Experimental study of a possible role of the scrape off layer radial electric field in determining H-mode confinement properties on ASDEX Upgrade

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1. Introduction

The high confinement (H-) mode is an attractive regime in which to operate fusion-grade tokamak plasmas. The H-mode formation is associated with the establishment of steep electron and ion pressure gradients over a radially narrow region in the plasma edge (the pedestal, $0.96 < \rho_{pol} < 1.00$, where ρ_{pol} is the normalized poloidal flux coordinate), as well, as the development of a deep radial electric field (E_r) well across the same region. The goals of this study are: 1) to develop a viable technique that can modify (or bias) the E_r in the scrape-off layer (SOL, $\rho_{pol} > 1.00$) using Ion Cyclotron Range-of Frequencies (ICRF) power operated in non-standard phasing and, if successful, 2) to assess the impact of the SOL E_r on the H-mode performance. The first results show that a significant level of ICRF power ($P_{ICRF} \geq 1$ MW) operated in non-standard phasing ($\pi/2$ compared to standard π phasing) leads to a change in the edge localized mode (ELM) behaviour from predominantly large amplitude ELMs to small ELMs. At the same time, the change in the ELM behaviour is accompanied by an increase in tungsten (W) sources from the active ICRF antenna limiters, an increase in the core W contents and the associated increase in the core radiated power, a decrease in the non-radiated power crossing the separatrix (P_{sep}), an increase in the normalized electron collisionality at the pedestal top (ν_e^* at $\rho_{pol} \sim 0.96$), and little to no change in the E_r well profile in the pedestal region. At this time it remains unclear if ICRF power operated in non-standard phasing was able to modify (or bias) the SOL E_r profile.

2. Experimental Method

In order to significantly modify (or bias) the E_r value ($|\Delta E_r| \geq 10$ kV/m) across the SOL region (~5 cm wide region at the outer midplane for a standard H-mode discharge on ASDEX Upgrade), it is necessary to raise the SOL plasma potential (ϕ_p) by several hundred volts ($\phi_p \geq 500$ V for the case of a standard H-mode on ASDEX Upgrade). ICRF power is known to

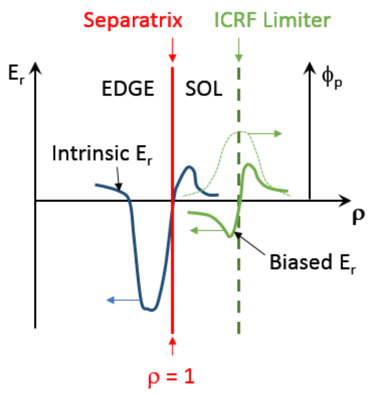

Figure 1: SOL E_r biasing with ICRF power.

increase the SOL ϕ_p in the vicinity of the ICRF limiter to values >100 V [1-3]. Note, that SOL biasing with ICRF power is expected to generate plasma potentials that peak radially near the ICRF limiters and, hence, apply negative E_r's ($E_r = -\nabla\phi_p$) across the SOL region radially between the separatrix and the limiter, see Fig. 1. The discharge parameters for this study were: the toroidal magnetic field B_T = -2.5 T and the plasma current I_p = 0.8 MA. The edge safety factor q_{95} = 5.4. The working gas was deuterium. The plasma shape was a lower single null. The H-mode was maintained by a combination of 4.9 MW of neutral beam power (P_{NBI}) and 1.4 MW of electron cyclotron heating power (P_{ECRH}). The operating frequency of the ICRF antennas was 36.5 MHz with antenna strap phasing varying between standard (π) and non-standard (π/2).

3. Experimental Results and Discussion

Changing ICRF strap phasing to a π/2 configuration is expected to increase unabsorbed ICRF power in the SOL through a combination of higher near- and far-ICRF fields. The increase in the ICRF field strength, in turn, leads to stronger RF rectification [4] and, hence, plasma potentials in the SOL. Fig. 2 shows the plasma response to a change of ICRF antenna phasing on ASDEX Upgrade, the time periods of interest are highlighted. The key observations are: 1) an increase in the W sources from the active ICRF antenna limiter surface (W_{Lim}, Fig. 2 (e)). The W_{Lim} increase is present both during the ELM and between the ELM cycles, ruling out the change in the ion temperature within the ELM cycle as the cause of the W_{Lim} increase.

