Status of the Negative Hydrogen Ion Test Stand at CEA Saclay

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Abstract:

At CEA-Saclay, in 2003, the new 2.45 GHz ECR source, based on pure volume H^- ion production, showed a dramatic increase of the H^- extracted ion beam. In fact, since the rectangular plasma chamber is separated in two different parts by a stainless steel grid, the extracted H^- current rose from few µA to 1.5 mA. Of course the grid position and its potential with respect to the plasma chamber were optimised. Ceramic plates allow increasing the electron density and lead to an improvement of the negative ion production. Plasma characterization by using Langmuir probes and positive charge analysis are also presented. The last results are reported and discussed.

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INTRODUCTION

Some of the future high power proton accelerators (HPPA) like SNS, ESS or neutrino factories require reliable and efficient H^- ion production to inject in compressor rings. These high intensity facilities plan to work in pulsed mode with high duty cycle requiring source improvements. Moreover, existing machines are also interested in new source developments.

In this framework, the CEA decided an important R&D program to develop high intensity light ion sources. At CEA/Saclay, the SILHI team develops a 2.45 GHz source [1] delivering a high intensity proton beam (more than 100 mA in CW mode) with a good efficiency for several years. The proton source performance encouraged the development of a negative ion source program. So a test stand has been built to study a new 2.45 GHz ECR negative ion source. This source has been initially designed with SILHI spare parts, to operate in pulse mode (mostly 1 or 2 ms – 10 Hz). Up to the beginning of 2003, only a small amount of H- ions was observed. Since then, measurements performed with the rectangular plasma chamber separated in 2 zones showed an important improvement. This upgrade is shortly recalled in the next section. The third section will insist on the last results obtained by testing different materials and by varying the production zone volume. To improve the source behaviour understanding, plasma characterisation measurements were performed. So, recent Langmuir probe measurements and positive ion extraction analysis will be presented. Finally the source now regularly produces a 1.5 mA pulsed negative hydrogen ion beam through a 5 mm diameter aperture.

PLASMA CHAMBER SEPARATION

To produce negative hydrogen ions, the sources are generally based on the double stage principle [2]. First, in the plasma creation zone, energetic electrons of about 20 to 40 eV interact with the gas to excite the molecules and then in a second zone, slow electrons (about

1-2 eV) react with these excited molecules to give an H atom and an H^- ion. This process is called the dissociative attachment. Generally, both zones are separated by a magnetic filter to avoid the high energy electron flux enters into the negative ion production zone.

At Saclay, the preliminary design of the source based on plasma generated by electron cyclotron resonance, followed this principle. The 2.45 GHz RF power was injected in the plasma production zone where the axial magnetic field provided by 2 coils reached close to 1000 Gauss. Then a tunable C-shape magnetic filter separated this zone and the negative ion production area. With this magnetic configuration, only few µA of H^- ions have been observed [3] while the plasma chamber was biased to a - 10 kV power supply.

Previous spectroscopic plasma measurements showed for example the $\lambda = 674.0$ nm line indicating the presence of excited molecules able to produce H^- ions by dissociative attachment. So this small H^- ion production may be attributed to negative ion destruction close to the plasma electrode. The microwave power, not completely absorbed by the plasma, could contribute to H^- loss. Simulations showed that a metallic grid can stop the microwave penetration. So the magnetic filter was replaced by a 5 mm mesh stainless steel grid. As a result, an important improvement has been observed when the plasma chamber has been effectively separated in 2 zones. Then the grid and the plasma electrode have been simultaneously negatively polarised and the H- ion current increased. Figure 1 presents the grid in the plasma chamber and summarizes the wiring of the test stand.

