Study of hydrogen ion species in a multicusp ion source

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Introduction

Multicusp ion sources have been developped for several years to inject neutral particles in tokamaks. Such hydrogen plasma generators are useful to produce various species of hydrogen ions in a steady-state plasma at a low pressure [1]. Reaction processes are well known [2] and the species ratio is ruled by collisions leading to different terms of production and loss. The ion production is controlled by the discharge parameters as it has been shown experimentally and numerically. The proton ratio depends strongly on the surface state of the ion source walls.

Experimental set-up

A hydrogen plasma is produced in a small multicusp ion source (Fig. 1) of 10 cm in length and 10 cm in diameter, surrounded by eight alternated permanent magnets of 3.4 kGauss. The hydrogen gas pressure (P) is regulated by a controlled microleak and measured by an ionization gauge in the range of 10^{-5} mbar. To produce the plasma discharge, a hot cathode made by a Tungsten filament is biased negatively (Vd) from the wall of the chamber to extract primary electrons with a sufficient energy. Primary electrons density depends on the heating filament current (If) following the Duschmann-Richardson law. These three parameters P, Vd and If are the control parameters for the following study of the multicusp ion source.

Principle of the measurement

The ion source is insulated by ceramics and can be biased (Vb) to produce an ion beam at 500eV. Adjusting the bias voltages (Ve) of the Einzel lenses, the ion beam is focused inside a vacuum test chamber containing a mass spectrometer. Spectra of the ion species are obtained for pressures from 10^{-5}mbar to 10^{-4}mbar. The discharge voltage (Vd) is adjusted to be at the saturation discharge current (Id). A higher filament current (If) increases the ionization rate of the plasma and the saturation discharge current and so the ion production yield. Following these considerations, the next results are presented for
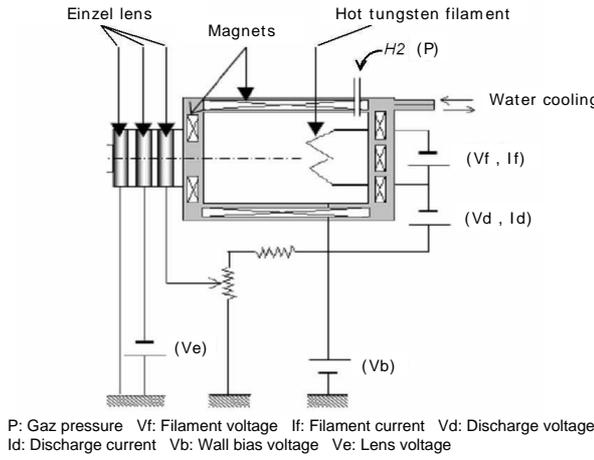
P: Gaz pressure Vf: Filament voltage If: Filament current Vd: Discharge voltage
Id: Discharge current Vb: Wall bias voltage Ve: Lens voltage

Figure 1: Diagram of the multicusp ion source
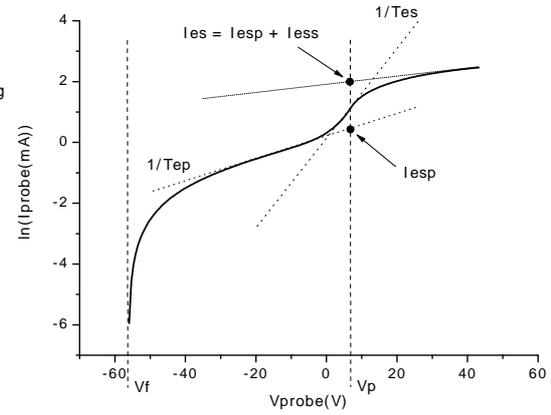
Figure 2: Langmuir probe characteristic in the center of the chamber, along a radius

Vd=80V and If=11.3A, which gives a discharge current Id=3A. Langmuir characteristics in a semilogarithmic plot (Fig. 2) for each value of pressure bring informations about electronic temperatures for primary (T_{ep}=17-31eV) and secondary (T_{es}=3-8eV) electrons. Densities are given through the primary electrons saturation currents (I_{esp}=2mA) and the total electronic saturation current (I_{es}=9-25mA).

Numerical approach

The experimental data allow us to calculate the normalized energy repartition function F(E) [3] introduced for the electronic collisions :

$$F(E) = \frac{2}{\sqrt{\pi}} \frac{1}{1+\frac{n_2}{n_1}} \sqrt{E} \frac{1}{(kT_1)^{3/2}} e^{-E/kT_1} + \frac{2}{\sqrt{\pi}} \frac{1}{1+\frac{n_1}{n_2}} \sqrt{E} \frac{1}{(kT_2)^{3/2}} e^{-E/kT_2} \quad (eV^{-1}) \quad (1)$$

The bi-maxwellian velocity distribution function can also be obtained from the second derivative of the experimental Langmuir probe characteristic. The two electronic populations are used to explain the reaction rates (Fig. 4) :

$$k = \langle \sigma v \rangle = \int_0^\infty \sigma(v) v G(v) dv = 10^2 \sqrt{\frac{2e}{m_e}} \int_0^\infty \sigma(E) \sqrt{E} F(E) dE \quad (cm^3/s) \quad (2)$$

