Welcome to XXXI ICPIG

Granada, Spain 14-19 July 2013

This prestigious conference has been the forum for discussion of nearly all fields in plasma science since 1953, from the fundamentals of the interaction of charged particles with molecules to plasma chemistry, surface treatment and thin film technology, plasma medicine, light sources, plasma assisted combustión, plasma material processing, atmospheric and stellar plasmas, environmental protection and pollution control, plasma aerodynamics, and non-thermal plasmas in fusion devices.

Our conference will offer a complete scientific programme consisting of 10 general and 24 topical invited lectures (see the timetable) covering nearly all topics in the field of ionized gases, given by worldwide leaders in their fields, besides regular contributions and two special sessions on:

Special Session 1: Plasma Space Propulsion
Special Session 2: Plasma Flow Control and Combustion

Finally, the scientific programme also includes lectures from the winners of the von Engel & Franklin Prize and the IUPAP Young Scientist Medal and Prize in Plasma Physics.

On behalf of the International and Local Organizing Committees of XXXI ICPIG, we are kindly inviting you to participate. We look forward to seeing you in Granada.

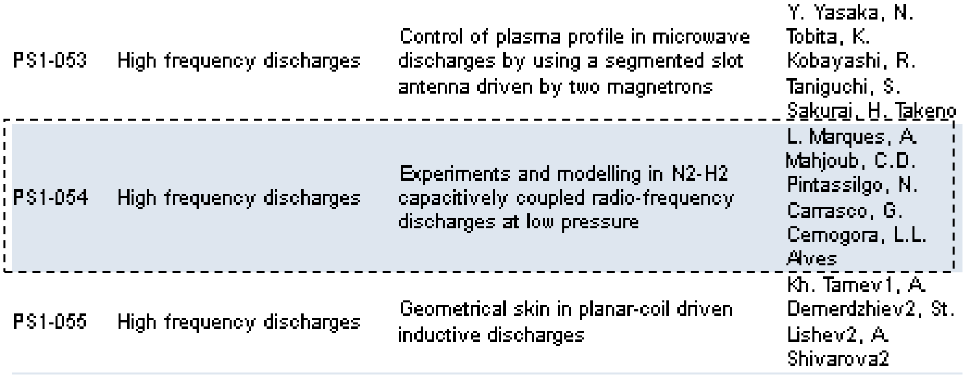
F. J. Gordillo-Vázquez

ICPIG – 2013 LOC Chair

ICPIG-2013

The XXXI edition of the International Conference on Phenomena in Ionized Gases (ICPIG) is held in Spain for the first time after the first ICPIG that took place back in 1953 in Oxford (UK) 60 years ago. The ICPIG, a tradicional International conference with a remarkably long history, is held every two years and covers nearly all aspects of phenomena in ionizad gases from fundamentals to applications. The ICPIG topics are grouped into four major sections (A. Fundamentals; B. Modeling, Simulation and Diagnostics; C. Plasma Sources and Discharge Regimes; D. Applications) with each major section structured into several sub-topics.

The last three ICPIG editions were held in Prague (Czech Republic, 2007), Cancún (Mexico, 2009) and Belfast (UK, 2011).



PS1-053	High frequency discharges	Control of plasma profile in microwave discharges by using a segmented slot antenna driven by two magnetrons	Y. Yasaka, N. Tobita, K. Kobayashi, R. Taniguchi, S. Sakurai, H. Takeno
PS1-054	High frequency discharges	Experiments and modelling in N2-H2 capacitively coupled radio-frequency discharges at low pressure	L. Marques, A. Mahjoub, C.D. Pintassilgo, N. Carrasco, G. Cernogora, L.L. Alves
PS1-055	High frequency discharges	Geometrical skin in planar-coil driven inductive discharges	Kh. Tarnev1, A. Demerdzhiev2, St. Lishev2, A. Shivarova2

Experiments and modelling in N_2-H_2 capacitively coupled radio-frequency discharges at low pressure

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This work uses experiments and simulations to analyze the modifications induced in pure N_2 capacitively coupled radio-frequency discharges, running at low pressure (0.6–1.2 mbar) and low power (5–20 W), by the addition of small amounts of H_2 (up to 5%). Simulations use a hybrid code coupling a two-dimensional time-dependent fluid module, describing the dynamics of the charged particles, to a zero-dimensional kinetic module, describing the production and destruction of nitrogen and hydrogen neutral species. The discussion is particularly focused on the results obtained for the electron density and the radiative transition intensities with nitrogen species. Model predictions are in qualitative agreement with measurements, for the evolution of these quantities with changes in both the gas pressure and the hydrogen percentage in the gas mixture.

