# RF Capacitively coupled plasmas in N2-H2 mixtures

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# RF CAPACITIVELY COUPLED PLASMAS IN $N_2$-$H_2$ MIXTURES

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This paper studies the modifications induced in low-pressure radio-frequency capacitively coupled nitrogen plasmas, by the addition of a few amount of hydrogen (up to 5%). The plasmas are studied using both experiments (electrical and optical emission spectroscopy measurements) and simulations (using a fluid+kinetic code). Results reveal that the electron density increases with the amount of injected $H_2$, at constant coupled power.

## 1-Introduction

Radio-frequency (RF) capacitively coupled plasmas (CCP) are currently used in planetary studies to simulate the reactivity of ionospheres. The present work is an intermediate step towards the study of $N_2$-$CH_4$ plasmas (containing hydrogen due to the dissociation of methane), for the simulation of the ionospheric chemistry of Titan, the biggest satellite of Saturn. The project started with the study of pure nitrogen RF-CCPs, already concluded [1].

## 2-Experiment

The experimental setup is described in detail in [2]. We recall that the parallel-plate electrodes (driven at 13.56 MHz frequency) are surrounded by a cylindrical metallic grid, which confines the discharge. The resulting closed system acts as a resonant cavity in the microwave range, used to measure the electron density. Optical Emission Spectroscopy (OES) diagnostics are used to study the evolution, with the working conditions, of: (i) the First Negative System (FNS) with the molecular nitrogen ionic band; (ii) the atomic hydrogen $H_\beta$ line at 486.1 nm; (iii) the atomic argon line at 811.5 nm (Ar is used here as an actinometer). Note that these H and Ar lines are chosen in order to prevent overlapping with the nitrogen bands [3]. The effective RF power coupled to the plasma $W_{eff}$ is determined using the subtractive method [1], hence accounting for the circuitry power losses.

## 3-Modelling

Simulations use a hybrid code that couples a 2D ($r$, $z$) time-dependent fluid-type module, describing the transport of the charged particles, to a very complete 0D kinetic module, for the nitrogen-hydrogen mixture. The fluid module solves the charged particle continuity and momentum transfer equations, the electron mean energy transport equations, and Poisson's equation for the RF electric potential. The kinetic module solves the two-term homogeneous and stationary electron Boltzmann equation (accounting for inelastic collisions from ground-state molecules and atoms, and inelastic and superelastic collisions involving vibrationally excited states) and the rate balance equations of the ground-state vibrational excited states and the main electronic excited states with the $N_2$ and $H_2$ molecules, and of the most relevant electronic excited states with the N and H atoms. The kinetic module yields a set of electron transport parameters and rate coefficients for the processes involved in the charged particle production and destruction, which include: (i) direct and stepwise electron-impact ionisation; (ii) associative ionisation involving metastable states; (iii) ion conversion; and (iv) electron-ion recombination.

## 4-Results

Figures 1 presents, as a function of the injected amount of $H_2$, the evolution of the H atoms relative density and of the effective power coupled, for different pressures and for a given RF voltage Vrf. For all studied pressures, one observes that: (i) [H] increases linearly with the concentration of molecular hydrogen; (ii) $W_{eff}$ is not affected by the admission of $H_2$ in the $N_2$ discharge.

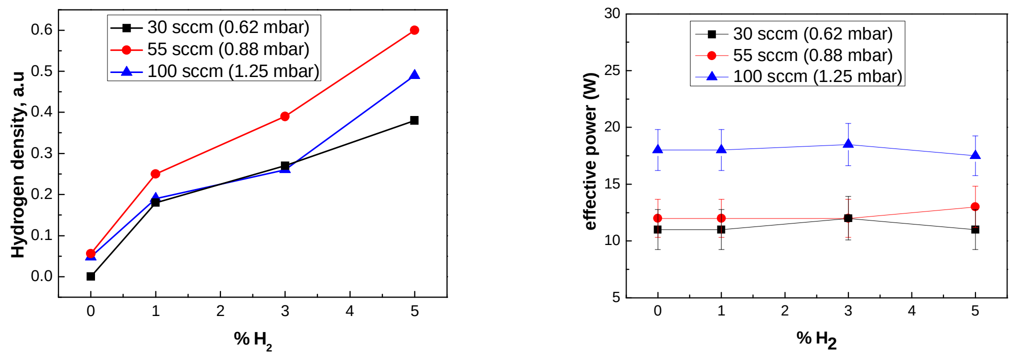


Fig.1 H atoms relative density (left) and effective RF power coupled to the plasma (right), as a function of the concentration of molecular hydrogen, at Vrf=220V and for various pressures.

The plasma ionization degree can be monitored by analyzing either the electron density or the molecular band of $N_2^+$. Figure 2 presents measurements of these quantities, as a function of the concentration of $H_2$, for various pressures.

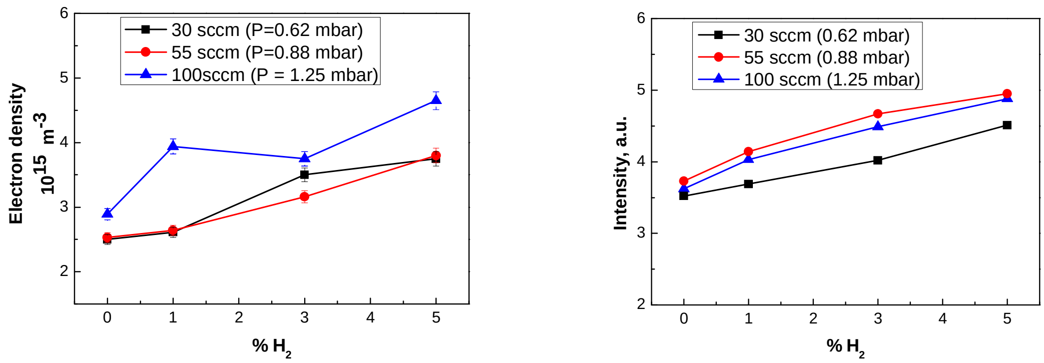


Fig. 2 Electron density (left) and intensity of the FNS band of $N_2^+$, (right), as a function of the concentration of molecular hydrogen, at Vrf = 220V and for various pressures.

One observes that the electron / ion production increases with the amount of $H_2$ in the mixture, revealing that the ionization efficiency increases with the hydrogen (molecular and atomic) concentration, at constant coupled power.

The paper will also compare simulations and measurements, discussing the results obtained in validating the model.

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