Characterization of the RF plasma in ISHTAR

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IShTAR (Ion cyclotron Sheath Test ARrangement) is a testbed dedicated to the investigation of the interactions between Ion Cyclotron Radio-Frequency (ICRF) antenna and plasma [1]; the interplay between the plasma transport, the electromagnetic field generated by the antenna and the boundary conditions at the near wall (the sheath) locally modifies the plasma potential (rectification) and can lead to spurious effects: acceleration of ions and resulting sputtering and hot spots and a local deposition of wave power [2]. Theoretical and numerical models have been developed but their validation requires accurate measurements of key characteristics like the electric field (both its RF and DC rectified components) in the sheath and near the antenna. The precise control of the diagnostic position, makes these operations difficult in a tokamak. IShTAR offers a flexible complementary setup (long operation times, easy access to the antenna) and a controlled environment (magnetic field, pressure, plasma density profile) dedicated to these measurements.

Experimental setup

It is equipped with a main vacuum vessel (down to 10^{-6} mbar) with two coils (max. 0.23 T) producing a magnetic linear configuration where the ICRF antenna is installed. The plasma is provided by a RF plasma source equipped with magnetic coils (max. 0.08 T), a half-turn right-handed helical antenna (max. power of 3 kW) and supplied in Argon or Helium. The testbed has been upgraded end 2015 to align the plasma source on the axis of the main vessel where the test ICRF antenna is located, with the purpose to remove possible instabilities due to magnetic curvatures and get an overall axially sym-

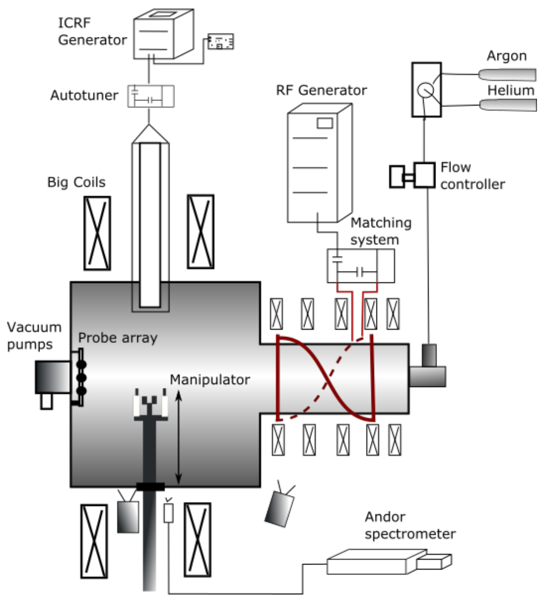

Figure 1: *IShTAR configuration with new aligned position of the plasma source.*

metric geometry, simpler to model and analyze [1]. The instrumentation includes two cylindrical Langmuir probes and two B-dot probes mounted on a manipulator which can scan the radial profile of plasma and wave characteristics. An array of Langmuir probes is installed on the back flange, The probes used for the detailed plasma characterization are not compensated but preliminary comparison with compensated probes and the application of RF-robust methods [3] seem to show that the RF field does not affect the probes for density measurement but this is a result to confirm with the interferometer. An array with four Langmuir probes is mounted on tha back flange facing the plasma flow. A high resolution ANDOR™ spectrometer is connected to optical fibers with line of sights either in the main vessel or in the plasma source. Its future purpose is to detect the Stark effect generated by the ICRF electric field near the wall.

Plasma characterization

The purpose of the plasma characterization is twofold: first, we search to optimize the control parameters to get the plasma with the highest density possible ($10^{18} m^{-3}$) in Argon and the most uniform radial profile: these parameters determine the nature and propagation of the waves launched by the ICRF antenna and the plasma transport, both required to be similar to the tokamak case. These conditions would best be achieved at high injected power to reach the

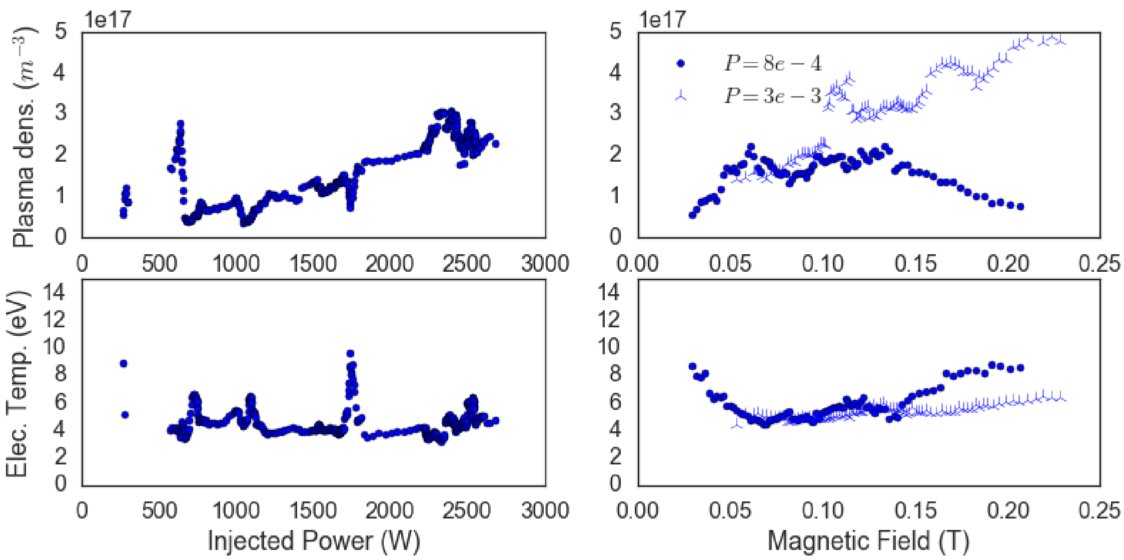

Figure 2: *Power and magnetic scan of the plasma parameters in Argon (left at constant B=0.12 T and Right constant Power P=2.7 kW).*

