dushman currents from molten W PFCs can drastically, up to orders of magnitude, exceed the incident plasma currents. Such imbalance cannot be sustained by the standard quasi-neutral pre-sheath and modifications of the sheath potential profile occur [2]. In particular, charge accumulation leads to the formation of a potential well that suppresses emission (*space-charge effect*). Furthermore, in the presence of inclined B-fields, TE electrons can also be absorbed during their first Larmor gyration (*prompt re-deposition*). The mechanisms coexist and the evaluation of the escaping thermionic current from PFCs should be based on describing the trajectories of the strongly magnetized cold TE electrons in the self-consistent non-monotonic potential sheath profile. Without a-priory knowledge of the scales involved, such problem is analytically intractable but well-suited for particle-in-cell (PIC) simulations [3].

Comprehensive simulations of strongly emissive thermionic sheaths have been performed with the 2D3V PIC code SPICE2. Varying magnetic field strengths and orientations have been explored and the inter-/intra-ELM plasma conditions of JET and AUG have been targeted, where experiments featuring the intentional melting of W PFCs had been recently carried out [4,5]. The results revealed that the strict limitation of the escaping thermionic current is a global characteristic of the space-charge limited regime irrespective of the magnetic field inclination. A physically transparent semi-empirical expression has been identified that accurately describes the limited thermionic current dependence on the plasma conditions and the B-field inclination angle. The suggested analytical formula is of great practical value for different plasma-surface interaction problems and has been implemented in the MEMOS-U code that describes W melt motion under the action of the bulk Lorentz force generated by the replacement current flowing through the PFC as a response to the escaping thermionic current [6].

In the case of hot intra-ELM plasmas (T_e>300 eV) relevant for ITER, the contribution of electron-induced electron emission (EIEE) to the escaping emitted current must be assessed. In such energy regimes, both secondary electron emission & electron backscattering are important [7]. State-of-the-art analytical expressions for the emission yields (as functions of the incident electron energy and angle) as well as for the energy and angular distributions of the emitted electrons have been identified and implemented in SPICE2. Sheath simulations featuring both TE and EIEE were performed in order to capture possible synergies between these processes.

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