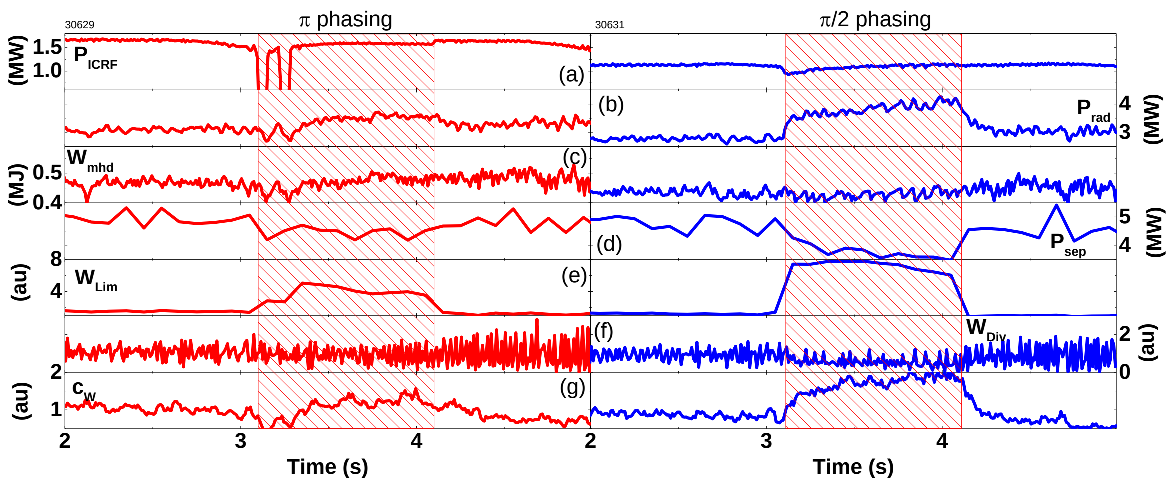

Figure 2: The time histories of the key plasma parameters in the presence of ICRF power in standard (π) and non-standard (π/2) phasing. The quantities shown are (a) the ICRF power P_{ICRF}, (b) the radiated power P_{rad}, (c) the stored plasma energy W_{mhd}, (d) the non-radiated power crossing the separatrix P_{sep}, (e) the tungsten source from the limiter surface W_{Lim}, (f) the tungsten source from the divertor surface W_{Div}, and (g) the core tungsten concentration c_W.

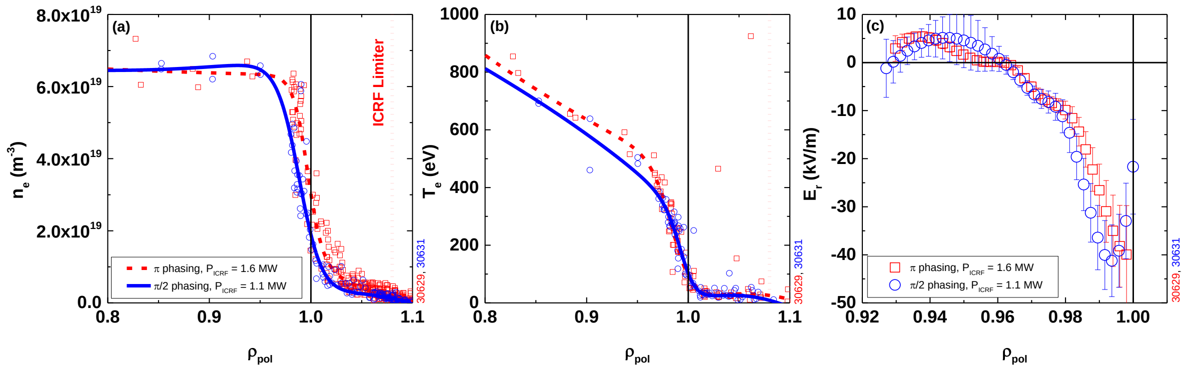

Figure 3: The radial profiles of (a) the plasma density n_e, (b) the electron temperature T_e, and (c) the radial electric field E_r across the pedestal region in discharges heated with ICRF power in standard and non-standard phasing.

The observed W_{Lim} increase is consistent with increased ϕ_p (or biasing) at the limiter surface, as significant sputtering of W surfaces by D^+ ions requires incident ion energies in excess of 200 eV [5]. Such high ion energies have been measured previously on ASDEX Upgrade in ICRF-heated discharges in the vicinity of the limiter surfaces [6]. 2) Simultaneously, we also observe an increase in the core W contents c_W (Fig. 2 (g)), a corresponding increase in the radiated power P_{rad} (Fig. 2 (b)), and a drop in the non-radiated power crossing the separatrix P_{sep} (Fig. 2 (d)). The drop in P_{sep} ($P_{sep} = P_{heat} - P_{rad} - dW_{mhd}/dt$, where P_{heat} is the total heating power and W_{mhd} is the plasma kinetic energy) is dominated by the increase in the radiated power as the total heating power and the stored energy is little changed over the highlighted time periods (Fig. 2 (c)). 3) The response of the W sources from the divertor (W_{Div}) is the opposite of the limiter response (Fig. 2 (f)): W_{Div} drops with the application ICRF power in non-standard phasing. The drop in W_{Div} is consistent with the change in the ELM behaviour, which will be the subject of a later paragraph.