Experiments and modelling in N_2-H_2 capacitively coupled radio-frequency discharges at low pressure

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Abstract

This work uses experiments and simulations to analyze the modifications induced in pure N_2 capacitively coupled radio-frequency discharges [1], running at low pressure (0.6–1.2 mbar) and low power (5–20 W), by the addition of small amounts of H_2 (up to 5%). Simulations use a hybrid code coupling a two-dimensional time-dependent fluid module, describing the dynamics of the charged particles, to a zero-dimensional kinetic module, describing the production and destruction of nitrogen and hydrogen neutral species. The discussion is particularly focused on the results obtained for the electron density and the radiative transition intensities with nitrogen species. Model predictions are in qualitative agreement with measurements, for the evolution of these quantities with changes in both the gas pressure and the hydrogen percentage in the gas mixture.

Model description

We use a hybrid code that couples a two-dimensional (r, z) time-dependent fluid-type module, describing the transport of electrons and positive ions in the reactor under study, to a very complete 0D kinetic code for the nitrogen-hydrogen gas mixture. The fluid code 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 electron Boltzmann equation and the rate balance equations for the most relevant plasma species. The space-time map of the electron transport and rate coefficients is obtained from the electron mean energy profile using the local mean energy approximation [2].

Fluid module equations

Electron transport

- Continuity equation

$$\frac{\partial n_e}{\partial t} + \vec{\nabla}\cdot\vec{\Gamma}_e = S_e$$

- Momentum transfer equation

$$\vec{\Gamma}_e = -n_e\mu_e\vec{E}\text{-}\vec{\nabla}(D_e n_e)$$

- Energy density transport equations

$$\frac{\partial(n_e\varepsilon)}{\partial t} + \vec{\nabla}\cdot\vec{\Gamma}_\varepsilon = -\vec{\Gamma}_e\cdot\vec{E} - \theta_e n_e$$

$$\vec{\Gamma}_\varepsilon = -n_e\varepsilon\,\mu_\varepsilon\vec{E}\text{-}\vec{\nabla}(D_\varepsilon n_e\varepsilon)$$

Ion transport

- Continuity equation

$$\frac{\partial n_i}{\partial t} + \vec{\nabla}\cdot\vec{\Gamma}_i = S_i$$

- Momentum transfer equation

$$\vec{\Gamma}_i = n_i\mu_i E_i^*\text{-}\vec{\nabla}(D_i n_i)$$

- Effective electric field equation

$$\frac{\partial\vec{E}_i^*}{\partial t} \approx \nu_c(\vec{E}-\vec{E}_i^*) - \frac{(\mathrm{v}_i\cdot\nabla)\mathrm{v}_i}{\mu_i N} - \frac{1}{\mu_i N}\left[\frac{S_i\,\mathrm{v}_i}{n_i}\right]$$

Poisson's equation

$$\varepsilon_0\nabla^2 V = -e\Big(\sum_i n_i - n_e\Big)$$

Boundary conditions

Electrons:

$$\begin{cases}\Gamma_{e\perp} = \dfrac{n_e\langle \mathrm{v}\rangle}{2} & \Gamma_{e//} = 0 \\ \Gamma_{\varepsilon\perp} = \dfrac{n_e\langle \mathrm{v}u\rangle}{2} & \Gamma_{\varepsilon//} = 0\end{cases} \qquad \left(\frac{\partial n_e}{\partial r}\right)_{r=0} = 0 \qquad \left(\frac{\partial n_e\varepsilon}{\partial r}\right)_{r=0} = 0$$

Ions:

$$\begin{cases}\Gamma_{i\perp} = \dfrac{n_i \mathrm{v}_{thi}}{4} + \beta\, n_i\mu_i E_\perp^*\,, \quad \beta = \begin{cases}1, & E_\perp^* > 0\\ 0, & E_\perp^* < 0\end{cases} \\ \Gamma_{i//} = 0\end{cases} \qquad \left(\frac{\partial n_i}{\partial r}\right)_{r=0} = 0$$

Potential:

$$\begin{cases}V_{dc} + V_{rf}\cos(\omega t) & \textbf{at driven electrode} \\ 0 & \textbf{at grounded surfaces}\end{cases} \qquad \left(\frac{\partial V}{\partial r}\right)_{r=0} = 0$$

