Development and first operations of the IShTAR test facility

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Abstract

Tthe IShTAR testbed facility, used for the study of RF waves/plasma interactions, is now in a fully operational status, equipped with an external plasma helicon source and an ICRF antenna. We present the first measurements of the density and of the helicon and ICRF wave structures in the plasma.

Experimental setup and objectives

The IShTAR (Ion cyclotron Sheath Test ARrangement) is a linear magnetized testbed dedicated to the analysis of plasma/ICRF waves interactions in controlled conditions [2]. Detailed description of the testbed assembly and analysis of the first produced plasma have been previously presented [3]. The setup consists of (cf. Fig 1): the plasma source composed of 4 magnetic coils and a helicon antenna ($B = 0.1\ T$, $P = 3\ kW$, $f = 11\ MHz$), the main vessel with two coils operating up to 8 kA and the ICRF single-strap antenna; its operational instrumentation comprises a cylindrical 0.8 mm diameter Langmuir probe and two $\dot{B}$-probes (oriented parallel and perpendicular to the static magnetic field), all of them mounted on a manipulator arm moving between the wall and the vessel center.. The objective of this study is to characterize the plasma produced by the auxiliary plasma source and the behaviour of the ICRF antenna in presence of this plasma (plasma density profile, position inside the vessel, the regime of power coupling: capacitive C, inductive H or helicon W [4], the wave profiles from helicon and ICRF antennas, and the instabilities). These preliminary results are required firstly to provide inputs for theoretical models and for the antenna design; secondly, they will help to refine the requirements on the future plasma instrumentation (compensated probes, E-field measurement); and, thirdly, they support the optimization of the plasma source operation (by reaching the helicon mode [1]).

Plasma characterization

The purpose is to reach the highest possible plasma densities and to get a uniformal profile to be representative of a tokamak edge (so that the dipsersion relations of the wave propagating

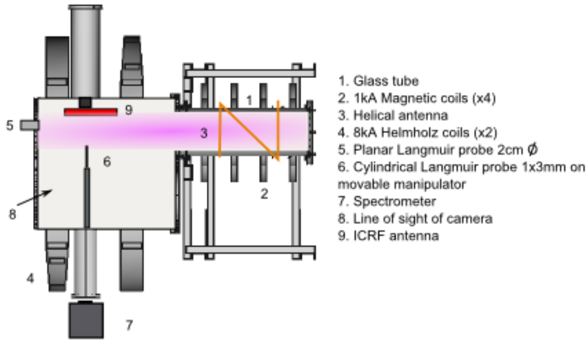

Figure 1: Cutaway (top view) of ISHTAR with its main components

inside the plasma are similar). Measurements of the plasma density made3 during a power scan 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 transition. There is no clear evidence yet of the type of mode reached in regime 2: it could be helicon (but there is no observation of a first jump from capacitive 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 cylindrical Langmuir probe shows a strongly oscillating signal in the vessel center for some discharges, confirming the presence of an instability. The density fluctuates from $1.8 \cdot 10^{18}\ m^{-3}$ to below $10^{17}\ m^{-3}$, lower than for stable discharges at the same power (cf. Fig. 3). As confirmed by video recordings, it is 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.

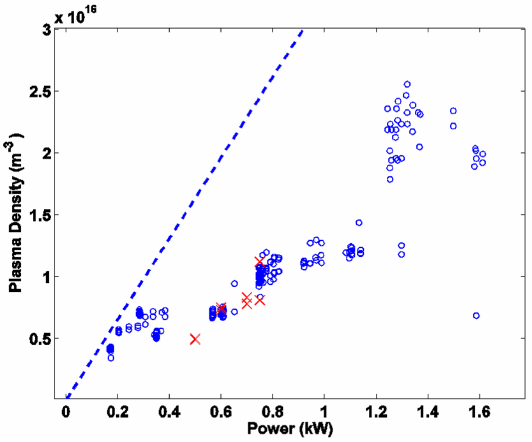

Figure 2: Density as a function of the injected power for a series of discharges . Black line is the maximum density due to losses.

The behavior of the plasma is conditioned by the mechanisms of ionization and coupling between the helicon wave and the plasma. A first step is to measure the wave spatial structure with the $\dot{B}$ probes when the plasma source is operating alone. The evolution of the fields (parallel and perpendicular) intensity during a power ramp up shows on Fig. 4 a) a mode transition between 300 and 400 W. On Fig. 4 b), the spatial profile perpendicular to the magnetic field is represented (perpendicular field) for an injected power of 750 W: a bump is visible and could correspond to the position of the plasma, which has to be confirmed by Langmuir probes measurements.

Yet, we notice that the change in amplitude along the manipulator axis is not important: the wave "fills in" the vessel, which can be explained by the low frequency (11 MHz) relatively to the characteristic dimension (1 m) of the testbed. The absence of a spatial localization of the wave on the coupling with the plasma still has to be evaluated.