One of the key features of an H-mode plasma is the appearance of an electron and ion pressure pedestal. The response of the plasma density n_e and the electron temperature T_e across the pedestal region to ICRF power in non-standard phasing is shown in Fig. 3: the n_e profile shows a radial inward shift (Fig. 3 (a)), while T_e at the top of the pedestal ($\rho_{pol} \sim 0.96$) shows a small decrease (Fig. 3 (b)). The net effect of the T_e and n_e changes is the increase in the pedestal electron collisionality ν_e* ($\nu_e^* \sim n_e/T_e^2$) from 2.0 to 2.6 (where the effective charge Z_{eff} is assumed ~1). Within the experimental uncertainties the E_r profiles across the pedestal (as measured with charge exchange recombination spectroscopy [7]) show little to no variation before and after the application of ICRF power in non-standard phasing (Fig. 3 (c)). Note that E_r measurements in the SOL region on ASDEX Upgrade are typically carried out using Doppler reflectometry [8]. However, due to a combination of high stray ICRF fields and low amplitude of the poloidally propagating turbulence in the SOL, the Doppler reflectometer diagnostic was unable to resolve the SOL E_r profiles for these discharges.

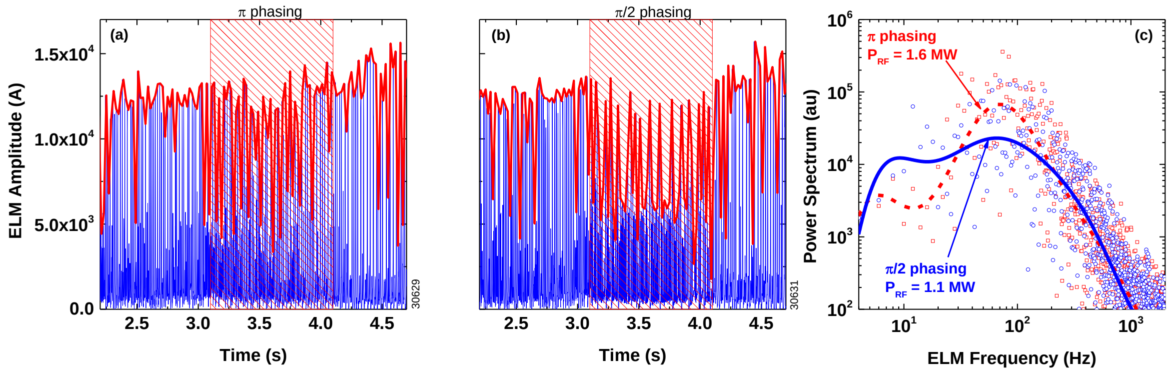

Figure 4: The evolution of the ELM amplitude and frequency spectra in the presence of ICRF power operated in (a) standard and (b) non-standard ICRF phasing, the relevant time windows are highlighted (3.1<t<4.1 s). The response of the ELM frequency spectra is shown in (c).

Therefore, it remains unknown if ICRF power in non-standard phasing affects the E_r profiles in the SOL region.

ELMs are another key feature of a steady-state H-mode on ASDEX Upgrade. The evolution of the ELM behaviour (amplitude and frequency spectrum) in the presence of ICRF power in π/2 phasing is shown in Fig. 4: the ELMs change from predominantly large amplitude, low frequency ELMs (Fig. 4 (a)) to predominantly small ELMs with a broad frequency spectrum (Fig. 4 (b)). The change in the ELM behaviour is consistent with the change in P_{sep}, which suggests that the ELMs change from predominantly Type-I to predominantly Type-III [9]. However, an unambiguous identification of the dominant ELM type requires additional analysis of the pedestal stability limit and the magnetic ELM precursor signatures.

4. Conclusion

Operating ICRF antennas in π/2 phasing on ASDEX Upgrade has a strong effect on the H-mode plasmas: W_{Lim} increases (Fig. 2 (e)), c_W contents and P_{rad} increase (Figs. 2 (g) and (b)), while P_{sep} decreases (Fig. 2 (d)). Simultaneously, the ELM behaviour changes from predominantly large amplitude to predominantly small amplitude ELMs with a broad frequency spectrum (Fig. 4). While the increase in W_{Lim} is consistent with increased biasing of the SOL region, the radial extent of biasing remains unresolved. Future experiments will focus on decoupling the effect of tungsten impurities either by using boronization or an externally applied W source.

5. Acknowledgements

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6. References

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