NUMERICAL MODELING AND EXPERIMENTAL ASSESSMENT OF RF SHEATH GENERATION DUE TO FAR-FIELD RF ELECTRIC FIELD

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This paper reports our recent progress in multi-device assessment of RF sheath potential generation due to the interaction between RF waves and plasma-facing components (PFC) in the "far-field" region of the RF antenna during ion cyclotron range of frequencies (ICRF) heating experiments, including high harmonic fast wave (HHFW). ICRF antenna alignment to the magnetic field and power tapering are both found to be an effective approach to control high-Z impurity generation, as demonstrated on AUG [1], JET [2] and Alcator C-Mod [3,4]. However, the effectiveness of these approaches has primarily been understood in the context of RF-material interaction near the antenna structure. Our focus is to study the global full torus scale RF electric field distribution in fusion devices and the resultant RF sheath potential generation, caused by unabsorbed and/or parasitically coupled RF waves to the scrape-off-layer (SOL) plasma.

Experimental findings indicate a critical role for global RF modeling. The analysis of the parasitic coupling of HHFW power to the SOL on NSTX [5] shows that a far-field effect plays a role in the enhanced heat flux by generating spatially localized RF sheaths in the divertor region [6]. Data analysis of the ICRF experiments on Alcator C-Mod using the four-strap field-aligned ICRF antenna reveals that a heating effect is observed in the high-field SOL, which was not magnetically connected to the antenna, and depends on power tapering [7]. On the WEST tokamak, a higher level of RF sheath potential was observed with poor single-pass absorption [8], potentially driving stronger impurity sputtering. Unabsorbed RF power is also reported to cause multipactor issues on different antenna transmission-line due to antenna cross-coupling [9].

In order to better characterize the RF wavefield and the corresponding RF sheaths, we utilize the large-scale 3D RF wave simulation models developed using the Petra-M finite element analysis platform [10,11]. We use a large, realistic torus sector (>=180 degrees), which is directly generated from a CAD model and includes all the essential in-vessel components, such as the first wall, divertor and poloidal limiters, and RF antennas. An RF sheath boundary condition [12] is used in sheath simulations to evaluate the RF voltage. As shown in Figure 1, we assessed the excitation of RF sheath potentials in divertor regions on NSTX-U, finding a strong dependence of far-field sheath potential on RF antenna phasing. Analysis of Alcator C-Mod tapering experiments has revealed a global enhancement of wave field intensity in the far-field region near the divertor shelf, which correlates with the excitation of low toroidal mode number wavefields. Such a low toroidal mode number excitation was previously observed using a Petra-M-TORIC coupled simulation, emphasizing the crucial role of the actual geometrical configuration of the SOL plasma and antenna structure, rather than the core wave absorption physics alone (TORIC-only). The WEST experiment indicates that weaker single-pass absorption positively correlates with higher RF sheath voltage on the side limiter, as shown in Figure 2. The RF modeling shows that a weaker absorption can create a higher RF electric field in the SOL region globally, which could potentially lead to stronger sheath activity far away from the antenna.

In parallel with the wave analyses using our existing modeling capabilities, new simulation capabilities, and diagnostic suites are being developed. A SOL plasma profile model based on non-linear anisotropic heat diffusivity was developed [13]. This model was coupled with a 2D HHFW wave field simulation to re-assess the SOL cavity mode excitation [14, 15]. The impact of the e-folding length of the SOL density profile on the cavity mode structure is newly observed, which affects the wavelength and poloidal extent of the cavity mode. Extension of this analysis to 3D will quantitatively evaluate the wavefield in the divertor regions and sheath rectification.

An effort to improve the wave absorption physics model based on the dielectric response of Maxwellian plasmas is also made. Modeling and experiments indicate that turbulent plasma filaments can possibly redirect the HHFW power to the divertor [16]. Experimentally, divertor probes capable of measuring the RF voltage and spectrum are being prepared for the upcoming NSTX-U experiments, which will provide experimental data for a direct comparison with RF sheath modeling. On WEST, characterization of the RF rectified potential will be continued using reciprocating emissive probes, and additionally, a new direct RF spectral measurement, similar to the one prepared on NSTX-U, is planned. Direct detailed measurement of the RF field in SOL plasmas on multiple devices will allow for developing a unified picture of the connection between far-field wave excitation, sheath rectification, and for RF actuator performance improvement by power tapering and field alignment.

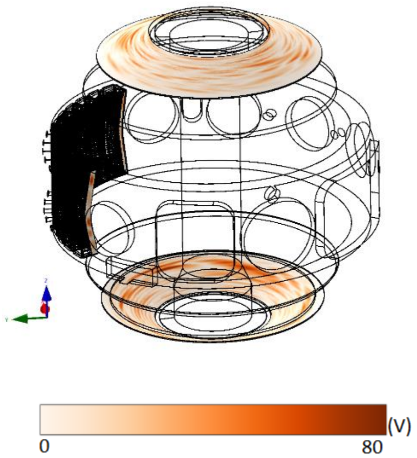

Figure 1. 3D full torus modeling of RF sheath potential distribution evaluated on the NSTX-U antenna side limiter and the top and bottom divertor regions.

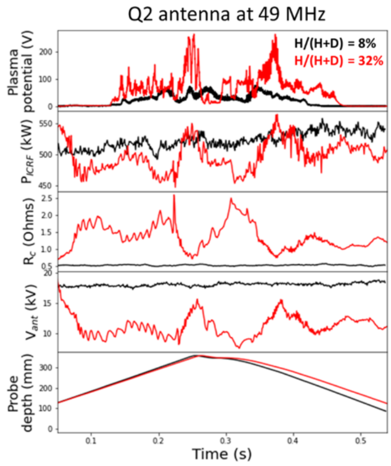

Figure 2. WEST experiments showing higher RF-rectified potential in a weaker single-pass absorption plasma with a higher ion minority fraction (red vs. black)

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