H_2 plasma kinetics in the PIC simulation of a 2.45 GHz ECR ion source

Lorenzo Neri[1], Gianpiero Colonna[2], Annarita Laricchiuta[2], Giuseppe Castro[1], Ornella Leonardi[1], Lugi G. Celona[1], Santo Gammino[1], Andrea Miraglia[1], Francesco Grespan[3], Michele Comunian[3], Giovanni Russo[4], Sebastiano Boscarino[4], Armando Coco[4], Giuseppe Bilotta[5]

[1] *INFN – Laboratori Nazionali del Sud, 95123, Catania, Italy*
[2] *CNR – Istituto per la Scienza e Tecnologia dei Plasmi, Sezione di Bari, 70126, Italy*
[3] *INFN – Laboratori Nazionali di Legnaro, 35020, Padova, Italy*
[4] *UNICT – Dipartimento di Matematica e Informatica, Catania, 95131, Italy*
[5] *INGV – Osservatorio Etneo, Sezione di Catania, 95125, Italy*

Corresponding author's e-mail: neri@lns.infn.it

This study uses a PIC simulation to investigate the kinetics of hydrogen plasma in a 2.45 GHz Electron Cyclotron Resonance ion source. The PIC code shows the evolution of microwave propagation as the plasma density grows from an almost empty plasma chamber (1E13 m^{-3}) to a plasma density of nearly 1E17 m^{-3}. Distinct electromagnetic stages were observed to impact plasma heating and density distribution. The simulation incorporates tridimensional charged particle motion, tridimensional electromagnetic simulation with tensorial (real and imaginary part) permittivity, axial symmetric Poisson solver (at every integration time step of 2E-11 sec), density evolution of neutral and excited particles, and interaction with conductive and insulating walls with secondary electron emission from Boron Nitride surface. The implemented chemical model includes all the collisional processes relevant to plasma evolution, profiling the diverse reaction channels. The excitation and the de-excitation of the first atomic level of H and the first excited vibrational level of H_2 are inserted to estimate the possible role of excited states and the actual need to extend the kinetics to a state-specific chemical scheme. The code is developed to explore how different ion source magnetic field configurations can result in an abrupt transition from an unstable beam production to the remarkable stability of the HSMDIS* configuration. The experimental investigation done during the commissioning of the Proton Source for the European Spallation Source (PS-ESS) also revealed the possibility of modifying the species fraction of the extracted beam, ranging from predominantly protons to the exclusive H_2^+ and H_3^+ ions. This study tries to unveil the interplay of phenomena contributing to the plasma dynamics in the ECR ion sources, offering valuable insight that can assist the optimization of source performances for specific applications.

* L. Neri, L. Celona, “High Stability Microwave Discharge Ion Sources”, Nature Scientific Reports 12, 3064 (2022) https://doi.org/10.1038/s41598-022-06937-7