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The geometry of ICRF –induced wave-SOL interaction: a multi-machine experimental review in view of ITER operation.

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Of the three additional heating methods envisaged for ITER, waves in the Ion Cyclotron Range of Frequencies (ICRF) are attractive as the only one capable of ion heating and central deposition at high density. Yet, since their first use in magnetic fusion devices, the non-linear interaction of ICRF waves with the Scrape-Off Layer (SOL) plasma has attracted attention. This interaction is now generally attributed to radio-frequency (RF) sheath rectification. In view of ITER, the topic has gained renewed interest. ICRF was applied in metallic machines where RF-enhanced wall sputtering might contaminate the core plasma with high-Z impurities. Besides, a spurious process tolerable in short pulses can hinder the machine lifetime when cumulated over long periods. A final challenge is to combine ICRF heating with other subsystems in Integrated Operational Scenarios (IOS). The subsystems might interfere via localized SOL modifications, e.g. Lower Hybrid (LH) and ICRF wave coupling and hot spots in present devices.

As part of ITPA-IOS activities, this contribution reviews recent experimental characterization of ICRF-induced SOL modifications on various tokamaks worldwide and LAPD linear device, with emphasis on their 3D spatial structure. Understanding this complex structure, in relation with the magnetic topology and the spatial distribution of RF currents, now becomes important. Geometry provides hints for judicious port allocation, antenna design and operation. It clarifies which plasma-facing components are likely eroded, and which species in mixed-materials walls like ITER. Reproducing the measured patterns also constrains interpretative RF-sheath models.

RF-induced SOL modifications include local changes in the Direct Component (DC) plasma potential and associated E×B flow, plasma density, DC currents, energy of the ions hitting the walls, heat loads and impurity production. Such modifications have been widely observed on the active wave launchers themselves and on magnetically connected objects. Field-aligned bright filaments reaching the divertor were visualized during ICRH on NSTX. On JET, the footprint of an active 4-strap (A2) antenna on a nearby outboard limiter could be followed over a scan of the edge safety factor ($q95$) using a Beryllium (BeI) filtered camera. Parallel propagation was extensively exploited to produce 2D (radial-poloidal) mappings by combining radially-resolved measurements over steps of q95. Implicitly assumed is that the measurements along the diagnostic lines of sight are representative of the SOL on the antennas. Although the SOL is modified at long toroidal distances, little is known of its parallel variation. ICRF likely affects the EAST divertor probes even if an obstacle is interposed between the antenna and the diagnostic. Besides the mapped field lines connect to the lateral sides of the antennas. Yet, more intense effects may arise in the less-diagnosed private SOL created by the 2 antenna side limiters.

2D mappings, corroborated with IR images on WEST, feature strong spatial inhomogeneity. In the radial direction local maxima are observed near the leading edge of the antenna limiters, with a typical extension of a few centimeters on both sides, including field lines not connected to the antenna. This might reveal a transverse transport mechanism possibly able to go round an obstacle, also coupling the private SOL to the free SOL around. This also suggests that "near-field"SOL disturbances could be kept far away from the separatrix by increasing the radial gap to antennas (nominal value ~15cm in ITER), at the expense of lower ICRF coupling resistances.

In the poloidal direction the strongest interaction does not necessarily occur at the antenna mid-plane closer to the separatrix. Instead local maxima of the heat loads or the effective sputtering yield often develop near antenna box corners. This poloidal structure was observed on many devices despite a large diversity of strap electric schemes. The interaction increases with higher RF antenna voltage. For a given power its pattern evolves with the electrical settings of the strap array. The poloidal pattern around the JET ITER-like antenna depends on whether its lower or upper part is energized. For 2-strap arrays local minima are obtained with balanced strap power and dipole (pi) phasing. The minimum is not pronounced (factor ~1.5 reduction of WI line brightness on WEST, and reduced Prad). Stronger reduction was achieved with 3-strap and 4-strap arrays phased pi, by requesting more power on inner straps. Minimization comes with less flexible k// spectrum (e.g. no current drive) and lower maximal power in the case of JET A2 antennas. All local minima correspond to low RF image currents induced on both sides of the antenna box. LAPD operated a strap inside a box with bulk ceramic side walls. The measured DC potentials in its vicinity nearly vanished. For JET A2 antennas, the central septum also needs to be accounted for. This calls for avoiding protruding elements on the ITER antenna front face.

Far less documented than the above "near-field"effects are RF-induced SOL modifications in regions never connected magnetically to the active antennas. Impurity production associated with such "far-field"effects is suspected on EAST. Molybdenum (Mo) is found mainly on one inner wall sector facing the I-port 4-strap antenna. Core Mo contamination is observed mainly as this antenna is energized. The Mo31+ brightness increases as the phase evolves from pi to 0. This is ascribed to lower single-pass absorption (SPA). The SPA will likely improve in larger devices.

Also scarcely documented is the contribution of each object to the central impurity contamination. Parametric dependencies on JET and EAST indicate that the W production near the divertor strike points is not dominated by RF effects, despite disturbed floating potentials on the EAST divertor Langmuir probes. While RF-specific Be-sources are frequently observed on its outer limiters, no RF-induced W-source could so far be localized directly on JET. On AUG, replacing the W-coated limiters with B-coated ones on the 2-strap antennas led to ˜70% reduction in the incremental W content. Significant contribution from W tiles on new LH limiters is also reported on EAST, from USN/LSN comparisons of the VUV spectroscopy. Therefore the W contamination will likely be lower in ITER than in a similar full-W machine.

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