OBSERVATION OF H$^-$ IONS EXTRACTED FROM A 2.45 GHZ MICROWAVE ION SOURCE

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Abstract

H$^-$ ions have now been observed in currents extracted from the Saclay microwave proton source. A pulsed, 90 degree dipole magnet has been installed 14.8 cm downstream from an ion beam extraction system designed to operate up to -10 kV. The plasma chamber can be biased by a negative or positive HV power supply and the diagnostics are grounded. The dipole analyzer was equipped with an electrostatic-shielded Faraday cup that properly suppresses secondary electron emission. The dipole magnet was calibrated with a 6.4 keV proton-ion beam. The microwave source magnetic field was configured to establish two ECR zones in the plasma chamber. However, the magnetic field is much reduced from 875 G at the emission aperture. The measured hydrogen ion fractions show a large amount of H_2^+. First measurements at negative extraction potential (–3.2 to –9.0 keV) give electron to H$^-$ ratios ranging from 13/1 to 27/1. The derived H$^-$ currents are 1-2 mA. Ion source operation with He gas showed no peak for the H$^-$ dipole magnet calibrated current. Future experiments are to optimize the plasma and extraction system for maximum H$^-$ beam production.

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1 INTRODUCTION

Applications of high current accelerators include the production of high flux neutron beams for spallation reactions [1] and neutrino production for high-energy particle physics[2]. The high intensity beams for these accelerators may reach multi-GeV energies. 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 High Intensity Proton Injector (IPHI) [3] demonstrator project. 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 [4]. 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.

Since the last report on our 2.45 GHz microwave H$^-$ project [5], installation of a dipole magnet with Faraday cup has resulted in the definite identification of H$^-$ ions extracted from the microwave-generated plasma. In this report, the ion source configuration and diagnostic techniques used are discussed in the first section. Results for the important e/H$^-$ ratio appear to be strongly related to the magnetic filter configuration, and will be discussed in the third section.

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2 H$^-$ SOURCE AND DIAGNOSTICS

2.1 Mechanical set-up

To minimise the source and beam collector heating, the source is routinely operating in pulsed mode (1 ms – 10 Hz). Figure 1 shows the configuration where H$^-$ ions were first identified in the CEA-Saclay source. Originally the plasma chamber was grounded and the extraction system was biased by a high-voltage (HV) power supply. Due to the complexity of the diagnostic (also biased by HV) measurement analysis, it has recently been decided to modify the source configuration. The plasma chamber is now insulated from the main mount flange by an epoxy plate and a DC break made of a 3 mm thickness Teflon sheet allows HV insulation from the waveguide.

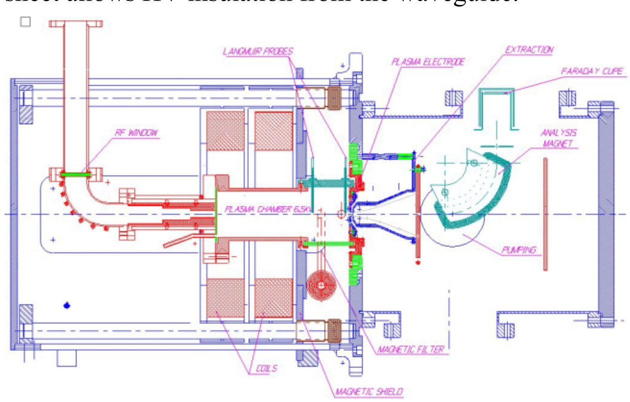

Fig.1: Experimental test stand drawing with insulated plasma chamber.

So the diagnostics are now grounded and the plasma chamber could be biased either by positive or negative HV power supplies. This allows us positive or negative particles extraction analysis.

2.2 Magnetic configuration

Previous magnetic measurements [5] indicated a strong transverse influence of the coils on the magnetic filter (MF) iron yoke. Figure 2 shows the axial magnetic configuration provide by 2 coils (144 turns each, 55x55 mm, 200 mm inner diameter). The influence of the MF on the axial magnetic field B_z does not depend on the

MF tunable coil current. Two resonant zones (B_z=875 Gauss) appear within the plasma chamber, one near the microwave entrance to the chamber and the second one 50mm before the emission aperture. Between the two ECR zones, B_z > 875G.

