Topic: EX-W

High Harmonic Fast Wave Coupling Through The NSTX Plasma Edge

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The High Harmonic Fast Wave (HHFW) system on NSTX consists of six pairs of antenna straps, connected to form a 12-element array that can deliver up to 6 MW at 30 MHz. The array can be phased to provide balanced wave spectra with dominant peaks at $k_z = \pm 7$ or $\pm 14\ m^{-1}$ for plasma heating, or directional spectra with k_z peaks at 3 or 7 m^{-1} to drive current in the same or opposite direction as the plasma current. The plasma has a large dielectric constant due to relatively high plasma density and low magnetic field ($\varepsilon = \omega_{pe}^2/\omega_{ce}^2 \sim 50\text{-}100$) and the waves readily damp on electrons via Landau damping and TTMP.

Although both full-wave and ray tracing codes predict high single pass absorption and damping on electrons, current drive experiments on NSTX indicate that a relatively large fraction of HHFW power is not being deposited on central electrons at the associated lower wavenumbers. Subsequent RF power modulation studies using a Thomson scattering system to measure the power deposited on the electrons have shown both a wavelength and a phase dependence on the power coupling efficiency. Typical efficiency values[1] are 70-80% for $k_z = \pm 14\ m^{-1}$ (heating), 60-70% for $k_z = +7\ m^{-1}$ (counter-CD), and 40-55% for $k_z = -7\ m^{-1}$ (co-CD). An Edge Rotation Diagnostic[2], which observes the Doppler shift and broadening of emission lines from excited He and C ions residing in the plasma edge in both the toroidal and poloidal directions, measures strong heating of edge ions with application of HHFW power. The perpendicular ion temperatures increase an order of magnitude (50 eV to 500 eV) for 4.3 MW of power at $k_z = -7\ m^{-1}$. Ion cyclotron resonance heating is expected to be negligible at these low temperatures and high harmonics of the fundamental ($\omega \sim 13\Omega_i$). A candidate mechanism for efficient interaction with the edge ions is an Ion Bernstein Wave (IBW) arising from parametric decay of the 30 MHz HHFW. Parametric decay instability theory extended to NSTX conditions[3] predicts generation of wave pairs: a quasi-mode at $\omega_{qm} = n\Omega_i$ and an IBW mode at $\omega_{IBW} = \omega - n\Omega_i$, where n is an integer.

The characteristic PDI spectra have now been observed with both a Langmuir probe and a microwave reflectometer (Fig. 1). The X-mode edge microwave reflectometer is located between array elements 2 and 3 and has a frequency sweep range of 6 to 37 GHz, allowing it to probe densities of 1×10^{17} to $8\times10^{18}\ m^{-3}$. The electronics have been modified to process the dc–500 MHz IF output of the I/O demodulator to measure the RF-related 30 MHz sidebands in the plasma. It has detected the characteristic PDI spectra previously observed on NSTX using a floating Langmuir probe located between array elements 10 and 11. Moreover, both the reflectometer and probe now use a fast (100 MHz) digitizer to process the signals, allowing time resolved measurements.

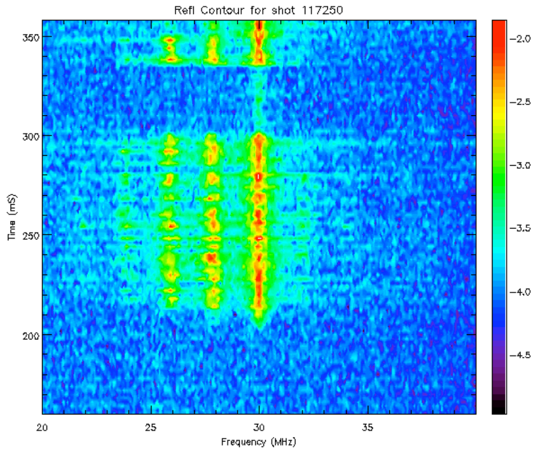

Fig. 1 Parametric decay sidebands measured with microwave reflectometer (RF power on at 200 ms, notched off from 300 to 330 ms)

