RECENT RESULTS OF THE 2.45 GHz ECR SOURCE PRODUCING H$^-$ IONS AT CEA/SACLAY

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Abstract

Low frequency ECR plasma sources have demonstrated their efficiency, reproducibility and long life time for the production of positive light ions. In 2003, the new 2.45 GHz ECR test stand based on a pure volume H$^-$ ion production, developed at CEA/Saclay, showed a spectucar increase of the extracted H$^-$ ion beam intensity. In fact, a stainless steel grid now divides the plasma chamber in two different parts: the plasma generator zone and the negative ion production zone. By optimizing the grid position and its potential with respect to the plasma chamber, the negative ion current reached nearly 1 mA. Ceramic plates covering the plasma chamber walls help electron density and lead to an optimisation of the ion production. A 1.32 mA H$^-$ extracted current has been measured. New Langmuir probe measurements have also been done on both sides of the grid. The last results are reported and discussed. This work is supported by the European Union under contract HPRI-CT-2001-50021.

INTRODUCTION

Future high intensity proton accelerators like SNS, ESS or neutrino factories ask for reliable and efficient H$^-$ ion production to inject in compressor rings. These facilities have been planned to work in pulsed mode (roughly 1 to 2.5 ms pulse length at a frequency ranging from 15 to 50 Hz). Many existing machines such as HERA, ISIS, LANCSE and others are also interested in source developments. Taking into account these demands, CEA has undertaken an important R&D program on high intensity light ion sources.

Since the SILHI source [1] showed a good efficiency for high intensity proton beam production with a very long source life time, parallel programs are in progress. A permanent magnet deuteron source is now delivering its first deuteron beams [2] for the SPIRAL 2 project. In parallel, the development of the 2.45 GHz ECR negative ion source is still in progress and the H$^-$ ion production slightly increases.

One year ago, measurements performed with a plasma chamber separated into 2 zones showed an important improvement [3]. These results are shortly reported in the next section. The third section will insist on the last results obtained by testing different materials. Then recent Langmuir probe measurements are presented.

ELECTRIC FILTER

To produce negative hydrogen ions, the sources are generally based on the same principle. 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 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 limit the high energy electron flux entering 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. And only few µA of H$^-$ ions have been observed [4].

So the small H$^-$ ion production may be attributed to negative ion destruction close to the plasma electrode. It is possible that microwave power not completely absorbed by the plasma contributes to H$^-$ loss. Simulations show that a simple metallic grid with a large transparency can stop the microwave penetration. As a result, an important improvement has been observed when the plasma chamber has been effectively separated in 2 zones by a stainless steel grid. This grid is polarised at the same potential than the plasma electrode.

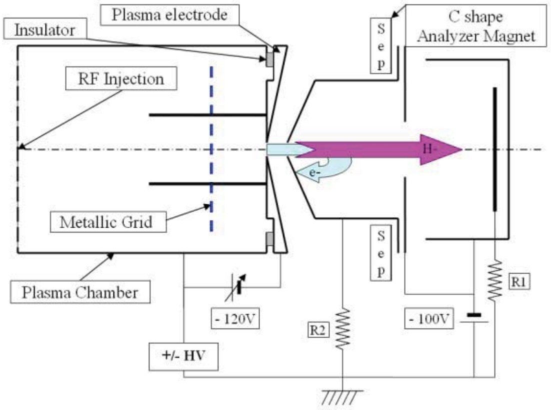

Figure 1: Scheme of the H$^-$ ECR source.

After optimisation of the grid position, the maximum H$^-$ current occurred while the grid was located at 30 mm from the plasma electrode. By tuning the potential of the grid and plasma electrode from 0 to – 120 V compared to

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the plasma chamber, the 10 kV H$^-$ extracted current rose from the precedent maximum value (84 µA) to 950 µA.

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. The source was typically working in pulsed mode (1 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.

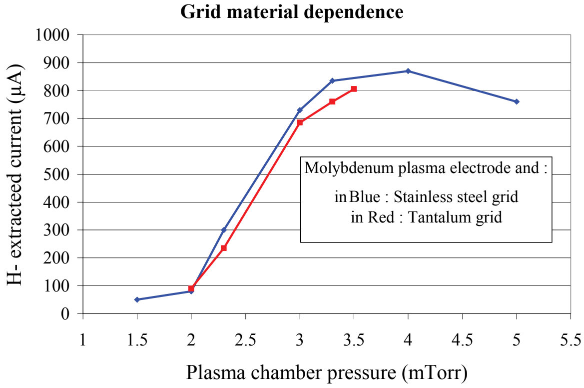

Figure 2: Extracted H$^-$ current vs pressure with Tantalum grid (black) and Stainless steel grid (red).

Several authors already reported hydrogen negative ion production improvements while using Tantalum material inside the plasma chamber [5, 6]. So a Tantalum grid has been tested while the Saclay source operated at 10 kV and the performances did not change dramatically (Fig. 2). But if both the grid and the plasma electrode are made of Tantalum, the extracted H$^-$ current decreases by about 25 % (Fig. 3).

