Sheath rectification modelling on WEST: comparison of dielectric layer and boundary condition approaches

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The decision by the ITER organization to make the first wall out of the heavier tungsten (W) instead of the lighter beryllium (Be), which was the original plan, has sparked renewed interest in impurity sputtering. ITER will be partially heated by Ion Cyclotron Range of Frequencies (ICRF) heating [1,2], a heating method known to enhance impurity sputtering [3]. While in present-day tokamaks the ICRF-specific sputtering can be kept under control by utilizing phasing control to suppress near-fields in the neighborhood of sputtering-prone antenna surfaces (a technique used with great success on AUG [3,4]), ITER foresees operating regimes which, from the RF physics point of view, are not directly analogous to those encountered today. For example, one density profile foreseen for ITER has the S=0 layer, the Lower Hybrid resonance, intersecting the limiter surfaces. In the S>0 regime (lower density, deeper into the antenna), the limiter surfaces obey the resonance condition for resonance cone excitation [5]:

$$\vec{n} \cdot \varepsilon \vec{n} = 0 \tag{1}$$

Where $\vec{n}$ is the surface normal and ε is the plasma dielectric tensor. This leads to the expectation that in these operating regimes, the near-field RF fields at the limiter surfaces may be dominated by resonantly excited slow waves, a situation not seen in today's machines.

Numerical modeling of the ICRF-specific sputtering on the ITER ICRF antenna has not reached general agreement. This is partly due to the several orders of magnitude difference in the edge density between the different operating regimes envisioned. It is likely also due to different simplifying assumptions made by the different modeling codes themselves.

For example, tSSWICH code [6] relies on a two-dimensional approximation, slicing the antenna into radial-parallel slices. The antenna is assumed to be flat and invariant in the poloidal direction. Within each 2D slice, the geometry is further approximated by staircasing, such that all surfaces are either parallel or perpendicular to the confining magnetic field B. Thus, by construction, the resonance cone excitation condition (1) can never hold. Despite all this, for the scenarios common in current machines, SSWICH performs well.

Another approach is based on the commercial Finite Element software COMSOL. Despite several attempts, there have been no successful implementations of the RF sheath boundary condition in 3D in COMSOL to date. This boundary condition [7] is necessary to determine the rectified DC sheath potential which accelerates ions towards the plasma-facing surfaces, causing the sputtering. Lacking this boundary condition, an attractive alternative has been to model the plasma sheath as a thin layer within the computational domain [8]. It is much thicker than the true sheath thickness, yet much thinner than the other geometric length scales in the problem. This leaves open questions regarding the sensitivity of the solution to this artificial sheath thickness. This approach can handle the scenario where (1) holds, and reliably produces peak RF field amplitudes where it holds, but it remains doubtful if the waves emitted from the points where (1) holds can be resolved properly, and if their amplitude can be meaningfully constrained by a simple cold plasma collisionality. Like SSWICH, this approach has proven reliable in the scenarios conventionally encountered in today's machines [9,10].

Third but not least, the Petra-M code is at present the only frequency-domain RF solver that can truly handle the RF sheath boundary condition in general 3D geometries [11].

A new ITPA task is now dedicated to understanding those differences between these codes. This work reports on a comparison between COMSOL and Petra-M calculations for the WEST antenna, which is very much an apples-to-apples comparison and minimal differences are to be expected. Other ongoing research aims to compare COMSOL, Petra-M and SSWICH on the AUG 3-Strap antenna.

Figure 1: Finite Element mesh of the WEST ICRF antenna. Note that the Faraday Screen bars and the limiters are surrounded by a meshed layer ~2mm thick, which mimics the desired sheath behavior.

The mesh we use in this work is shown in figure 1. We used the same mesh in COMSOL and in Petra-M. While in earlier work [12], we used the meshed layer on the Faraday Screen to compute the rectified sheath potential on the Faraday Screen bars, for the purposes of the comparison exercise in this work, we stick to the conventional approach of computing the sheath potential only on the limiters. We make use of the experimentally measured density profile of WEST shot #57877