

## **Microwave absorption in dense and overdense plasmas generated in a Plasma Reactor for Environmental Applications**

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A Microwave Discharge Plasma Reactor devoted to the complex molecules dissociation has been designed and assembled at INFN-LNS in Catania. It operates with microwaves at 2.45 GHz triggering an off-resonance discharge in presence of a magnetic field provided by a Nd-Fe-B permanent magnet. A systematic characterization of the plasma properties (electron temperature and density, ion density, ecc.) by means of a Langmuir Probe has shown that the plasma distribution becomes strongly non-homogeneous for low pressures (below 0.3 mbar) and high power (above 70 W), as an overdense plasma is created in proximity of the microwave window [1]. Here a complete series of measurements about the power absorbed and reflected from the plasma is presented. The measurements have been carried out also during the plasma evolution towards the strongly non-homogeneous and overdense state, along with measurements of plasma physical characteristics by means of a Langmuir Probe.

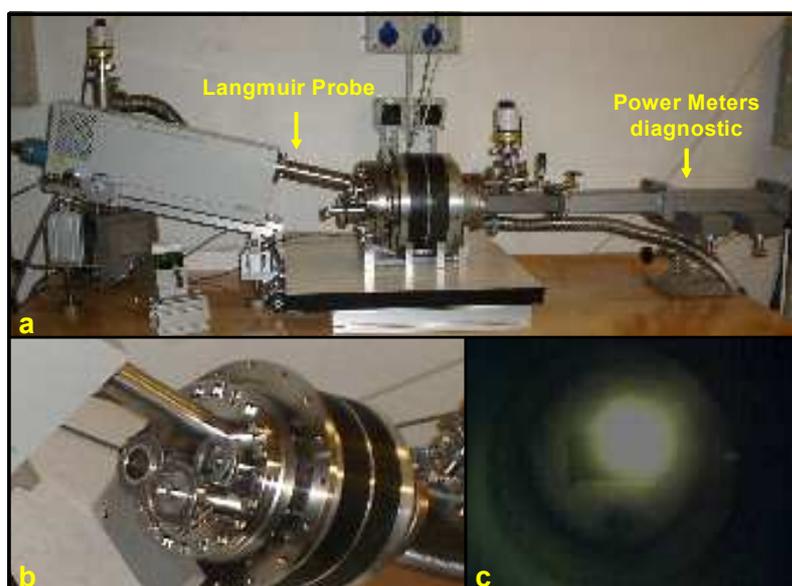
### **1. Introduction**

The design of the INFN-LNS plasma reactor devoted to environmental application was described in [1]. We have obtained a complete characterization of the plasma created in the reactor by means of a Langmuir probe, observing that in particular conditions of pressure and power, the formation of an “upstream” overdense plasma takes place, i.e. the plasma is generated only in the first part of the cavity, in proximity of microwave window. The different conditions of plasma density influence the transmission and the propagation of electromagnetic waves inside the cavity. Microwaves cannot propagate downstream inside

the cavity at low pressure and high power and high electron density is reached (even higher than the cut-off one).

In the region where the overdense plasma is created the magnetic field value corresponds to the first harmonic of the ECR resonance, as observed in the past by Popov [2]; in addition the magnetic field presents a small dip in such region, that may improve the plasma confinement with an additional increase of the electron density [1].

To better investigate such phenomenon a series of measurements with Power Meters has been carried out, thus measuring the transmitted and the reflected power in the reactor together with measurements of plasma parameters with Langmuir Probe. A picture of the plasma reactor is shown in fig.1.