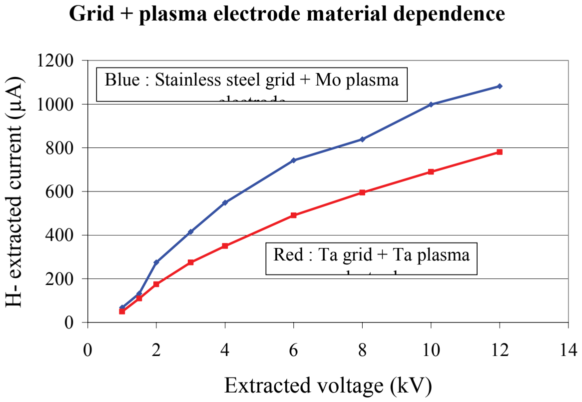

Figure 3: Extracted H$^-$ current vs extraction voltage with:
- Ta grid and plasma electrode (red)
- Stainless steel grid and Mo plasma electrode (black).

Measurements indicated [3] that the extracted current continuously increases from 140 to 850 µA while the RF power rises from 380 to 950 W. The continuous increase of the RF power can be associated to an increase of the electron production in the plasma generator zone. And simulations [7] 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.

LANGMUIR PROBE ANALYSIS

To better understand the plasma behavior in both parts of the source, Langmuir probe measurements have been done. A 2 mm diameter molybdenum probe has been placed perpendicularly to the source axis. In the plasma creation zone, it was located at 58 mm from the plasma electrode (28 mm from the grid). At this location, the solenoïdal magnetic field reaches nearly 500 Gauss. Hence the Langmuir probe characteristics are not easy to interpret. Figure 4 seems to indicate that, in these conditions, the electron temperature increases in this region when the grid potential varies from – 0 to – 90 V. This may be explained since the negative polarization of the grid accelerates backward all electrons with low energy.

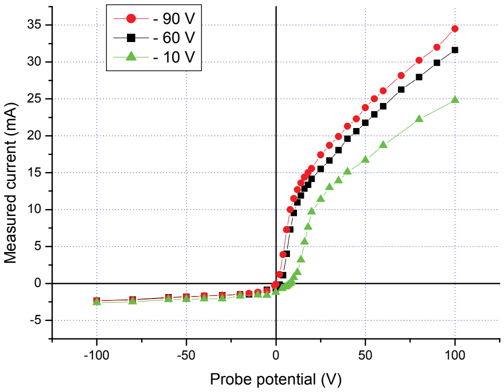

Figure 4: Probe characteristic at 2.4 mTorr pressure in the electron production chamber.

In the second part of the plasma chamber, i.e. in the negative ion production zone, the same probe has been installed, downstream the grid, at 6 mm from the plasma electrode. Here the axial magnetic field is much lower (around 200 Gauss). Figure 5 compares the probe characteristics in both zones for the same grid polarization. We can observe that the grid has an important effect on reducing the electron temperature in the H$^-$ production zone. This electron energy reduction allows an important improvement of the H^- ion extraction current.

The red curve shows a negative floating potential equal to – 8 V which points out the presence of very high energy electrons in the source. This curve confirms the assumption on the electron energy obtained in the ECR ion source. With no use of polarized grid the negative ion production is much lower since high energy electrons are the cause of H^- ion losses.

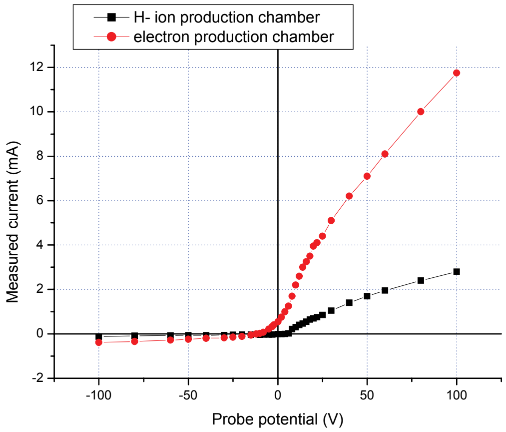

Figure 5: Comparison of probe characteristics in both parts of the plasma chamber.

By analyzing the extracted current while the probe is located close to the extraction aperture (6 mm), the maximum H^- current is obtained for – 30 V grid polarization instead of – 120 V. This confirms the plasma perturbation due to the probe. New extraction analysis will be performed when the probe is installed a little bit further from the axis to minimize the harmful effect.

10 GHz SOURCE

Moreover in the last 2 years, a new source based on 10 GHz ECR plasma generator has been studied at CEA/Grenoble. The design is now completed, the magnetic field will be provided by an octopolar permanent magnet structure. This research program will be transferred to Saclay in the near future. The construction of the source is expected at the beginning of next year. The aim of this new test stand is to verify the well-know frequency scaling law applied in the heavy ion source community: the increase of the frequency allows a better gas ionisation. As a result a larger amount of hydrogen excited molecules and an H^- ion production improvement are expected.

ACKNOWLEDGMENTS

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