# Experimental characterization of capacitively coupled radio-frequency discharges in $N_2$-$CH_4$

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We have performed extensive measurements in capacitively coupled radio-frequency discharges, producing $N_2$-$CH_4$ plasmas for methane concentrations between 0% and 10%. These dusty plasmas are well characterized by monitoring the evolution, with the methane concentration, of the electron density, the self-bias voltage, the coupled power, and the spectral line intensity of a number of optical transitions. The plasma properties exhibit drastic changes that are found correlated with the dust production regime.

## Introduction

The interest in $N_2$-$CH_4$ capacitively coupled radio-frequency discharges (ccrf) has grown in recent years due to its potential to simulate, at laboratory scale, the atmosphere of Titan. In particular, the large amount of dusts and precipitates produced by these plasmas are of great interest to planetology, given their analogy with the *tholins* found in Titan's atmosphere [1].

## Experiment

This work reports an extensive study of these plasmas, performed in the PAMPRE experiment at the LATMOS laboratory. The experimental setup is thoroughly described in [1-2]. The discharge is driven by an rf power generator, running at 13.56 MHz, coupled to an asymmetric parallel-plate cylindrical reactor through an impedance matching box. Both the rf-applied voltage $V_{\mathrm{rf}}$ and the dc-self-bias voltage $V_{\mathrm{dc}}$ were measured, in addition to the effective power coupled to the plasma $W_{\mathrm{eff}}$ (obtained by using the subtractive method [3]), and the electron density $n_e$ (obtained by micro-wave resonance frequency shift [4], using the $TM_{010}$ cavity mode). Optical emission spectroscopy (OES) measurements were performed upon the second positive and the first negative systems of $N_2$, as well as upon the violet CN bands.

Measurements were carried out both at constant $V_{\mathrm{rf}}$ and at constant generator power, bearing in mind that the applied voltage is an input parameter to simulations [5], whereas the coupled power is the key parameter controlling the experiment.

## Results

Figure 1 presents measurements, at constant $V_{\mathrm{rf}}$ and at constant generator power, of the electron density (accuracy of $4\times10^{13}$ $m^{-3}$) and of the absolute value of $V_{\mathrm{dc}}$, as a function of the methane concentration. For the measurements at fixed power, one notices a sudden drop in the values of both $n_e$ and $|V_{\mathrm{dc}}|$, when the gas composition goes from pure $N_2$ to a mixture containing 1% of $CH_4$. At constant power [see figure 1(b)], after the initial drop the electron density and the self-bias voltage increase with the concentration of $CH_4$, becoming similar to those observed in pure $N_2$ plasmas for mixtures containing 7-8% methane. The decrease of these two quantities from the pure $N_2$ values is well correlated with the variation of dust production efficiency as a function of $CH_4$ concentration [6]. At constant $V_{\mathrm{rf}}$, however, [see figure 1(a)] the effect of dust is somewhat masked by the fact that the experiments were ran by varying the generator power, in order to maintain the desired $V_{\mathrm{rf}}$.

This behavior can be confirmed in figure 2. Here, one observes that: (i) the coupled power must initially increase [see figure 1(a)], to compensate for the drop in the applied voltage [see figure 1(b)] due to the formation of dust; (ii) for $CH_4$ concentrations above 1%, $W_{\mathrm{eff}}$ decreases to ensure a constant

$V_{rf}$ [see figure 1(a)], since the applied voltage tends to increase with the admixture of methane, at constant power [see figure 1(b)].

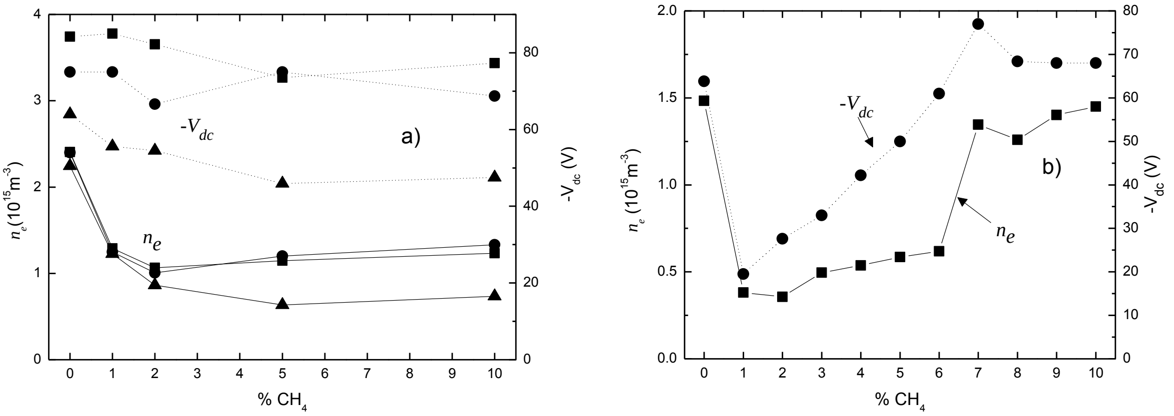

Fig. 1: Electron density (solid lines) and self-bias voltage (dotted), as a function of the $CH_4$ concentration, at: a) fixed $V_{rf}$ = 220 V and three different pressures (■-0.50 mbar; ●- 0.77 mbar;▲-0.98 mbar); b) fixed 30W generator power and 0.9 mbar pressure.

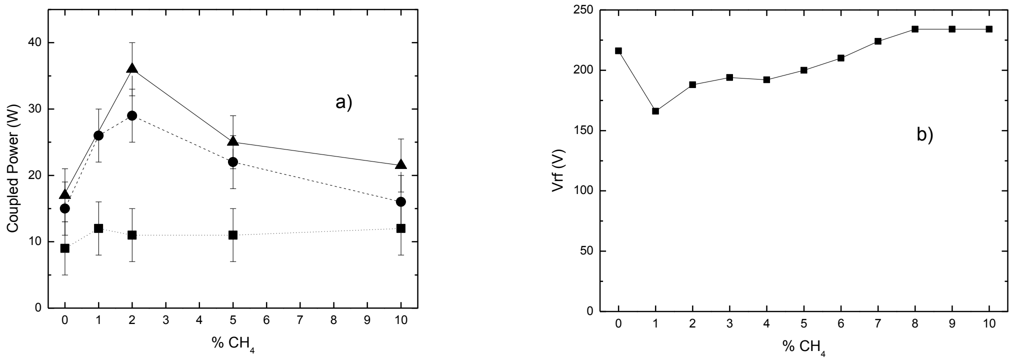

Fig. 2: a) Effective power coupled to the plasma, as a function of the $CH_4$ concentration, at fixed $V_{rf}$ = 220V and three different pressures (■-0.50 mbar;●-0.77 mbar;▲-0.98 mbar); b) Applied voltage, as function of % $CH_4$, at fixed 30 W generator power and 0.9 mbar pressure.

The paper will also present and discuss the OES measurements performed for the different operating conditions.

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