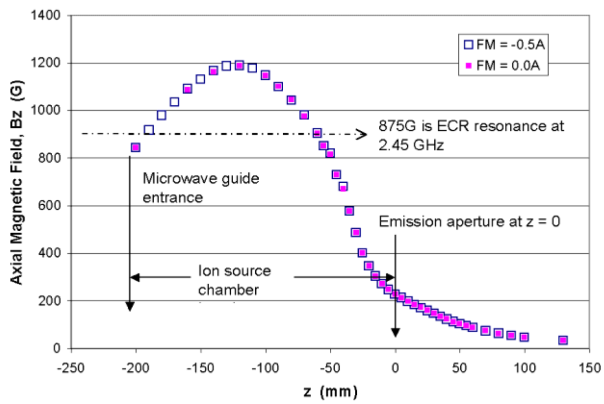

Fig.2: Measured axial magnetic field profile.

2.3 Diagnostics

A pulsed 90° dipole analysing magnet has been installed behind the beam collector plate. A 6-mm hole allows a portion of the extracted beam to pass into the dipole magnet for species analysis. The dipole magnet comprises a 10-mm pole gap, n=0 radial field gradient, with non-zero entrance and exit to allow vertical focussing. Good transmission through the dipole magnet is predicted for extreme particle trajectories at the limits of geometrical acceptance. The geometrical acceptance is defined by the extraction aperture and the 6-mm hole in the beam collector plate. As this magnet is not cooled it operates in pulsed mode, typically at a repetition rate of 1 Hz. The timing of the source is tuned to extract a single pulse during the flat-top portion of the magnet current pulse. A shielded Faraday cup is located at the dipole exit to eliminate plasma effects and secondary electrons.

Pulsed beam current monitoring (ACCT) allows to measure the total extracted beam. Beam currents could be also measured on extractor and collector plates. The Faraday cup measurements are done with a current-to voltage operational amplifier. The Faraday cup electron suppressor is biased by a few hundred volt tuneable power supply.

A multi-wire beam profiler could also be installed after removing the dipole analyser magnet.

3 H^- EXTRACTION RESULTS

3.1 Positive charge analysis

To calibrate the dipole analyser, measurements were made with positive extracted charges. The source was fed with hydrogen gas and the plasma chamber was set at 6.5 kV.

A 3 mA total extracted beam has been produced with the following species fraction: H^+ = 23 %, H_2^+ = 47 % and H_3^+ = 30 % (Fig.3). The proton fraction is here very low compare to this kind of source capability when the magnetic field is 875G at the extraction aperture [4]. So, for the H^+ peak, the dipole magnet was set to 2.8 A and the transmitted current through the magnet reached 12 μA.

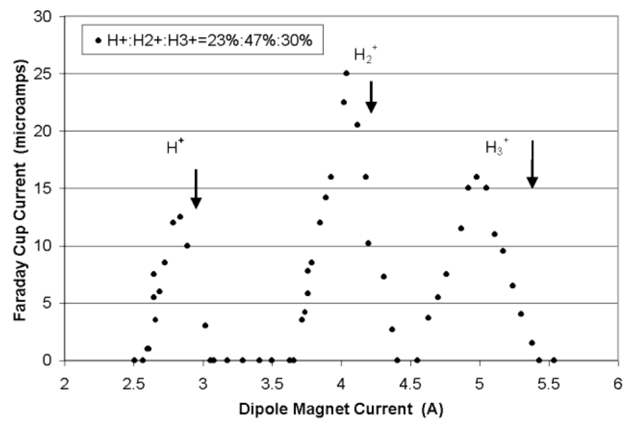

Fig.3: Hydrogen-ion beam fraction at 6.4-keV

3.2 Negative charge analysis

To definitely show the H- ion production, the source was set at - 6.4 kV and fed by hydrogen and helium gas. A total 40 mA beam is easily extracted in these conditions. Negative charge analysis is plotted versus the dipole analyser magnet intensity. A peak corresponding to H^- ions is observed at 2.8A dipole magnet excitation in H_2 plasma. This is in good agreement with H^+ peak position in the positive charge analysis (cf. Fig. 3). The 2.8A peak does not appear with helium plasma. The figure 4 shows the difference between hydrogen and helium negative charge measurements. The presence of the H- ions, produced in pure volume, has been proven.

An unidentified peak occurs in both He and H_2 cases at 1 A dipole excitation. These particles seem to be electrons, which possibly follow trajectories outside the dipole magnet main field before reaching the Faraday cup. Complementary investigations with improved Faraday cup entrance collimation have to be done to identify this peak.

Two other sets of e^- and H^- data were acquired at 3.2 and 9.0 keV. The peak displacements are in good agreement with momentum scaling predictions. The unknown peak also seems to scale up in Bρ as the extraction voltage increases.