helicon regime where whistler waves start to propagate in the plasma core. Second, the sheath characterization requires an accurate knowledge of the environment in front of the antenna: to provide input for the transport codes, to evaluate the impact of the plasma source RF field (which have to be discriminated against the ICRF fields) and to reconstruct the distribution of the different excited plasma states for the spectroscopic measurement of the Stark effect. Thus we have carried out a parametric scan of both the injected power (at constant $B = 0.12\ T$ and $P = 10^{-4}\ mbar$) and of the main magnetic field (with the source coils turned off and a power of 2.7 kW).

The results presented in Figure 2 show that the density evolves linearly with the power except for a small drop at 1.7kW probably due to the excitation of a cavity mode. The electron temperature stays constant around 4 eV. We do not observe any clear jump (of an order of magnitude) in density characteristic of a mode transition towards the helicon mode. At the same pressure conditions, the scan in magnetic field shows that the density saturates at 0.14T and then decreases. The linear scaling is recovered only when the pressure is increase ($3.10^{-3}\ mbar$). The electronic temperature is almost independent on B.

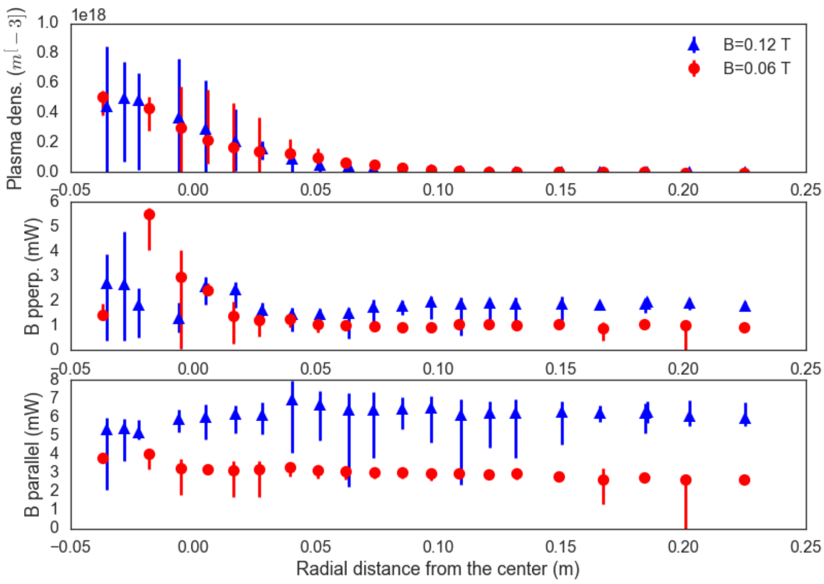

Figure 3: *Radial profile of density and RF magnetic field for injected power P=2.8 kW.*

With the manipulator, the density and the parallel and perpendicular component of the RF B-field were scanned for two amplitudes of the static B-field (cf. 3). The density profile follows a Gaussian shape with a width of about 15 cm which corresponds to the section of the static magnetic flux tube connecting the glass tube. The profile does not change with B, which confirms the previous scan. Yet, the profiles of the RF field do evolve with the magnetic field: at 0.12 T, $B_\perp$ is low and constant outside the plasma and increase to reach a peak in the center; $B_\parallel$ remains low all along the profile. When the magnetic field decreases to 0.06 T, the parallel component drops everywhere but remains higher in the plasma. The perpendicular part increases in the plasma presenting a single peak on the axis. The electron temperature (not presented in the plot) exhibits in the plasma a constant value of $6 \pm 3eV$.

When the source coils are switched on, the signal from the Langmuir probes is not longer measurable, the structure of the wave changes and the light intensity measured by the spectrum in the visible range drops. Either the plasma production decreases in the source or the plasma stays confined and does not flow anymore in the main vessel. This homogeneous case should the most favorable mode of operation. Further investigation will be required (changing the boundary conditions from conductive to dielectric, measuring parameters in the source) to understand the cause of this anomaly.

Discussion

Thus, we observe that in the range of the magnetic field where the density stagnates, the RF field structure reorganizes itself to keep a constant density profile (at constant power: the coupling of the antenna does not change when the field is varied). This would mean that in this mode of operation, the radial transport is not driven by the effects of the RF field (ionization, heating), but the RF field is constrained by the transport. The operational advantage is the gain in flexibility: we can make the magnetic field vary in a certain range and keep a constant profile, which will be very useful for ICRF sheath studies to analyze separately the effects of the field and of the plasma density. The question is to determine what drives the transport: the magnetic potential (with a mirror-like structure), the electric potential (strongly affected by the boundary conditions on the grounded end plates, i.e., the sheaths), or the collisions between the different species (peaks of neutral pressure are observed during the discharge). To conclude, we still have to understand the nature of the RF plasma and especially its transport to take into account any spurious effects disturbing the ICRF/plasma interaction. But most important, we have a set of parameters that gives us a stable plasma suitable for the sheath studies that will start with the measurement of the Stark effect due to rectified electric fields.

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