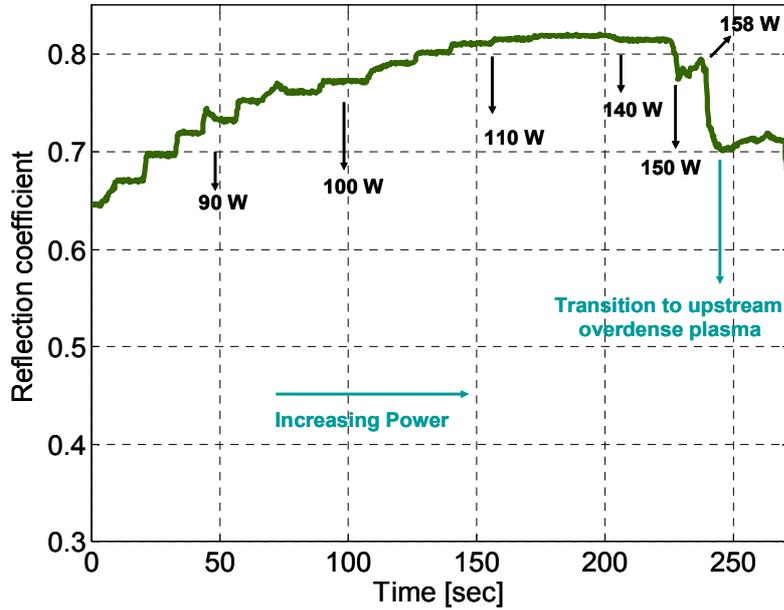


**Fig. 1:** (a) A panoramic view of the plasma reactor and related diagnostic tools. (b) A detail of one of the two plasma chamber flanges with LP location and optical window. (c) An image of the plasma obtained through a window of the plasma chamber.

## 2. Measurement with power meters

The measurements of reflected and transmitted power have been performed by means of power meters connected to the waveguide directional coupler (shown in fig.1 on the right side of the plasma reactor). Fig. 2 clearly shows that at measured  $P_{RF}=104.55W$  (corresponding to 150W of magnetron output power) the reflection coefficient abruptly decreases because of the transition to “upstream” overdense plasma. Such a transition is characterized by a strong absorption of microwave power that probably occurs at first ECR harmonic ( $\omega = 0.5\omega_{ECR}$ ), as suggested in [2, 3]. Many authors have demonstrated that strong microwave absorption occurs in particular conditions of pressure and rf power for some

cyclotron harmonics (absorption at  $mB_{ECR}$ , where  $m$  is an integer). Experimental results demonstrate also that this absorption mechanism maybe more efficient (in particular conditions) than usual mechanisms as ECR or collisional absorption.



**Fig.2:** Trend of reflection coefficient vs. time at 0.1 mbar, featuring a transition to overdense plasma above 158W.

### 3. Measurements of Reflected and Transmitted Power by means of Power Meters and comparison with plasma parameters

The plasma parameters (electron density and electron temperature) have been determined in parallel with the reflection coefficient  $R$  for different powers (30-70W) and pressures (0.1-0.9mbar). Fig.3 shows that at  $p=0.1$  mbar the electron density measured at 22cm ( $n_e^{22cm}$ ) increases as the reflection coefficient increases, whereas at 0.9 mbar  $n_e^{22cm}$  increases as the reflection coefficient decreases. This behaviour seems apparently strange, as one expects that also at 0.1 mbar electron density and reflection coefficient were inversely proportional. However we have to take into account that the plasma distribution inside the cavity is strongly non-homogeneous. In fact measurements performed at  $p=0.1$ mbar and at 30 cm of probe position (i.e. close to the microwave window) show that the electron density ( $n_e^{30cm}$ ) is close to the cut-off one ( $n_{cut-off} = 7.5 \cdot 10^{16} m^{-3}$ ), thus determining an increase of the reflected power and the following decrease of the electromagnetic wave which propagates downstream. As the reflection coefficient increases,  $n_e^{30cm}$  slightly decreases, thus permitting to a greater fraction of electromagnetic energy to propagate downstream (in fact  $n_e^{22cm}$  slightly increases).

