Physics of power loading on the gap edges of castellated plasma-facing components in fusion reactors

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In order to manage thermal stresses, actively cooled tokamak plasma-facing components (PFCs) in high heat flux areas must typically be divided or “castellated” into small units separated by gaps both in toroidal and poloidal directions. Heating of the edges introduced by this castellation is a serious, and, until recently, little studied complication for component power handling [1]. It will be critically important on ITER and imposes careful PFC shaping design to mitigate the consequences. In support of the ITER tungsten divertor target design and as an interpretive tool for experiments on several devices designed to study this problem, plasma interaction with castellated PFCs and the related role of sheath electric fields has been investigated by means of the SPICE 2D and 3D particle-in-cell codes. In addition to providing predictions of detailed ITER divertor power loading, this work substantially improves the general understanding of the processes occurring in the magnetized sheath which forms in the vicinity of the PFCs and is a key quantitative tool for validation of simpler ion orbit approaches which neglect the sheath electric field [1], but which are less computationally intensive when deployed for PFC design. These studies are being augmented by the investigation of thermionic emission from tungsten surfaces, including 3D effects relevant to localized hotspots, and providing in addition important constraints for the modelling of melt motion on PFCs subject to high energy transients.

A number of interesting physics phenomena in the magnetized sheath affect the heat load distribution on gap edges. Inside toroidal gaps, depending on the magnetic field orientation, electrons and ions can either strike the same side (with the magnetically wetted side receiving all the heat load entering the gap), or opposite sides (with the heat load shared between the two sides of the gap) due to ion Larmor gyration and radial E×B drift in the sheath. Dedicated PIC simulations have confirmed that the former is the dominant mechanism of the toroidal gap power loading for ITER plasma conditions, providing further confidence that ballistic ion orbit simulations can be used as a good approximation in the study of gap edge loading for component design.

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