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Interaction of ICRF electric fields and the SOL plasma in ASDEX Upgrade

Vl.V. Bobkov, D. A. Hartmann, J. Neuhauser, J.-M. Noterdaeme, F. Wesner, R. Wilhelm and ASDEX Upgrade Team

MPI für Plasmaphysik, EURATOM Association, Garching, Germany

Introduction

The interaction between radio-frequency (RF) electric fields of the ICRF (Ion Cyclotron Range of Frequencies) antennas and the scrape-off-layer (SOL) plasma in front of the antenna leads to a number of non-linear phenomena, often described by sheath effects. The phenomena and their consequences, like arcing in the antenna and the parasitic absorption of the power at the edge, are studied experimentally with a help of an RF probe in ASDEX Upgrade (AUG).

Experiment and measurements

The RF probe [1, 2, 3] is an open end of the coaxial stainless steel resonator to model a high RF voltage region of the ICRF antenna operated at the resonance frequency of $f_0 = 52$ MHz. Inner conductor of the probe head has a 55 mm diameter and is 6 mm inside the outer conductor of 89 mm diameter. The probe is installed ≈ 3.5 cm deep in the limiter shadow on the AUG midplane.

RF measurements include measurements of forward and reflected power as well as voltage and current. Main RF signals are saved using a fast data acquisition system (500 Msamples/s). This makes an accurate phase measurement possible.

Due to non-linearities and asymmetries of the sheath current-voltage characteristic, high rectified electric fields can appear near the electrodes. A DC break is connected in the inner conductor, hence the conductor is DC isolated and can be charged up by plasma. If the external DC circuit is closed, a rectified current is measured.

Results

In an external magnetic field, the sign of the rectified current is measured opposite to that expected in the RF system with the RF-driven electrode of smaller area than that of the grounded electrode. This can be explained by the key role of the front surface of the inner conductor of the probe head. This surface is oriented nearly parallel to the magnetic field and collects predominantly ions because of high RF electric fields at frequencies well above ω_{ci} ($f_0 \approx 4 f_{ci}$). An important aspect of measurement of the rectified current is that the current is a direct (but qualitative) measure of the ion density in front of the probe.

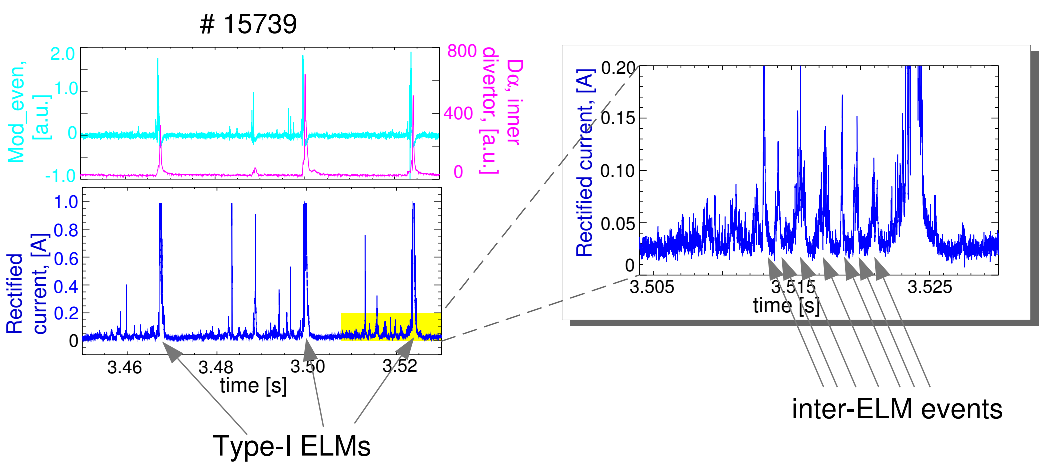

Figure 1: *Rectified current and correlation with D_α and measurements by Mirnov coils.*

