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Abstract. IShTAR (Ion cyclotron Sheath Test ARrangement) is a linear magnetized plasma test facility dedicated to the investigation of RF wave/plasma interaction [1] in the Ion Cyclotron Range of Frequencies (ICRF). It provides a better accessibility for the instrumentation than tokamaks while being representative of the neighboring region of the wave emitter. It is equipped with a magnetized plasma source (1 m long, 0.4 m diameter) powered by a helical antenna up to 3 kW at 11 MHz. We present the results of the first analysis of the plasma characteristics (plasma density, electron temperature) in function of the operating parameters (injected power, neutral pressure and magnetic field) as measured with fixed and movable Langmuir probes, spectrometer and cameras. The plasma is presently produced only by the helical antenna (no ICRF). We show that the plasma exists in three regime depending on the power level: the first two ones are stable and separated by a jump in density; a first spatial profile of the plasma density has been established for these modes; The third mode is unstable, characterized by strong oscillations of the plasma tube position.

EXPERIMENTAL OBJECTIVES AND CONSTRAINTS

The purpose of IShTAR (Ion cyclotron Sheath Test Arrangement) is to investigate the coupling between ICRF (Ion Cyclotron Range of Frequency) antennas and a plasma representative of the edge of tokamaks [1]. The antenna is located in a vacuum vessel ($P_{min} = 10^{-6}$ mbar) equipped with two 8 kA coils (operated at 2.4 kA) providing a linear magnetic field near the antenna [2] and an external plasma source made of a Duran© glass tube, four magnetic coils (operated at 1 kA) and a right-handed helical antenna [3] (cf. 1 and a detailed description can be found in [4]). The objective of this study is to characterize the plasma produced by the source alone. The properties investigated are: the plasma density profile (and, globally, the position of the plasma inside the vessel), the electronic temperature, the regime of power coupling (capacitive C, inductive H or helicon W [5]) and the stability in time of these three characteristics. These preliminary results are required first to prepare the investigation of the ICRF antenna by providing inputs for theoretical modes and for the antenna design; second, they will help to refine the requirements on the future plasma instrumentation (e.g. compensated probes); and, third, they support the optimization of the plasma source operation to reach plasma conditions relevant for a tokamak edge (by reaching the helicon mode [6]). The instrumentation is indicated on Fig. 1; the Langmuir probes voltage are modulated between -100V and 100V at 100Hz. The spectrometer is used to measure the intensity of the Ar^{+} line, which is proportional to the square of its density.

These tests also aim at evaluating the present limitations and possible improvements of the testbed. Most issues result from the use of available or refurbished components, thus not specifically designed for IShTAR. The main issue is the off-axis position of the plasma source relative to the main magnetic field [2]: it leads to a non-axisymmetrical plasma (cf. Fig. 2a) which is difficult to interpret (position of plasma dependent on magnetic field intensity), to model and to control (increase of losses on tube walls). In addition, the RF power generator for the plasma source is not controllable above 750 W: the level of power up to 3kW is determined only by the interaction between the plasma and the generator: the high-power level thus can fluctuate from discharge to discharge. An issue for this campaign was also that the gas feed valve which is affected by the magnetic field (kept blocked open), limiting the minimum neutral pressure to about 10^{-3} $mbar$. As for the instrumentation, the main difficulty comes from the Langmuir probe which are not RF compensated and, in the case of the planar probe, have a too large diameter to be resilient to capacitive pickup or, in the case of the cylindrical probes, are too small to capture ion current at plasma densities below 10^{-16} m^{-3}.

Radio Frequency Power in Plasmas
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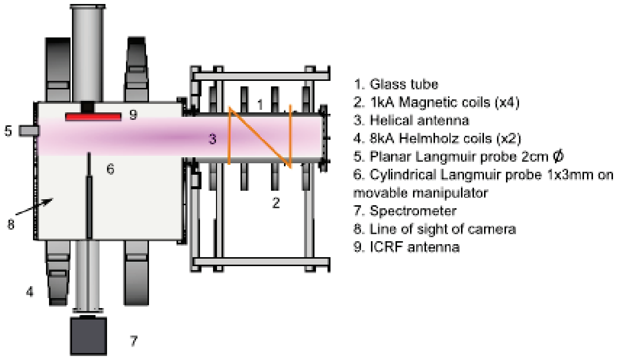

FIGURE 1. Cutaway (top view) of ISHTAR with main components

PLASMA REGIMES

The analysis of the data from the planar Langmuir probe, the spectrometer and the cameras reveals three plasma regimes depending on the injected power level *P*:

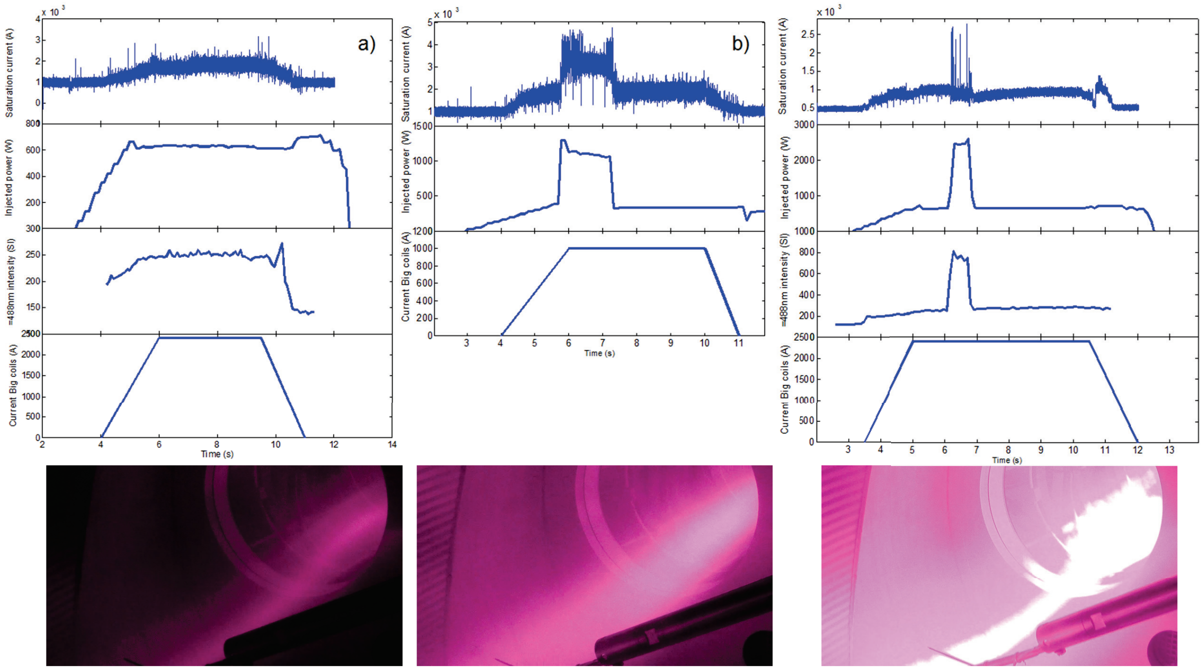

FIGURE 2. Plasma regimes for same neutral pressure $P = 10^{-3}$ mbar and field B=0.1 T : a)regime 1 b) regime 2 and c) regime 3. From top to bottom: ion saturation current with planar Langmuir probe, Injected RF power, $\lambda = 388\ nm$ intensity (no data for regime 2), main magnetic field, view from back camera.

- Regime 1: 0 < P < 1.3 kW (cf. Fig. 2a): we get a stable plasma with a density near the vessel wall evolving continuously between $10^{-15}\ m^{-3}$ and $10^{-16}\ m^{-3}$. The electron temperature is estimated between 5 eV and 10 eV. 20 % of the power is reflected back to the generator.
- Regime 2: 1.3 < P < 2.2 kW (cf. Fig. 2b): the plasma is still stable but higher in density, following a jump (cf Fig. 4). The temperature is around 10 eV. The reflected/forward power ratio decreases to 10 %, usually a sign of better coupling.

- Regime 3: 2.2 kW < P (cf. Fig. 2b): the plasma tube becomes more narrow unstable with strong oscillations of its position as seen on the camera. The signal on the planar probe is lost but not on the cylindrical probe in the center (cf. Fig. 5), confirming the reduction of its radial extension (but still visible on the spectrometer). The reflected/forward power ratio stays at 10 %. axis.

PLASMA DENSITY PROFILE

In the two first regimes, the plasma is stable enough to scan the plasma radius at three points spaced by 5 cm near the vessel center with the cylindrical Langmuir probe. Combined with the data of the planar probe, which is further away from the center, we can get a first trend of the plasma density profile, as shown on Fig. Fig. 3.