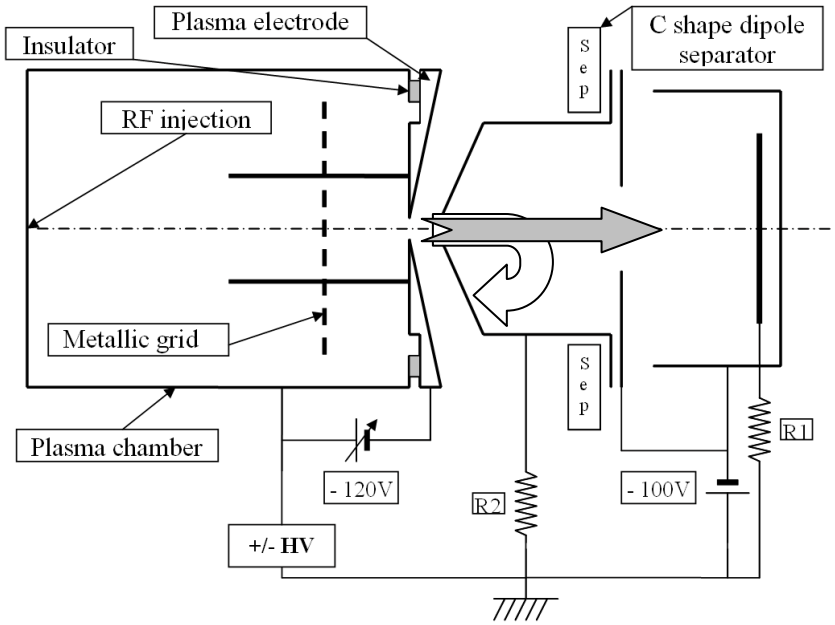

Fig 1: Scheme of the H^- ECR source

After optimisation of the grid position, the maximum H^- current occurred while the grid was located at 25-30 mm from the plasma electrode. By tuning simultaneously the potential of the grid and plasma electrode from 0 to – 120 V compared to the plasma chamber, the 10 kV H^- extracted current rose from the precedent maximum value (84 µA) to 950 µA. Then both the plasma electrode and the grid were biased by independent negative power supplies in order to allow a slight voltage difference. But no improvement was observed.

MATERIAL DEPENDENCE

The above-mentioned results were obtained with a stainless steel grid and a molybdenum plasma electrode. The rectangular plasma chamber is made of water-cooled

copper and a 2 mm thick boron nitride disc is inserted between the RF ridged transition and the plasma chamber [4]. The source was typically working in pulsed mode (1-2 ms – 10 Hz) 5 days a week for several months. And no degradation has been observed. The first stainless steel grid, installed in June 2003, has never been changed excepted during the Tantalum grid test reported hereinafter.

Several authors already reported hydrogen negative ion production improvements while using Tantalum material inside the plasma chamber [2, 5]. So a Tantalum grid has been tested while the Saclay source operated at 10 kV. The H- extracted current was plotted as a function of the plasma chamber pressure (5 points between 2 and 3.5 mTorr) with both Stainless steel and Tantalum grid. The performances did not change dramatically but the results with the Tantalum grid always reach few percents lower than those obtained with the stainless steel grid.

Moreover, if both the grid and the plasma electrode are made of Tantalum, the extracted H^- current decreases by about 25 % (Fig. 2) compare to the typical design.

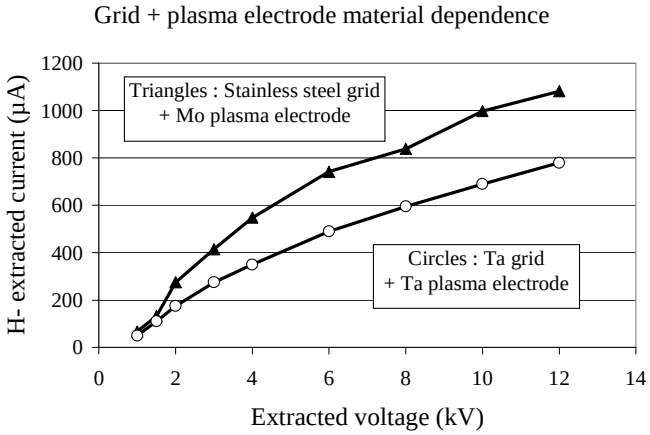

Fig. 2: Extracted H^- current versus extraction voltage with:
- Ta grid and Ta plasma electrode (circles)
- Stainless steel grid and Mo plasma electrode (triangles)

The extracted current continuously increases from 140 to 850 µA while the RF power rises from 380 to 950 W [3]. This continuous increase of the RF power can be associated to an increase of the electron production in the plasma generator zone. And simulations [6] predict the increase of the H^- ion production as a function of the electron density. Ceramic materials like quartz, alumina or boron nitride produce an important amount of secondary electrons under plasma particle bombardment. So to confirm the dependence of the H^- ion production with respect to the primary electron density, 4 boron nitride plates have been installed in the plasma creation zone. And the H^- extracted current increased from 950 µA to 1.32 mA with the same source running conditions.