Both diagnostics observe up to three sidebands below the 30 MHz drive frequency and which are separated by the local cyclotron resonance (the separation decreases with lower magnetic field). The number of sidebands and the strength of each peak increase for plasma conditions and array phasing where the core heating efficiency is poor. Time resolved appearance of the sidebands during the 20 ms HHFW ramp-up indicate the power threshold for parametric decay products to be in the range of 100-400 kW for co-CD phasing at $k_z = -7\ m^{-1}$, depending on the plasma edge conditions.

Estimates of the power absorbed by the edge ions have been made, assuming it to be the power to maintain the observed T_i-T_e difference in the edge under collisional equilibration, and indicate power losses of about 17% at $k_z = \pm 14\ m^{-1}$ and 25% at $k_z = -7\ m^{-1}$ (Fig. 2). These are larger than the losses typically associated with PDI in conventional tokamaks, but still may not account for all of the central heating loss under low k_z operation. Other edge loss mechanisms under investigation are surface waves (both propagating and evanescent), collisional heating, direct IBW excitation, scattering off fluctuations and near and far-field sheaths.

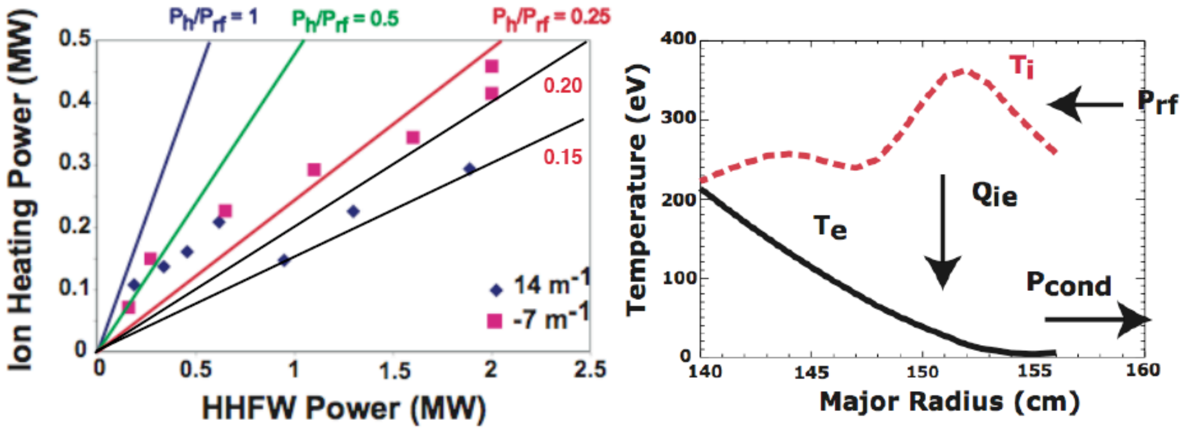

Fig. 2 A substantial fraction of the HHFW power is needed to sustain the observed temperature difference in the plasma edge.

A fast ion gauge, located between array elements 10 and 11, shows increased neutral pressure levels in the antenna region when operating at co-CD phasings compared to counter-CD at the same power levels. A Langmuir probe in the shadow of the rf protection tiles between the same array elements also observes an increase in the floating potential for co-CD phasing, indicating stronger rf fields in the antenna region. These diagnostics, along with newly installed B-dot loops, will be used in 2006 to delineate the role of surface waves and/or collisional damping of evanescent waves in power propagation through the edge plasma.

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[1] Hosea, J. C., et al, *16th Top Conf on Radio Frequency Power in Plasmas*, 82 (2005)
[2] Biewer, T. M.. et al, *Rev. Sci. Instrum.* **75**, 650 (2004)
[3] Wilson, J. R., et al, *16th Top Conf on Radio Frequency Power in Plasmas*, 66 (2005)