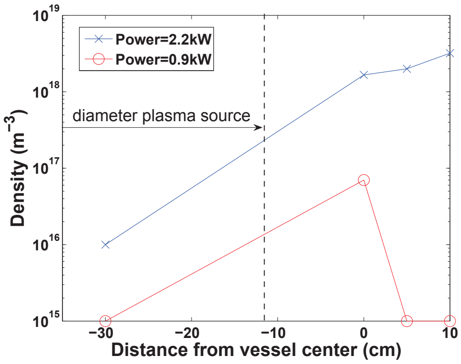

FIGURE 3. Evaluation of density profile for two types of discharge

In regime 1, we observe a fast decrease from the center to the right wall (with almost no probe signal at the outer position), indicating that the peak is located somewhere further to the left in direction of the plasma source. In regime 2, the density globally increases by two orders of magnitude and the density peaks is located now to the right. This could be an indication that the plasma moves radially away from the plasma source axis when the power is increased.

MODE TRANSITIONS

A scan in power of the plasma density measured by the planar Langmuir probe (which can detect smaller densities) reveals a jump between regime 1 and 2, characteristic of a transition from capacitive to inductive coupling or from inductive to helicon. A drop in the floating and plasma potential confirms this trend. It is no clear evidence of the mode reached in regime 2: it could be helicon (but there is no observation of a first jump from capacitive mode to inductive mode at lower power) or inductive. The calculation of the dispersion relation shows that for $B = 0.1\ T$, the helicon mode $m = 1$ should start to propagate at a density of $10^{16}\ m^{-3}$. The use of B-dot probes will be required to investigate the nature of the electromagnetic field inside the plasma.

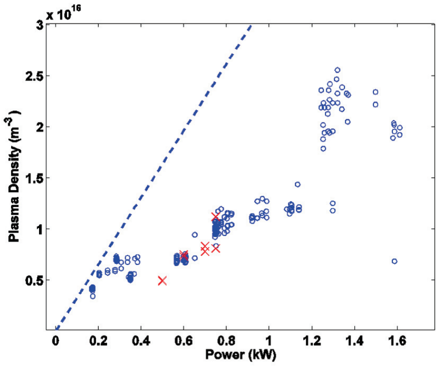

FIGURE 4. Density in function of injected power for a series of discharges. The dotted line is the maximum density calculated when the injected power is used to compensate the energetic losses.

INSTABILITY OF REGIME 3

In regime 3 the cylindrical Langmuir probe shows a strongly oscillating signal in the vessel center, confirming the presence of the instability observed on the cameras. The density fluctuates from $1.8 \cdot 10^{18}\ m^{-3}$ to below $10^{17}\ m^{-3}$, lower than regime 2 at the same power (cf. Fig. 5). It can be a sign of bursts of plasma moving over the probe. The floating potential from discharges with this instability reveals a different behavior than from stable discharges: at the beginning and during low power (<750 W) phases, the potential decreases and is negative instead of increasing and being positive. This would indicate that the instability could be triggered by changes in the initial conditions of the discharge.

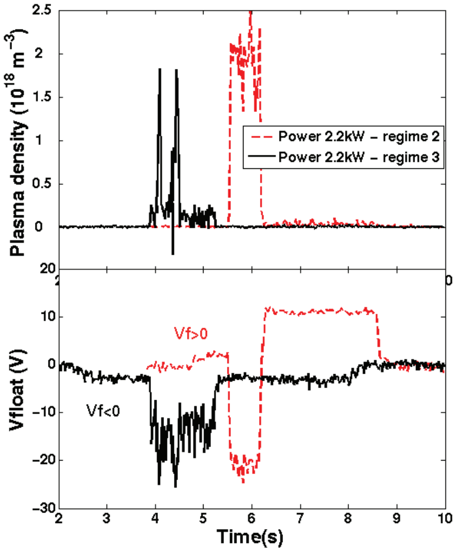

FIGURE 5. Comparison of density (top) and floating potential (bottom) for discharge in stable and unstable regimes.

CONCLUSION

The experiments show that a transition occurs with a jump of the plasma density when the power is increased. The increase of power is however limited by the development of an instability; it could be due to the off-axis position of the plasma source, increasing the losses on the wall of the glass tube. In the next months, the source will be centered, which will simplify the modeling and the analysis of the plasma behavior. The densities measured in stable discharges must be validated and more accurate profiles established: upgraded probes with 2 mm diameters will be mounted on the manipulator. The installation of a new generator for the helicon source with more power and a better control will give us the mean to provide IShTAR with more reproducible conditions for a tokamak edge relevant plasma.

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