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by

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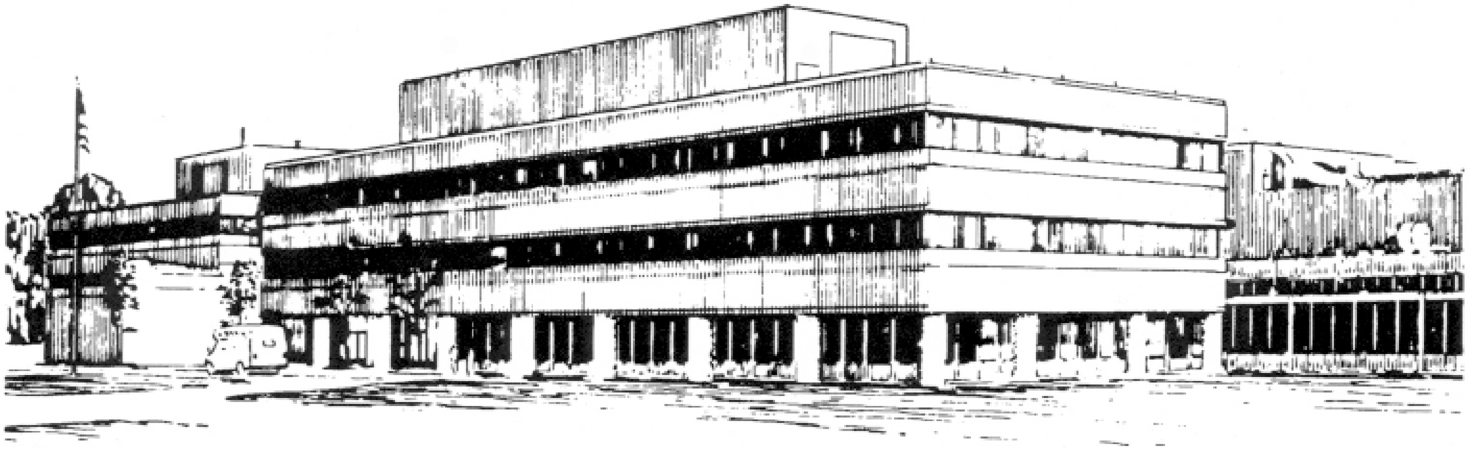

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Plasma Response to the Application of 30 MHz RF Power in the NSTX Device

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Abstract. Rf power at 30 MHz has been applied in a variety of situations to NSTX plasmas. The response of the plasma is observed in order to study both the physics of High Harmonic Fast Wave (HHFW) heating and as a tool to extend the performance of NSTX plasmas. In this paper we will discuss the progress made to date towards these goals.

INTRODUCTION

RF power at 30 MHz is applied to the NSTX plasma discharges via a twelve-element antenna array [1]. The array is configured to launch principally the fast wave polarization. For the parameters of NSTX 30 MHz falls between 10-15 times the deuterium cyclotron frequency. This frequency range has been dubbed High Harmonic Fast Wave (HHFW) heating [2]. The overall goal of HHFW heating on NSTX is to provide plasma heating and especially current drive to extend the plasma duration and approach quasi steady-state conditions. The antenna can be phased to launch waves with toroidal wavenumbers between ~2 m^{-1} and ~14 m^{-1} with peak directionality for current drive at 7 m^{-1}. Behavior of the antenna system is reported in a companion paper [3]. Experiments have been performed in deuterium and helium plasmas with differing plasma parameters and rf phasing. Both effective electron heating and large effects on plasma parameter profiles are seen in some circumstances.

EXPERIMENTAL RESULTS

Theory predicts strong absorption of the launched fast waves on the plasma electrons for target temperatures in excess of ~200 eV [2]. This value is dependent on the parallel wavelength of the launched waves. In this frequency range waves with parallel phase velocities less than 2.5 times the electron thermal velocity will be strongly damped. In NSTX strong electron heating has been observed at temperatures as low as 150 eV for waves launched from an antenna phased to launch predominately at $k_T = 14$ m^{-1}. This heating is in reasonable agreement with the theory. Detailed comparisons of measured and calculated deposition profiles have not been made to date. The evolution of the plasma stored energy and electron temperature for three different antenna phases is shown in figure 1.