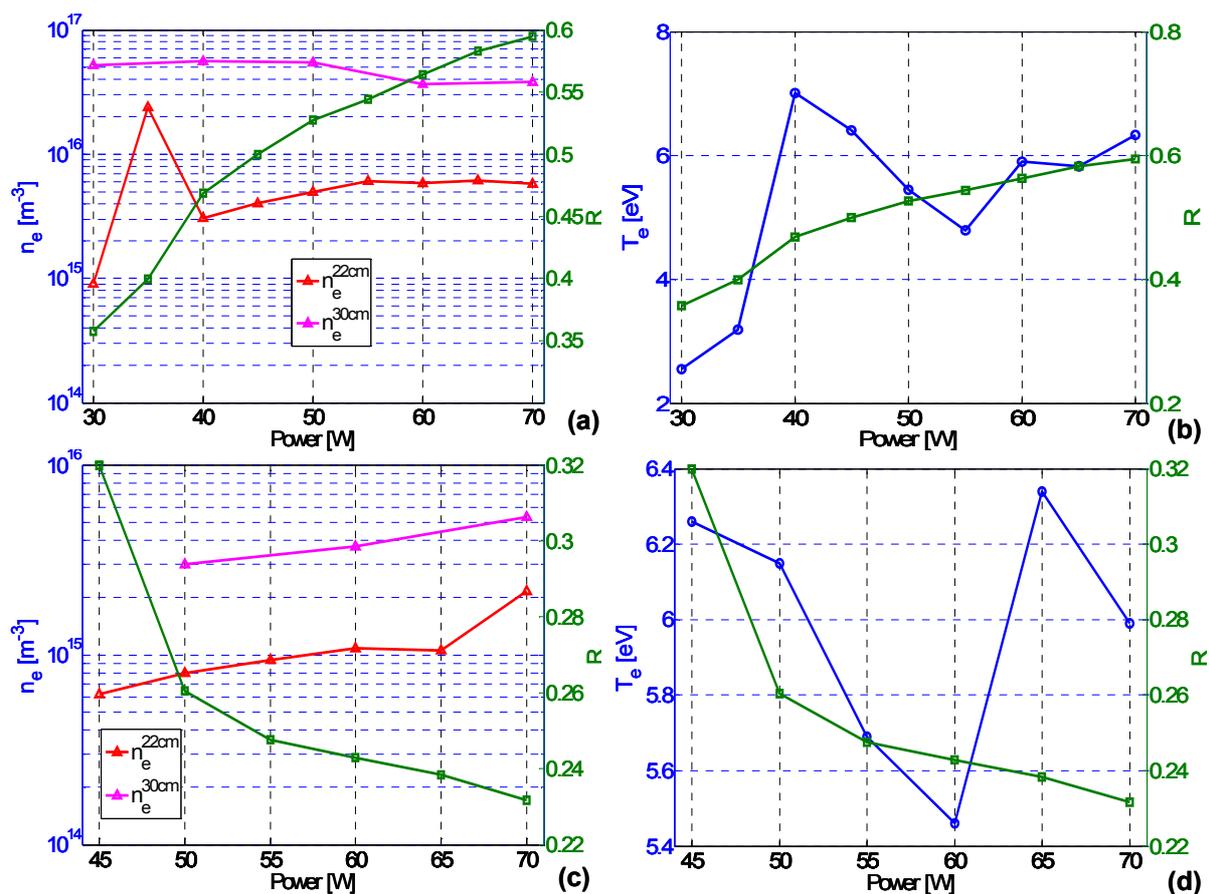


Fig. 3: (a) and (c) Electron density and Reflection coefficient vs power with LP at 22cm and 30cm at 0.1mbar and 0.9mbar respectively, (b) and (d) Electron Temperature and Reflection coefficient vs power with LP at 22cm and 30cm at 0.1mbar and at 0.9mbar respectively.

At 0.9 mbar the plasma is more uniformly distributed inside the cavity and the absorption of the electromagnetic waves occurs mainly in the off resonance and ECR zones (and weakly at the first harmonic) thus  $n_e$  increases both at 22 cm and at 30 cm as  $R$  decreases. The electron temperature at 0.1 mbar of pressure has a clear trend (except some fluctuations): it increases as the reflection coefficient increases as  $n_e^{22cm}$ , for the same reasons said above, whereas for higher pressures it becomes almost constant with power, thus demonstrating that the increase of the microwave power mostly affects the electron density.

## References

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