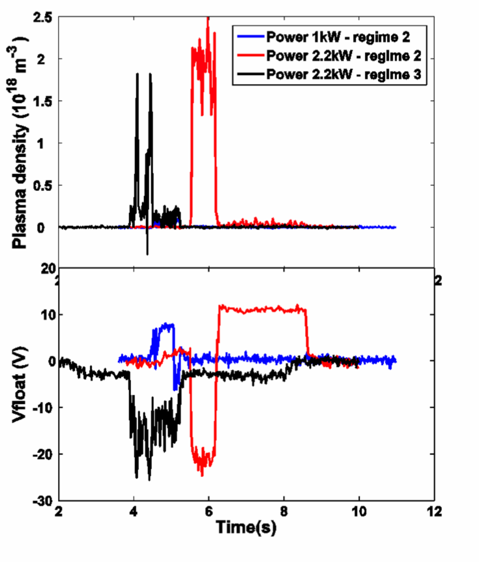

Figure 3: Comparison of density (top) and floating potential (bottom) for discharge in stable and unstable regimes.

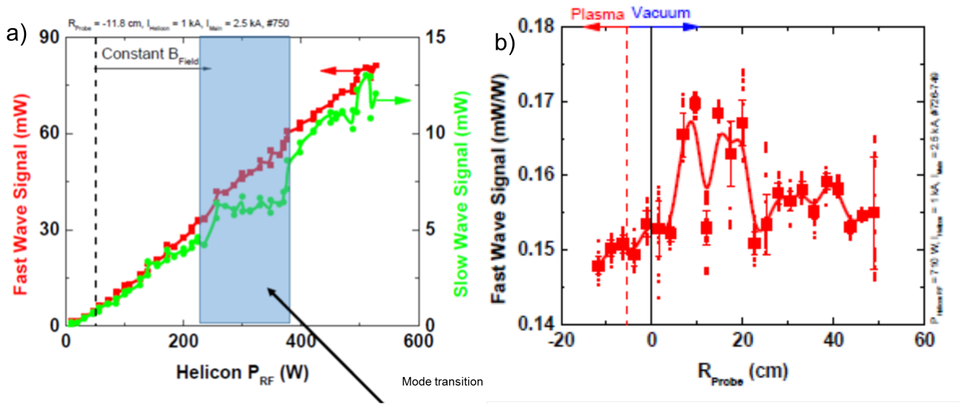

Figure 4: a) Evolution of helicon wave amplitude (perpendicular and parallel) with injected power. b) Helicon wave spatial structure perpendicular to the magnetic field at a constant power of 750 W.

ICRF operations

A simple strap ICRF antenna has been operated for the first time on the testbed in presence of the plasma (either self-generated by the strap or coming from the auxiliary plasma source). No major RF breakdown has been observed and the system has delivered a nominal power of up to 400 W at 5 MHz. An evaluation of the RF field profile perpendilar to the magnetic field has been done in vacuum ($P = 10^{-5}\ mbar$) and with Argon without external plasma. The comparison of the cases on Fig. 5 shows that the field amplitude decreases with the self-generated plasma, probably indicating a coupling/absorption of the wave within the plasma. A bump near the wall is also visible in the plasma case, in the region where the plasma density is the lowest. But, as in the case of the helicon wave, the spatial variations of the field amplitude are small, indicating that the field "fills in" the vessel. A numerical analysis with COMSOL is ongoing to check the impact of this uniform wave structure on the representativity of the sheath with respect to the tokamak case. Further tests at higher power and different frequencies will provide further experimental data.

Conclusion

A preliminary characterization of the plasma generated by the helicon source and of the RF fields from the ICRF antenna has been carried out. A plasma mode transition is observed but still has to be characterized. A Further steps involve the optimization of the operating parameters like the plasma density by adding more power to the helicon source, aligning it with the magnetic field and using other gas types (Helium,Hydrogen).

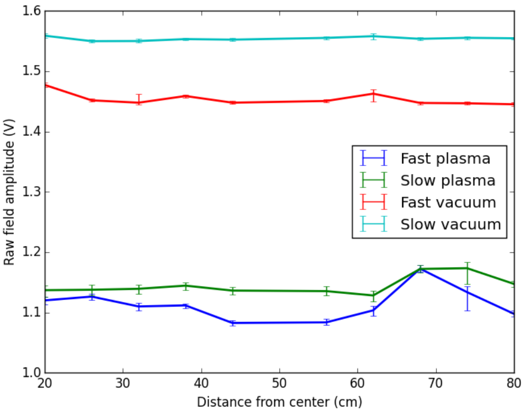

Figure 5: Measurement of field (perpendicular:fast and parallel:slow)profiles in vacuum and with self-generated plasma.

Acknowledgments

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