To derive a simplified Global Model, it is necessary to consider the collisional reactions described in Fig. 3. Recombination (4), (6) is a low energy process whereas ionization (1), (5) and dissociation (2), (3), (7) are higher energy processes. Ion densities are governed by the population balance equations which are written respectively for H, H^+, H_2^+, H_3^+:

$$\frac{\partial n}{\partial t} + \nabla . (n\mathbf{u}) = G - L \quad (cm^{-3}s^{-1}) \quad (3)$$

$$H_2 + e \xrightarrow{k_1} H_2^+ + 2e$$

$$H_2 + e \xrightarrow{k_2} H + H + e$$

$$H_2^+ + e \xrightarrow{k_3} H^+ + H + e$$

$$H_2^+ + H_2 \xrightarrow{k_4} H_3^+ + H$$

$$H + e \xrightarrow{k_5} H^+ + 2e$$

$$H_3^+ + e \xrightarrow{k_6} H + H_2$$
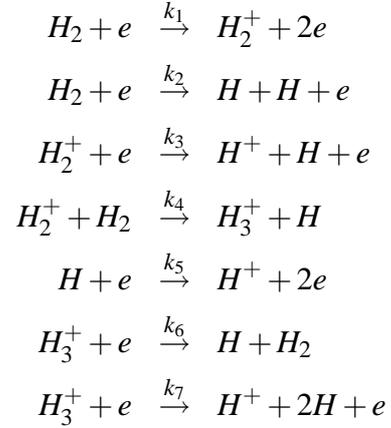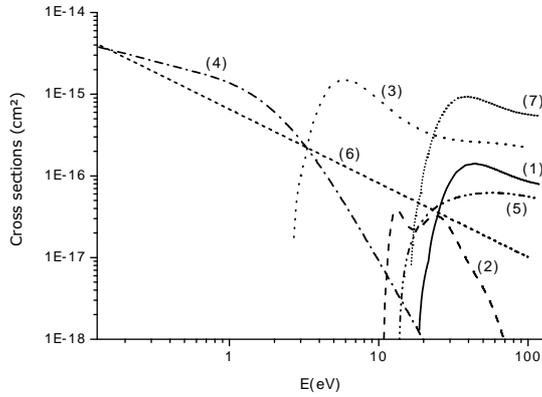
$$H_3^+ + e \xrightarrow{k_7} H^+ + 2H + e$$

Figure 3: Cross sections [4] and main reaction equations [2]

where *G* and *L* respectively stands for gains and losses, and the closing mass conservation equation in a weakly ionised and dissociated plasma. The diffusive loss term for atomic hydrogen introduces a sticking parameter γ which is related to the probability for H atoms to be adsorbed to the wall.

Results

Fig. 5 displays the numerically computed evolution of H^+, H_2^+ et H_3^+ relative ratios as a function of the pressure for different values of the sticking parameter γ. It shows that pressure is not predominant in the proton production process. The main parameter that governs the ion ratios is γ. The wall surface state is determinant, the best proton ratio being obtained for the lowest value of γ. It has been previously experimentally demonstrated that a few percentage of water added to hydrogen improves the proton ration. The water molecules are trapped at the wall surface, thus preventing hydrogen of sticking to the walls. We measured in these conditions the ion species relative quantities as a function of the total pressure, as displayed in fig. 6. These results almost perfectly fit our numerical results for $\gamma = 0.1$ (Fig. 6). However, it is difficult to experimentally obtain a proton ratio higher than 25% with our configuration.

Conclusion

The multipolar device is able to produce an ion beam of 500eV from a low pressure hydrogen plasma with 25% of H^+. The water vapor mixed with the hydrogen gaz modifies
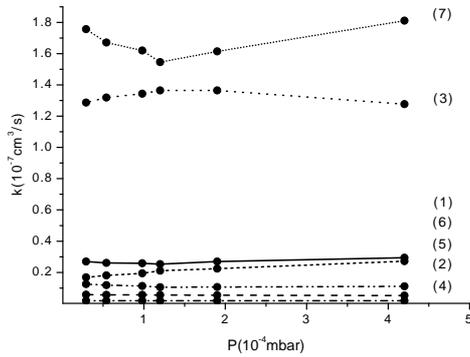
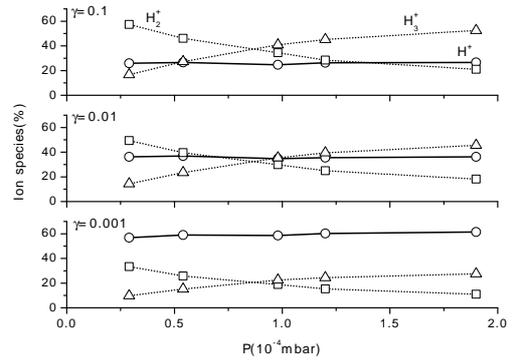Figure 4: Reaction rates (Vd=80V, If=11.3A)

Figure 5: Ion species percentage for γ=0.1, 0.01 and 0.01
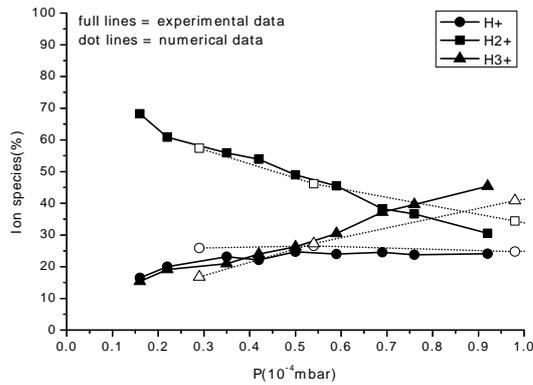

Figure 6: Experimental measures (Vd=80V, If=11.3A) and numerical results for $\gamma = 0.1$ of the ion species evolution

the surface state and so the adsorption probability to the wall for H atoms. Introducing helium gaz in order to increase the electronic temperature has no effect on the proton yield because primary electrons from the filament are sufficient.

References

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