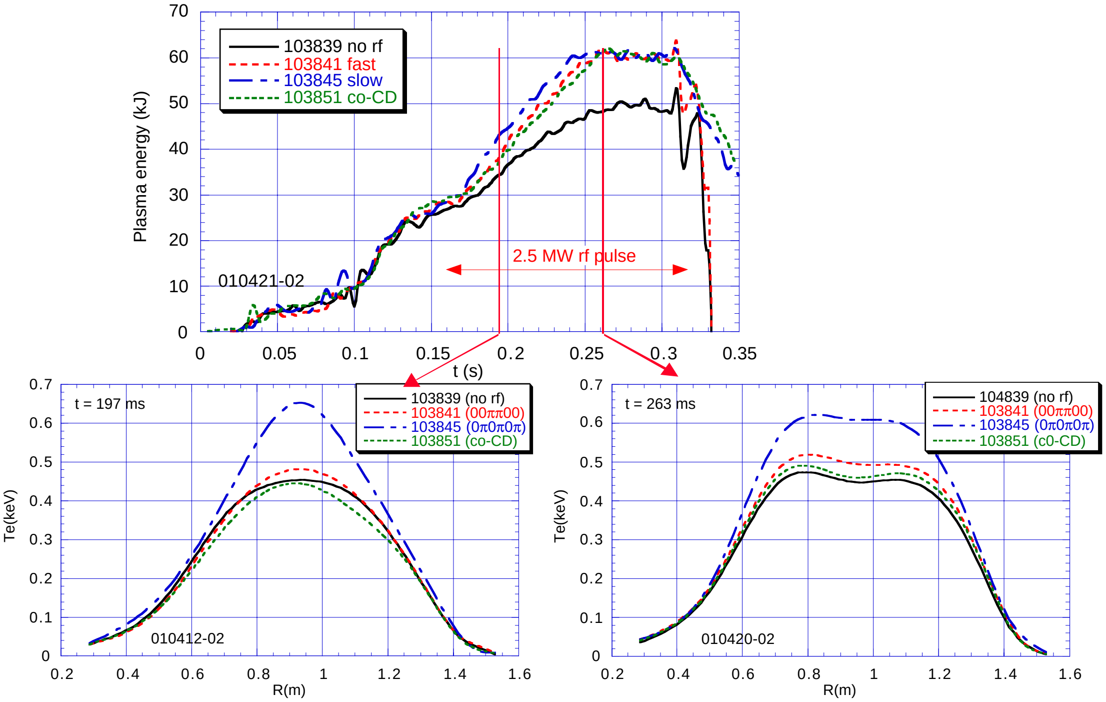

Figure 1. Evolution of stored energy and electron temperature for three antenna phasings: 14 m^{-1} (slow), 7 m^{-1} (fast), 7 m^{-1} directed (co-CD), P_{rf} = 2.5 MW

The stored energy increase is seen to be the same for all three discharges while the electron temperature increase is much larger for the slower phase velocity. Simple theory predicts strong electron absorption for all three cases. Theory does not predict strong ion absorption at this temperature. No ion temperature data exist for these discharges. The possible role of ion heating is presented in a companion paper [4]. An alternate explanation for this behavior due to wave-wave coupling to drift wave turbulence has been put forward by Ono [5]. The presence of MHD activity can significantly alter the plasma temperature and density profiles. If large levels of m=1 MHD, sawtooth oscillations or internal reconnection events are present the plasma heating can disappear. The initial experiments that indicated plasma heating inferred from the soft x-ray diagnostic were confused by this effect [6]. Differences in heating between deuterium and helium target plasmas are also observed. In helium plasmas the density remains constant and the rf power is converted to electron energy solely as increased temperature. In deuterium plasmas the electron energy increase is due to both a temperature and density increase. In addition, the total increase in electron energy is only ~70% that observed with helium plasmas. This may be a consequence of the differences in plasma energy transport in plasmas with different species, the ohmic electron energies are ~70% lower as well, and not an rf specific effect. A more curious phenomenon is observed in deuterium plasmas when the rf power application begins early in the current rise phase of the plasma evolution. When the antenna to plasma gap is large, ~12 cm, a spontaneous increase of the plasma density is observed with values reaching NSTX record levels of 8 x 10^{19} m^{-3}. See Fig. 2.

