First plasma analysis of the CEA/Saclay ECR hydrogen negative ion source.

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Abstract. Reliable high-intensity H^- ion source development is now part of the CEA/Saclay work in the field of high-intensity linear accelerators. A 2.45 GHz ECR H^- ion source and test bench have been built. This new source has been designed taking into account our experience on the French high intensity ECR proton source. For H^- ion production, the high-energy electrons created in the ECR zone are trapped by a dipole magnetic filter. A rectangular 210 mm long plasma chamber and an intermediate iron shield are used to minimize the magnetic field in the extraction region. A second magnetic dipole separates electrons and negative ions in a 10 kV extraction system. To reduce the electron/H^- ratio, the plasma electrode is biased by a power supply. The first helium plasma allowed us to verify the satisfactory electron separator behavior. Pulsed hydrogen plasma is currently produced. The first plasma characterization is under progress as a function of ion source parameters by using Langmuir probes and optical spectrometer. The first results are presented and possible evolutions toward a higher efficiency source will be discussed.

I. INTRODUCTION

Potential applications of high current accelerators include the production of high flux neutron beams for spallation reactions (ESS or SNS), future reactors, nuclear waste treatment, exotic ion facilities or neutrino and muon production for high-energy particle physics. The high intensity beams for these accelerators may reach an energy as high as 1 GeV. In France, CEA and CNRS have undertaken an important R&D program on very high beam power (MW class) light-ion accelerators for several years. Part of the R&D efforts is concentrated on the IPHI (High Intensity Proton Injector) [1] demonstrator project. This 10 MeV prototype of linac front end will accelerate CW beam currents up to 100 mA. The High Intensity Light Ion Source (SILHI) development, based on the 2.45 GHz ECR plasma production, has been performed for several years leading to a great experience in high current proton beam production [2]. Taking into account this advantage, CEA which is involved in the ESS studies, decided to develop a hydrogen negative ion source also based on the ECR plasma production.

The new hydrogen negative ion source is briefly described in section II. Several experiments such as plasma analysis and extracted beam measurements have been done and preliminary results are reported in section III. Plasma analysis have been undertaken by using Langmuir probes and optical spectrometry diagnostic. Up to now, no negative hydrogen ions have been observed. To conclude, possible diagnostic and test stand evolutions are presented to prove the pure volume H^- production.

II. TEST STAND DESCRIPTION

The aim of this source is to obtain a long lifetime with high reliability. As demonstrated with SILHI, these conditions could be reached with sources in which the plasma is generated by ECR. In previous H^- sources, filament or antenna lifetime considerably reduces the reliability and availability.

In negative ion sources, ions and electrons are often separated in the extraction system by means of transverse magnetic field. Moreover to avoid hydrogen negative ion destruction in the production zone, high energy electrons have to be eliminated in the plasma close to the extraction area by using a magnetic filter (MF). Magnet calculations have been performed to design the C shape magnetic electron separator (SEP) and MF. The axial magnetic field provided by the two coils to reach B_{ECR} has also been calculated as well as the iron shielding [3].

The ECR plasma generator operates at 2.45 GHz (B_{ECR} = 875 Gauss) with a water cooled copper plasma chamber. The rectangular (standard WR 284 waveguide) plasma chamber length has been chosen at 210 mm instead 100 mm for SILHI to reach an axial magnetic field as low as possible close to the extraction area in order to limit the amount of high energy electrons in this zone and to insert the C shape MF. The RF signal is produced by a 1.2 kW magnetron source. It is fed to the source via standard rectangular waveguides, an automatic tuning unit and a 3 section ridged transition. The quartz RF window has been moved behind a water cooled bend. A 2 mm boron nitride disc is located at the plasma chamber RF entrance. The molybdenum plasma electrode can be biased to a few volts.

Several ports have been managed in the plasma chamber for plasma diagnostics. The source and its ancillaries (power supplies, RF generator, gas injection, …) are grounded and the up to 10 kV extraction system is installed inside the vacuum chamber (Fig. 1). The collector is also linked to an independent HV power supply. The 80 mm aperture SEP is located inside the vacuum vessel. By using positive or negative HV power supplies, negative and positive extracted beams could be respectively characterized. Vacuum is provided by a 1000 l/s turbomolecular pump.