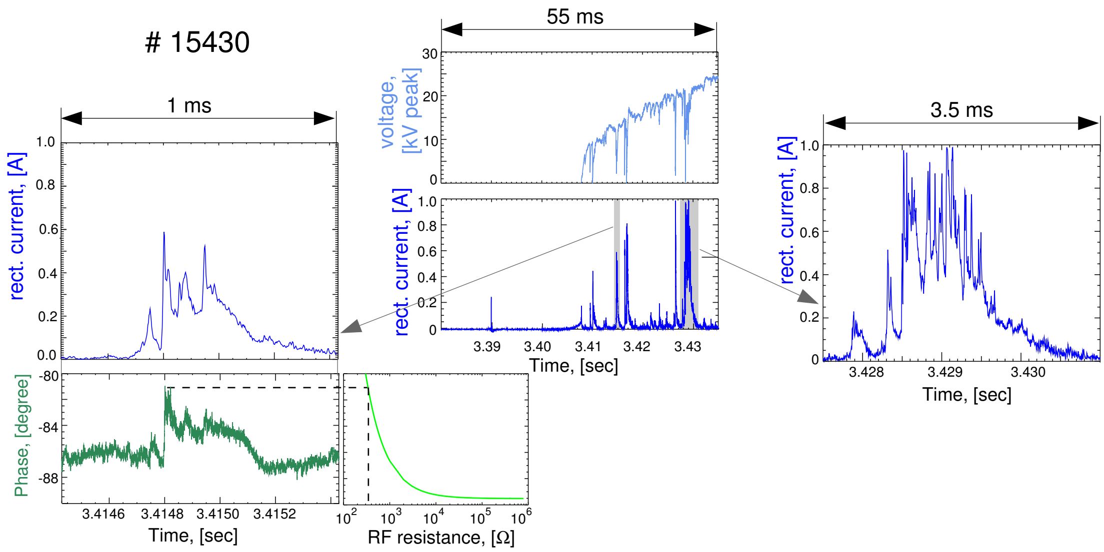

Figure 2: *Time resolved rectified current and the phase.*

Fig. 1 shows that edge localised modes (ELMs) are detected by the rectified current as well as by the signals from Mirnov coils (time trace for "Mod_even" built from signals of several magnetic coils is shown in the figure) and D_α radiation from the divertor. Small events between ELMs ("inter-ELM events") are often observed on the rectified current. This indicates that the probe is sensitive to resolve local burst-like changes of the SOL plasma density. The inter-ELM events are also often observed when the Langmuir probes are mounted at the AUG midplane manipulator [4].

Fig. 2 shows time resolved measurements during type I ELMs. Measurements of the rectified current and the phase (between the RF voltage and RF current) on the left side of the figure were taken for a single event identified from D_α and magnetic measurements as a "small" type I ELM. The rectified current as well as the phase during the small ELM shows a burst-like behavior. The bursty behavior of the rectified current indicates the bursts of the plasma density injected radially towards the probe head. The rectified current reaches 0.6 A during the busrst. The phase measurements are shown in figure together with a modeled RF resistance of the open end. The phase during bursts correspond to an RF resistance of $\approx$ 350 Ω. The right side of Fig. 2 shows the measurement of the rectified current during a "normal" type I ELM. The number of bursts is increased compared to the "small" ELM and amplitude of the current bursts increased to about 1 A. The "normal" type I ELMs are usually characterized by similar phase signal (not shown in the figure) as for the "small" ELM and a modeled resistance typically higher than $\approx$ 200 Ω for single bursts. A strong influence of ELMs is seen experimentally on the initiation of arcing. At the voltages above 50 kV on the probe, type I ELMs often provide prebreakdown conditions which lead to low open end resistance ($\approx 10 - 20\ \Omega$), i.e. to arcing. Arcing is initialized by type I ELMs for most of the pulses after the probe has been conditioned in plasma (for details see [2, 3]).