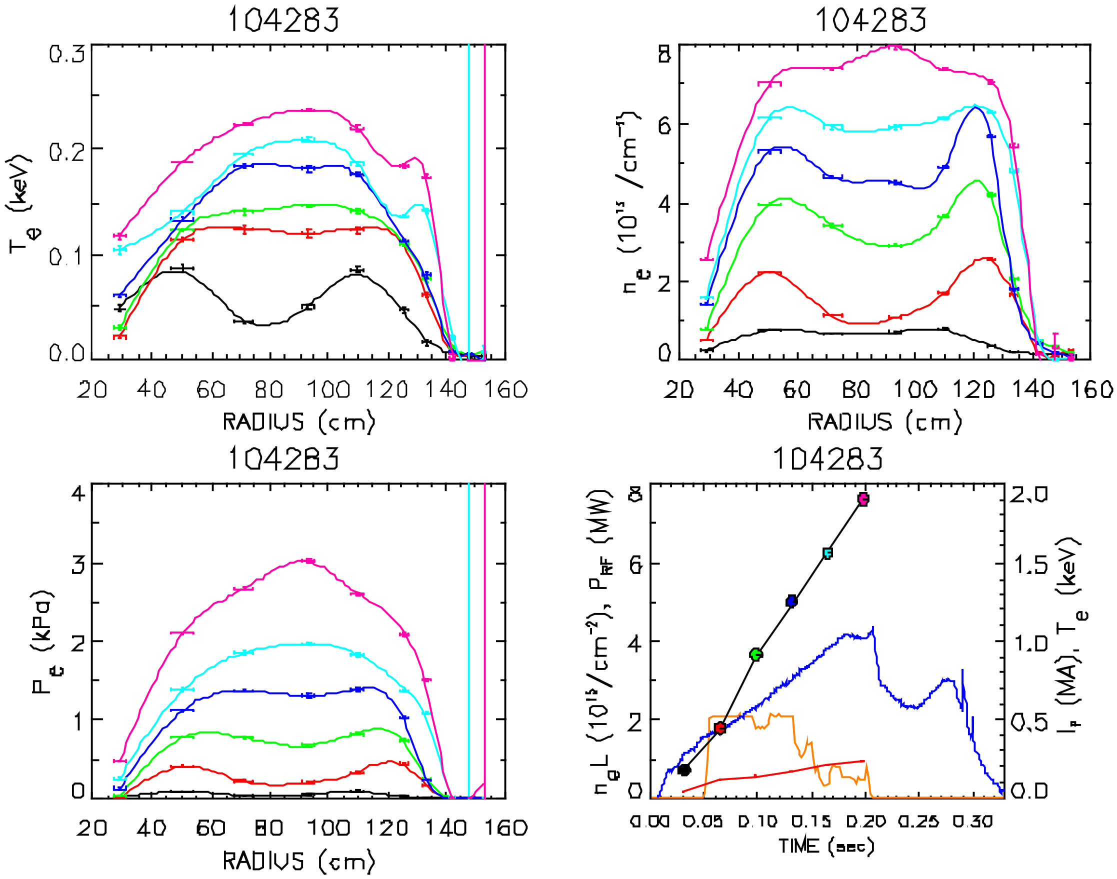

Figure 2. Time evolution of plasma parameters for rf heating during the current rise (a) density profile, (b) electron temperature profile, (c) electron pressure profile, and (d) central density, plasma current, and rf power

The density profile is broad and flat. The electron temperature increases nearly doubles, from 130 to 240 eV, as the density increases by a factor of 8. Spectroscopic and X-ray measurements indicate that Z_{eff} remains at a value of ~1.75 during this time. This density rise occurs without any gas being injected into the machine. If the gap between antenna and plasma is smaller, a much smaller increase in density and a larger increase in temperature is observed. The loop voltage decreases and flux consumption is less during the current rise. Central q remains above 1.4 instead of dropping below 1 and the plasma inductance, l_i, remains at 0.5 instead of increasing linearly with time. See Fig. 3. These discharges were subsequently utilized to study the beta limit at low l_i. The rf power is applied beginning at 0.05 s and subsequently NBI power is applied in a stepped fashion until the beta limit is reached. With this technique values of toroidal beta of 15% and beta normal of 3.3 were achieved.

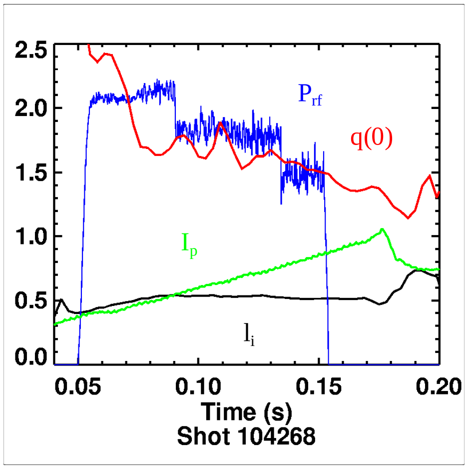

Figure 3. Time evolution of plasma current, I_p, internal inductance, l_i, central safety factor, q(0), and rf power, P_{rf} for a discharge similar to that in figure 2.

FUTURE WORK

The next steps to be taken in the NSTX HHFW experimental program include: experimental determination of the power deposition profiles and comparison with modeling predictions [7,8], study of ion absorption on the thermal, minority and NBI distributions [4], and studies of HHFW driven plasma current [8]. All of these require the operation of new diagnostics as well as continued progress in understanding how to effectively couple increasing amounts of rf power to the NSTX plasma.

SUMMARY

30 MHz rf power has been applied in the HHFW heating regime to the NSTX plasmas. Effective electron heating has been observed in a variety of situations. The most effective heating has been observed in helium plasmas with the rf antenna phased to launch waves with a primary toroidal wavenumber of 14 m^{-1}. In discharges where the rf power is applied during the plasma current ramp-up a large increase in the plasma density is observed when the antenna plasma gap is large, ~ 12 cm. Record values of plasma density, $n_e = 8x10^{19}$ m^{-3} have been obtained. In addition these discharges had significantly altered time evolution of the plasma current profile.

ACKNOWLEDGMENTS

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