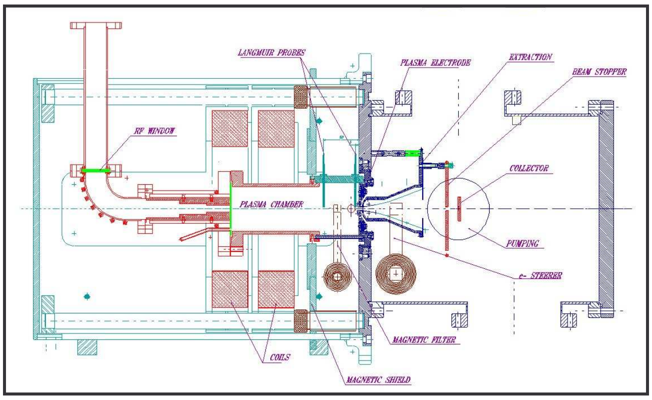

Fig 1: Cross-sectional view of the source and extraction system

III- PRELIMINARY RESULTS

The first continuous hydrogen plasma has been quite easily obtained when the ECR zone was located at the RF entrance with an operating pressure of 3 10^{-3} hPa in the plasma chamber. The beam extraction chamber pressure is 1.5 10^{-5} hPa. The magnetron pulsing mode is now efficient and allows us 1 ms – 20 Hz pulsed running operation. This 2 % duty cycle is limited by heating of the diagnostics. A 5 volt drop was measured on the extraction voltage while operating the source at 40 mA pulsed current in hydrogen discharge.

Langmuir probe measurements have been performed in 2 different locations inside the plasma chamber. For this experiment, MF was located at 12 mm from the plasma electrode and the Langmuir probes on both sides of it (6 and 58 mm from the plasma electrode). Electron temperature and density have been checked as a function of MF and SEP field. Close to the extraction aperture, the electron temperature never decreases below 4.5 eV and the electron density reaches 3.1 10^9 cm^{-3}. Upstream the magnetic filter, 9 eV electron temperature and 1.8 10^9 cm^{-3} density are measured.

Then the MF was moved and spectroscopic plasma analysis was made by switching MF on and off. A Jobin-Yvon spectrometer using a 330 – 1000 nm grating was installed in front of a plasma chamber view port. Some specific lines (λ = 7153 nm, 6740 nm, 6315 nm, 6270 nm) appeared with the MF switch "on". These results have to be confirmed with complementary measurements and to be compared with theoretical predictions.

Axial and transverse magnetic measurements have been performed. The rectangular intermediate iron shielding and the MF circuit induce significant transverse fields (Fig 2) when solenoids are operating to reach B_{ECR}. A minimum transverse field integral of about 200 Gauss.cm is obtained with MF switched off. It has been also observed that the SEP and the MF are coupled, because of the flux circulation in the iron yokes. This effect is strongly depending on the current sign on each magnet. Electromagnetic simulations with OPERA-3D code [4] have confirmed these results. According to that, it is clearly difficult to identify the individual influence of each parameter.

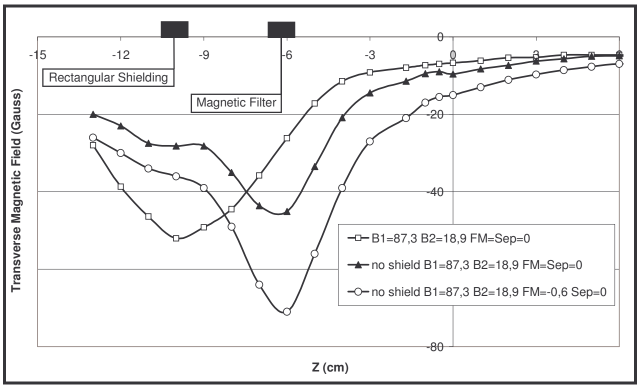

Fig. 2: Magnetic Filter (MF) transverse field with rectangular shielding, MF off (squares) and without shielding: MF off (triangles), MF on (circles)

Extracted beam analyses have been performed versus the extraction voltage and the SEP current while the MF was switched on and kept constant. The e^- and H^- separator scheme outlined in Fig. 1 did not provide separated e^- and H^- collector signals. Therefore, all beam measurements were made with both H_2 and He plasmas in order to search for enhanced collector signals, thus indicating presence of possible H^- beam. Figure 3 shows the ratio of the measured collector current to the maximum of the collector current for the hydrogen and helium plasmas as a function of the extraction voltage.

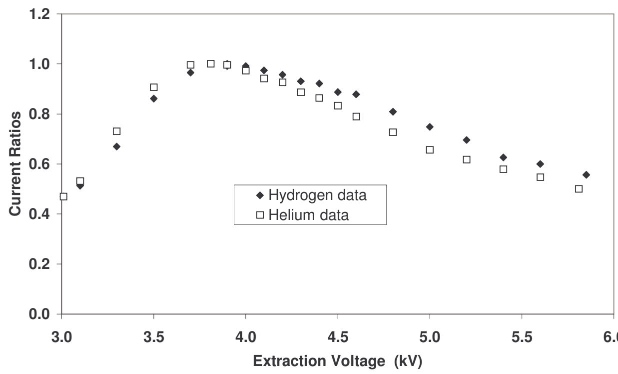

Fig. 3. Collector current measured ratios as a function of the extraction voltage. The collector voltage is fixed at 6.5 kV.