VOLUME and SURFACE EFFECTS

The extracted negative ion current strongly depends on the grid position [3]. By reducing the distance between the grid and the plasma electrode, the volumes of both the production zone and the plasma generation zone change. So to verify the production zone volume effect, a 30 mm diameter stainless steel tube was installed around the 2 rods which maintain the grid. The volume was thus limited at 21 cm3 compare to 73 cm3 for the typical

design. The tube was electrically linked to the grid and the plasma electrode. As a result, the smaller volume led to reduced performance.

Then the tube was replaced by a 5 mm mesh stainless steel grid cylinder. Once more the performance of the source was largely reduced. These results confirm the important influence of the plasma chamber shape. So, new designs with circular plasma chamber are envisaged.

PLASMA CHARACTERISATION

To facilitate the negative hydrogen ion production, several experiments have already been performed in order to increase the knowledge of the plasma. First the spectroscopic measurements showed the presence of excited hydrogen molecules [4]. Then a Langmuir probe has been successively installed in both parts of the plasma chamber [7]. And finally, by polarizing the source at positive high voltage, the extracted positive charge analysis gives important information on the plasma characteristics.

For the Langmuir probe measurements, the axial magnetic field led to difficult probe characteristic interpretation. Comparative curves indicate the tendency. The 2 mm diameter molybdenum probe has been placed on the axis of the source but perpendicularly to this axis. When the probe is installed at 58 mm from the plasma electrode (28 mm upstream to the grid), the axial magnetic field reaches 500 Gauss and the electron temperature increases when the grid potential varies from – 0 to – 90 V (fig. 3).

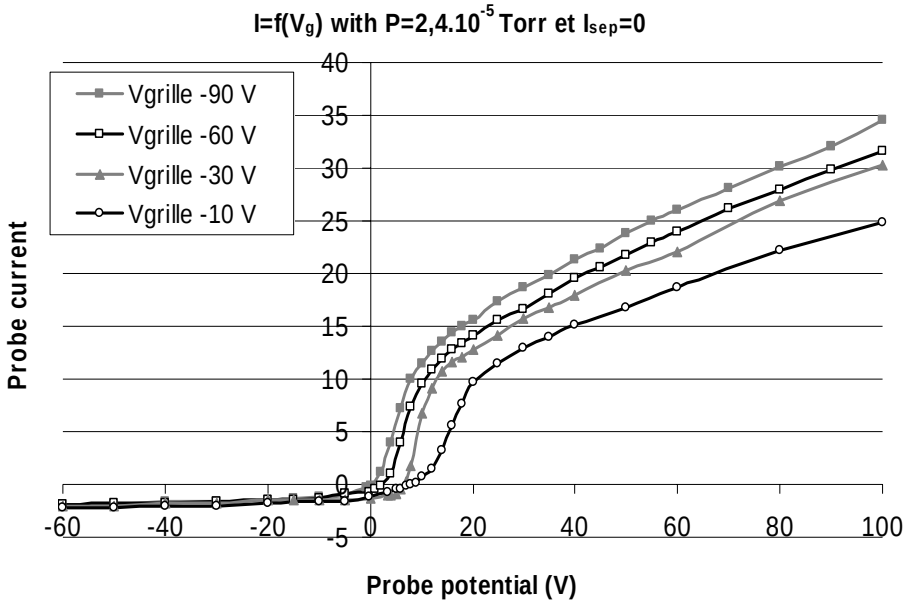

Fig 3: Probe characteristics in the plasma generation zone

The probe was then installed in the negative ion production zone at 6 mm from the plasma electrode. Here the axial magnetic field is much lower (around 200 Gauss). By comparing the probe curves on both sides of the grid, for the same voltage, the electron temperature is largely lower in the H^- production zone. This electron energy reduction could explain the increase of the H^- ion current.