The dependence of minimal values of the Q-factor (ratio between the stored reactive energy in the resonator and the energy dissipated per cycle) averaged for 200 μs during ELMs on the RF voltage between ELMs is shown in Fig. 3. The Q-factor tends to increase with the voltage, hence the effective RF resistance of the load (the open end of the probe) is a function of the RF voltage. Therefore there exists a non-linear mechanism responsible for the dependence of the load resistance on voltage. The dependence can be consistently explained by a reduction of plasma density inside the electrode gap when a high RF voltage is applied.

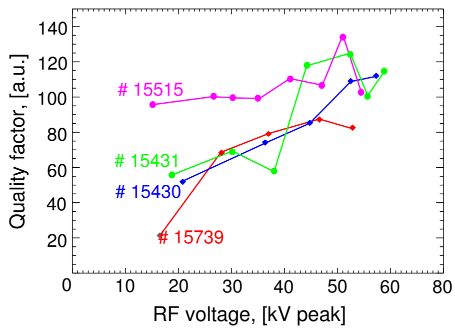

Figure 3: *Dependence of the Q-factor on the RF voltage.*

The density of the plasma can be efficiently reduced if the RF voltage drop across the electrode gap is not localized in a thin sheath near electrodes. In this case all electrons in the gap are accelerated towards electrodes and ions form a space charge DC electric field which drives all ions in the gap to the electrodes. If the secondary emission is assumed to be small, the integral effect will be the reduction of the density. The current towards electrodes is space charge limited unless the voltage becomes high and/or the plasma density becomes relatively low. For 1 cm gap, a voltage of 50 kV and the plasma density below $\approx 10^{18}$ m^{-3}, the space charge has no strong influence on the current collected by the electrodes and the density can be effectively reduced in the gap. As ELMs lead to bursts of the plasma density, these conditions can be fullfiled during ELMs between bursts or during small bursts.

The probe is actually an antenna that has no current carrying straps, but a high RF voltage electrode. To detect a power transmitted by waves, an ICRF heating antenna was used as a receiving probe. In [2] it was reported that the detected power drops down significantly during ELMs. In Fig. 4 the measurements of the coupled power, RF voltage and rectified current are present during ELM. One observes a significant increase of the coupled power.

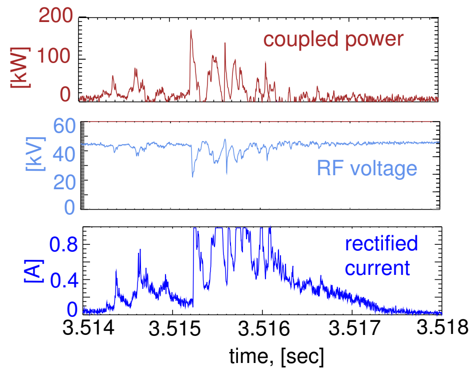

Figure 4: *Coupled power, RF voltage and rectified current during type I ELM.*

One of the possible explanations of the fact that the power is coupled more efficiently but does not reach the receiver is dissipation of the power locally. Measurements of the rectified current indirectly supports this explanation. A simple estimate of the power dissipated locally may be done by using value of the rectified current for RF conductive current at the probe head. As a result, at the time where the dissipated power equals ≈ 80 kW one gets about 30 kW (40%) of the coupled power that is locally dissipated. Therefore a large fraction of the coupled power is dissipated locally during intermittent events.

Conclusions

The experiments with the RF probe show that the intermittent events, in particular ELMs, can lead either to arcing at high electric fields or to an increase of the power coupled to the plasma. Since a large fraction of the coupled power is dissipated locally, the increase of the power coupled to the plasma by the ICRF antenna needs to be associated not only to an increase of the power launched with waves into the plasma, but also to an enhanced local interaction of the edge plasma with RF electric fields resulting in local power dissipation.

Furthermore, a large fraction of the total RF energy which is parasitically absorbed at the edge due to particle acceleration, can be dissipated during intermittent events (transients with an increased density in the SOL). This absorption depends on the RF voltage non-linearly. Therefore an account of the transient characteristics of the plasma density profile at the edge together with the non-linear sheath effects becomes important when the parasitic absorption associated with the particle acceleration is calculated.

References

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