SEP was set to give the maximum observed collector current which for the H_2 plasma is 5.7 mA and the He plasma is 12.8 mA. The maximum H_2 and He beam currents both occur at 3.9 kV extraction voltage. Examination of Fig. 3 shows that the maximum enhancement of the collector current ratios between hydrogen and helium plasmas occur at 4.75 kV extraction voltage. Figure 4 presents the collector current ratios with extraction voltage fixed at 4.75 kV as a function of the SEP current. The collector voltage remains fixed at 6.5 kV. The current ratios show a small but consistent enhancement of the hydrogen plasma results compared with the He plasma results. The integrated H_2 plasma current ratio measured in Fig. 4 is 10% higher than the integrated He plasma current ratio. The sum of the extractor and collector currents for the H_2 plasma is 36 to 38 mA.

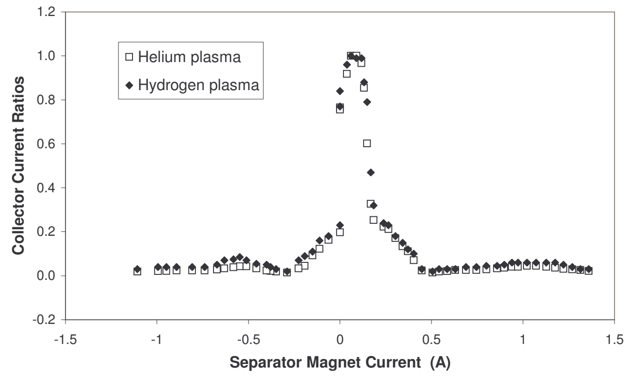

Fig. 4. Collector current ratios for the H_2 and He plasmas as a function of the separator magnet current.

IV- ELECTROMAGNETIC SIMULATION AND TRAJECTORIES COMPUTATION

The ECR magnetic configuration of this H^- prototype source has been derived from the SILHI one and calculated with OPERA-2D [4] code in axial symmetry. When MF and SEP have been added, 3D simulations have been performed using both TOSCA for electromagnetic design, and SCALA for multi-species space charged beam calculation. The extraction system has been first studied without magnetic deflection with AXCEL[5] code to design a simple 10 kV two electrodes extraction system with 5 mm diameter hole plasma electrode. It has been designed to extract a maximum of 40 mA negative charges. SCALA simulations have been performed and a magnetic separator with a 100 Gauss.cm field integral is large enough to ensure a complete separation between H^- ions and electrons. All the electrons are predicted to be collected on the extraction electrode. A small deflection is also observed on the H^- ions (Fig. 5).

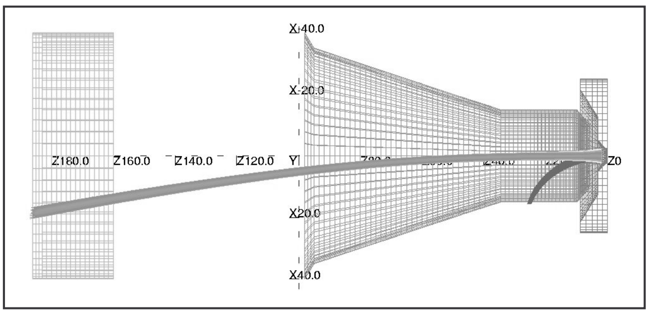

Fig. 5: Magnetic Separation between electrons and H^- ions 3D simulation with SCALA for 35 mA e^- and 50 µA H^-

V- CONCLUSION

Pure volume H^- ion production have already been tested with this kind of source [6,7]. No definite hydrogen negative ion beam has been observed in our work. However, the collector current measurements are consistent with small current enhancement in the H_2 plasma as compared to the He plasma. It is now planned to replace the collector current-separator magnet diagnostic with a slit-dipole magnet mass analysis system to get a good e/H^- measurement. An evolution towards a better independence and simplification of the magnetic circuits will be attempted. A simple few millimeters thick foil between SEP and MF, or a 90° rotation of one of the magnet to separate the deflection components could be some solution to eliminate the coupling between the magnets.

Understanding the coupling of microwave power to the plasma would also be useful for minimizing the RF influence on the negative ion production area. These modifications will be part of CEA/Saclay future H^- program. Several European laboratories are presently under negotiation with the European Community to fund a high intensity negative ion source program. The goal is to upgrade existing H^- sources and to develop new source generation able to fit in with the future high power accelerator request.

We are in the process of completing our first step of H^- volume production mode where a few mA of H^- ions are expected. Different wall material like tantalum will be also tested to understand the surface contribution. The third step will consist of improving the performance by injecting xenon or cesium in the production zone [8]. The CEA/Grenoble source team plans to build and characterize a 10 GHz ECR source devoted to H^- production.

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