The probe made of a 2 mm Molybdenum wire covered with a 0.5 mm Al2O3 layer largely influences the extracted ion current. Figure 4 presents the H- current versus the grid polarization. The empty circle curve represents the ion current with no probe in the plasma chamber. For this measurement, the Boron Nitride plates were not installed in the chamber

but the curve looks similar with a lower level. The triangle curve represents the ion current with the probe located at 6 mm from the extraction aperture. The plasma perturbation is probably mainly due to the secondary electron emitted by the probe alumina. As a result, the maximum extracted H- ion current (1.5 mA) was then finally obtained in these conditions.

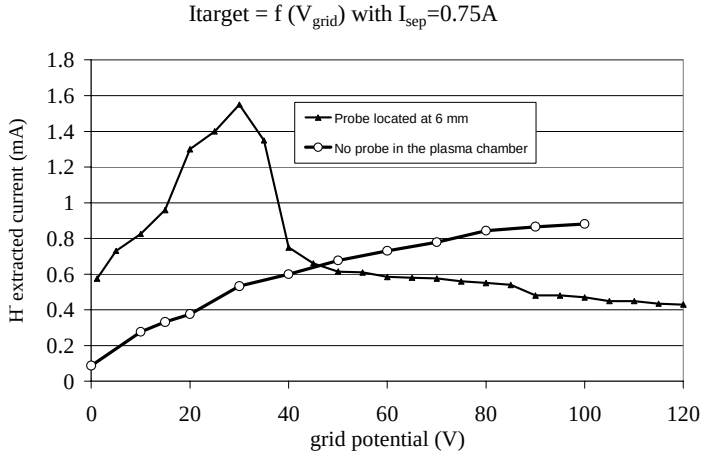

Fig. 4: Extracted H- current vs grid potential (with or without grid).

The electron energy reduction is confirmed by the positive charge analysis. A small dipole magnet (10 mm between poles) located just after the extraction system, in the vacuum chamber, allows us to check the different species (H^+, H_2^+, H_3^+) extracted from the source. A 5 mm diaphragm limits the current entering in the dipole and then the particles are collected on a Faraday cup (triangle curve). The measurements indicate a very low amount of H_2^+ while the grid is installed in the chamber (Fig. 5). Like in the cold plasma where the following reaction takes place, this analysis shows the H_3^+ peak becomes the highest one.

$$H_2 + H_2^+ \rightarrow H_3^+ + H + 1.71eV$$

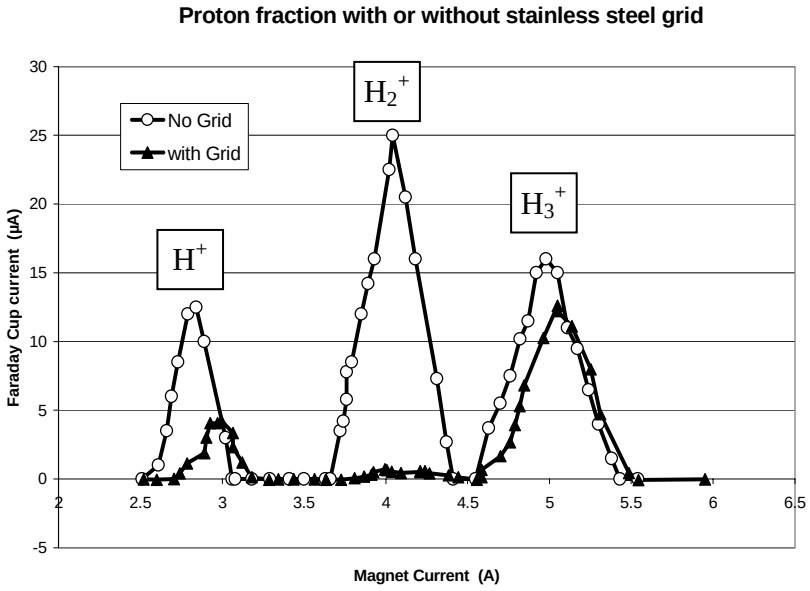

Fig. 5: Positive charge analysis (extracted current vs analyzer magnet) with or without the grid.

Otherwise, the distribution of positive charges depends on the plasma chamber pressure. The above triangle curve represents the different species when the pressure equals 3 mTorr. The species fractions are: H^+ = 22%, H_2^+ = 5% and H_3^+ = 72%. Whereas, with a 2.5 mTorr pressure, the fractions are: H^+ = 34%, H_2^+ = 13% and H_3^+ = 52%.

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