Identifying and quantifying mechanisms responsible for the substantial loss of HHFW power in the SOL of NSTX

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NSTX can exhibit a major loss of high-harmonic fast wave (HHFW) power along scrape-off layer (SOL) field lines passing in front of the antenna (Fig. 1) [1-6]. The losses can be up to 60% of the HHFW power, while the heat flux in the RF spirals can be up to 2 MW/m^2 for 2 MW of applied HHFW power [2,4]. Recent simulations using AORSA [7] have verified that the RF fields become significant as the righthand cutoff for fast waves is moved away from the antenna [8]. Despite these advances, the underlying mechanism(s) that convert RF wave power into a heat flux on the divertor has not yet been identified. Here we quantify the possible contributions of each candidate mechanism and compare them to experimental data in an effort to eliminate one or more candidates. This work will guide future experimentation on NSTX-U and other machines in definitely identifying the mechanisms and minimizing their effects, which is especially important for optimizing high-power long-pulse ICRF heating on ITER while guarding against excessive erosion in the divertor region.

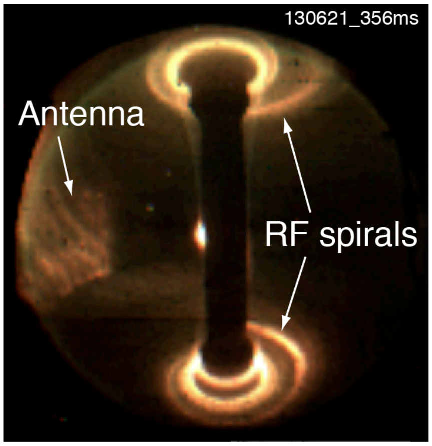

Figure 1. HHFW power is lost along SOL field lines as the waves propagate away from the antenna before reaching the last closed flux surface.

The probable candidates for the loss mechanism(s) are (1) a two-stream instability of the RF currents that volumetrically heats the SOL plasma [9], which in turn flows to the divertor along field lines (2) far-field RF sheaths at the divertor that drive ion bombardment into the divertor [10] (3) and parametric decay instability of the HHFW wave into a ion Bernstein wave that damps on ions at appropriate ion-cyclotron layers [11,12]. Any proposed mechanism must produced a spiral on the upper and lower divertor that is the footpoint of the SOL field lines passing in front of the antenna, and the amplitude of the proposed loss must match the infrared (IR) camera measurements.

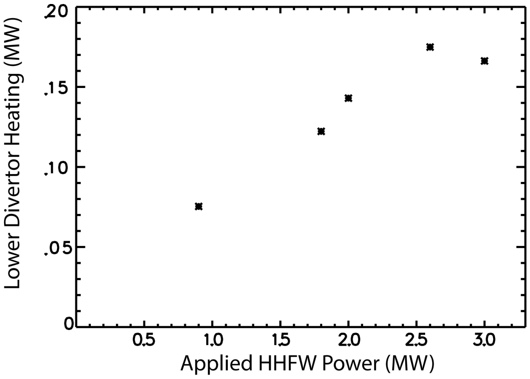

Figure 2. The RF-produced heat flux, measured at Bay I of the lower divertor using an IR camera, plotted against applied HHFW power for a series of shots with similar plasma conditions. A 'background' shot with no RF has been subtracted from the IR data.

The likelihood of each mechanism will be constrained by analyzing the scaling of the measured RF-produced heat flux against the applied HHFW power. The heat flux produced by each mechanism scales differently with input HHFW power, and these expected scaling can be compared against the measured scaling show in Fig. 2. We will further distinguish the measured heat flux into RF power being lost directly in the SOL and the RF power that couples to the core and then leaves through ordinary exhaust. Additionally, we will analyze the change in Langmuir probe characteristics when that probe lies under the RF spiral (Fig. 3). While we cannot yet distinguish whether these changes are due to plasma heating or an RF sheath voltage, the data does constrain to magnitude of each. For instance, in Fig. 3, we assume the change is entirely due to a shift in floating potential, which requires an RF sheath voltage of 76 V, which in turn can be used in analysis of Fig. 2.

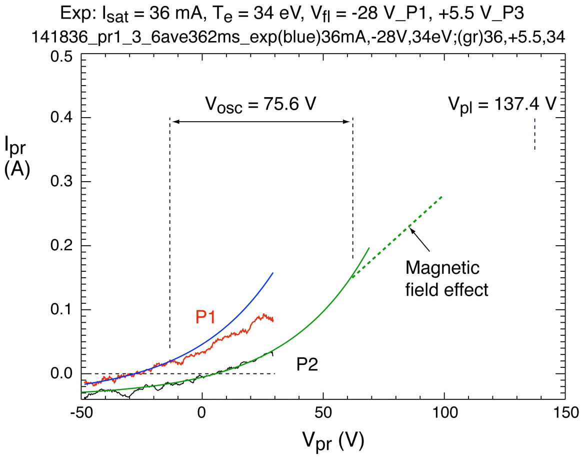

Figure 3. Characteristics from probe 1, located inside the RF spiral, and probe 3, located just outside the spiral. If the shift in floating potential is interpreted as an RF sheath voltage, the RF field must be around 76 V, which can be compared results from simulations.

We also constrain the candidate mechanisms by using the numerically-computed RF fields to estimate the losses and compare these to the experimentally observed heat flux in order to eliminate mechanisms with estimates that are far too low or high. The RF fields will be taken from AORSA and also from a cylindrical cold-plasma model. The latter models the core as a high-density plasma cylinder and the SOL as a lower-density annulus; the simplified geometry will aid in interpreting the field structures given by AORSA. For instance, the cylindrical model will show how closely the Poynting flux follows the field lines as wave propagate away from the antenna; this will in turn test the RF sheath hypothesis, which requires the Poynting flux to be mostly field aligned for the sheath to form in a spiral pattern. Fields from both codes can be used to compute the RF currents in the plasma for comparison to the two-stream instability threshold, and the fields from AORSA at the divertor can be used to estimate the amplitude of the RF sheath.

Direct measurements of RF fields in NSTX-U will ultimately be needed to ascertain the importance and magnitude of each of the above proposed loss mechanisms. Prior to that, this work will constrain the possible mechanisms and provide guidance in designing such experiments. The field-aligned RF losses studied here could impact other fusion devices, including ITER, as the recent results from AORSA suggest that the enhanced RF fields in the SOL are a property of fast waves in general.

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