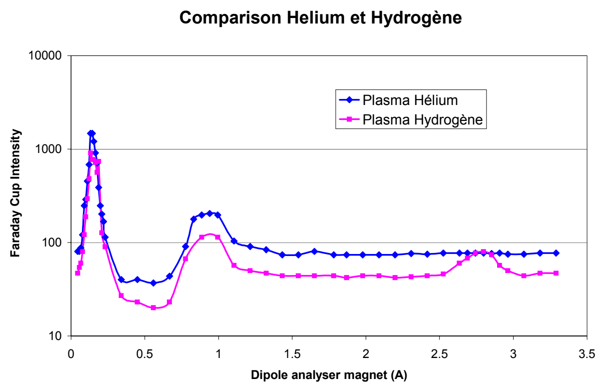

Fig.4: Negative charge analysis vs dipole magnet excitation

3.3 electrons and H⁻ ions ratio

To estimate the H$^-$ ion current, both peak height and integral peak methods are compared. By using the peak height method, the e$^-$/H$^-$ ion ratio range from 11 to 27. The peak integral method gives a ratio varying from 2.5 to 7. In both cases, the corresponding H$^-$ ion current is between 1 and 5 mA. Figure 5 shows Faraday cup and ACCT signals for electrons and H$^-$ ions. An "afterglow" signal appears for the hydrogen ions.

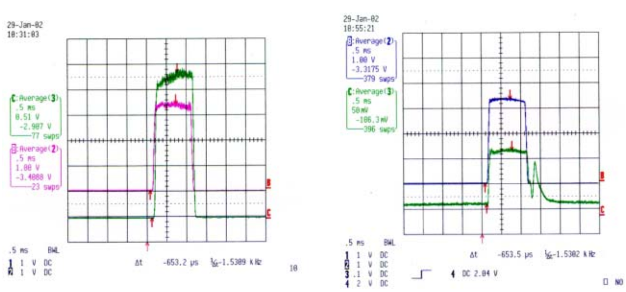

Fig.5: Scope views of electrons and H- ions (green traces)

Beam analysis have been done versus different sets of H_2 pressure and/or RF power. The H- peak does not increase. Any gas flow changes lead to a lower extracted beam. The total extracted beam increases from few mA to 50 mA when the RF power varies from 100 to 700 W.

The very low Faraday cup currents force us to analyse the beam transport from the extraction aperture to the final collector. So, a 32 wire profiler (1 mm between each wire) has been installed at the dipole magnet analyser location. Profile measurements made with source settings corresponding to the dipole measurements discussed above indicate a strong deflexion of the negative beam.

By tuning the MF to eliminate transverse B-field at the emission aperture, the negative beam comes back on the mechanical axis. This shows the induced magnetic field in the MF yoke strongly influences the negative beam trajectories at extraction. Only a slight deflexion is observed for a positive beam, indicating the e-/H- ratio could be underestimated in the dipole magnet measurements.

New beam analyses have been performed versus the dipole magnet excitation with MF adjusted to limit the negative beam deflexion. The electron peak increases much more rapidly than the H- peak.

4 CONCLUSION

The measurements are powerful evidence that H$^-$ has been formed and extracted from a hydrogen plasma generated by microwave power. It now seems clear that H$^-$ has been extracted from a microwave-generated hydrogen discharge. Summarising the evidence for positive H$^-$ identification from the dipole magnet measurements:

- Mass scaling between H$^+$ and H$^-$ is correct,
- Momentum scaling is correct.
- No Faraday cup peak corresponding to H$^-$ location while operating with He discharge.

Recent measurements confirmed the important effect of the residual transverse magnetic field in the extraction zone. By tuning the MF to minimise the beam deflexion, the efficiency of this MF is certainly changed. In these conditions, the e-/H- ratio increases rapidly.

Mechanical changes are under study to optimise the source magnetic configuration in order to minimise the residual transverse magnetic field. Diagnostic improvements are also necessary to definitely obtain the real e-/H- ratio which presently ranges from 2.5 to more than 1000. The H$^-$ source development philosophy followed will be to decrease the e/H$^-$ ratio to as low a value as possible in pure H_2 mode before adding caesium catalysis for enhanced H- production.

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6 REFERENCES

[1] R. Duperrier, et. al., “The ESS Front End Associated with the SC Linac”, ESS TAC Meeting n° 1, FZ Juelich, January 7-9, 2002.

[2] R. Garoby, "Status & plans of the SPL study at CERN" at ICFA2002, April 8 - 12, 2002 Fermilab.

[3] P-Y. Beauvais, "Status report on the construction of the French High-Intensity Proton Injector (IPHI)", this conference, THPLE028

[4] R. Gobin et al., "Saclay High Intensity Light Ion Source Status", this conference, THPRI003.

[5] R. Gobin, et. al., RSI, vol. 73, n°2, February 2002 (983)