Nitrogen – hydrogen kinetic scheme

V-V exchange

$N_2(v) + N_2(w-1) \rightleftarrows N_2(v-1) + N_2(w)$

$H_2(v) + H_2(w-1) \rightleftarrows H_2(v-1) + H_2(w)$

$N_2(v) + H_2(w-1) \rightleftarrows N_2(v-1) + H_2(w)$

$N_2(v) + H_2(w-1) \rightleftarrows N_2(v-2) + H_2(w)$

V-T exchange

$N_2(v) + M \rightleftarrows N_2(v-1) + M$ $M = N_2; H_2; N; H$

$H_2(v) + M \rightleftarrows H_2(v-1) + M$ $M = H_2; H$

$N_2(v) + M \rightleftarrows N_2(v-\Delta v) + M$ $\Delta v > 1$ $M = N; H$

$H_2(v) + H \rightleftarrows H_2(v-\Delta v) + H$ $\Delta v > 1$

e-V excitation/de-excitation

$e^- + N_2(v) \rightleftarrows e^- + N_2(w)$ $v, w < 10$

$e^- + H_2(v) \rightleftarrows e^- + H_2(w)$ $|v-w| < 3$

EV indirect excitation/de-excitation

$e^- + H_2(v) \rightarrow e^- + H_2(B^1, C^1) \rightarrow e^- + H_2(w)$

SPECIES

$N_2(v=0\ldots45)$, $N_2(A, B, C, a, a', a'', w)$,
$N(^4S, ^2P, ^2D)$,
$H_2(v=0\ldots14)$, $H(1s)$,
NH_3, NH_2, NH,
N_2^+, N_4^+, HN_2^+, H_2^+, H_3^+, H^+, H^-

Others process included

(i) electron-impact ionization from $N_2(v=0)$ and $H_2(v)$; (ii) electron recombination with N_2^+, N_4^+, HN_2^+, H_2^+, H_3^+ ions;
(iii) electron-impact ionization and associative ionization involving the excited states $N_2(A)$ and $N_2(a')$;
(iv) electron-impact dissociation from $N_2(v=0)$ and $H_2(v)$; (v) H^- production by dissociative attachment from $H_2(v)$;
(v) ion conversion from N_2^+ to N_4^+; from N_4^+ to N_2^+; from H_2^+ to H_3^+; from N_4^+, N_2^+, H_2^+ to HN_2^+;
(vi) H^- destruction by associative detachment, electron impact detachment, ion-ion neutralization with H_3^+, H_2^+, H^+;
(vii) Production/destruction of NH_x (x=1-3).

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Experimental methodology

Plasma discharge

The plasma is produced at 13.56 MHz within a cylindrical parallel-plate reactor surrounded by a grounded metallic grid. The discharges run at 0.6 – 1.2 mbar total pressures, 30 – 100 sccm gas flows and 5 – 20 W coupled powers (corresponding to V_{rf} = 100 – 220 V zero-to-peak applied voltages) in N_2-H_2 gas mixtures with hydrogen concentrations up to 5%.

Plasma diagnostics

Charged particle densities

- The electron density is measured using a microwave resonant cavity method [3].
- The evolution of the N_2^+ density is monitored by following the radiative intensity of the FNS, obtained using optical emission spectroscopy.

Effective RF power absorbed

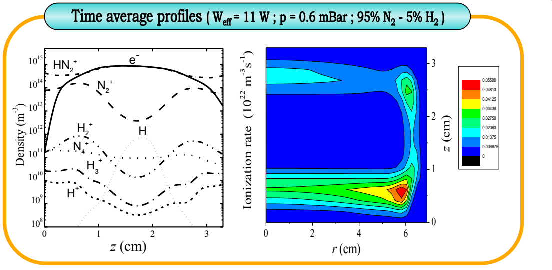
The effective power absorbed by the plasma at given V_{rf} is given by :

$$W_{eff} = W_{ap} - W_{ac}$$

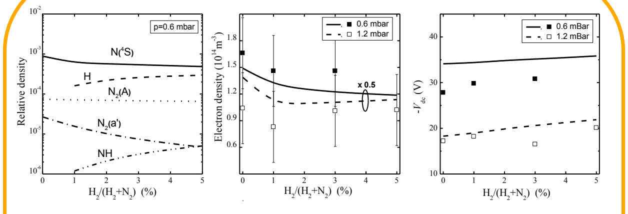
W_{ap} is the absorbed power with the plasma ON.
W_{ac} is the absorbed power in the impedance matching circuit with the plasma OFF.

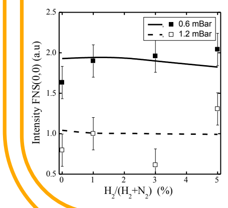
Results

Time average profiles (W_{eff} = 11 W ; p = 0.6 mBar ; 95% N_2 - 5% H_2)

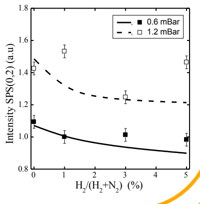


Comparison model-experiment (W_{eff} ~ 6 W)





Simulations of **FNS and SPS radiative intensities** are normalized to one experimental point, obtained at 1.2 mbar pressure for the FNS(0,0) and 0.6 mbar for the SPS(0,2), at 99% N_2 + 1% H_2 gas mixture.



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