ELECTROSTATIC PROBE AND LASER PHOTODETACHMENT MEASUREMENTS IN THE HYDROGEN NEGATIVE ION (H^-) SOURCE "PROMETHEUS I"

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ABSTRACT

In this work, the negative ion source Prometheus I, installed in the University of Patras, is presented. The plasma is sustained by five dipolar electron cyclotron resonance sources and characterized by means of electrostatic probe and laser photo-detachment technique. The source configuration and the installed diagnostic techniques are herein discussed. Indicative results of the plasma produced are then analyzed. Hot and cold electron populations are generated and negative ion densities in the order of magnitude 10^9 cm^{-3} are measured for the conditions tested.

1. INTRODUCTION

Modern, caesium-free, negative ion H^- sources, are interesting for fusion research as they constitute an essential part of the future neutral beam injection systems [1]. The main reaction for H^- formation is the dissociative attachment of cold electrons to highly rovibrationally excited molecules. High energy electrons have a smaller chance of attachment and they are responsible for the destruction of H^-. They are, however, useful for exciting hydrogen molecules rovibrationally [2]. Taking into account these statements, energetic electrons should be confined e.g. by a magnetic filter, while low-energy electrons must be left to escape towards another region, rich in highly excited molecules, where H^- production will take place. Based on this idea, the ion source Prometheus I has been implemented.

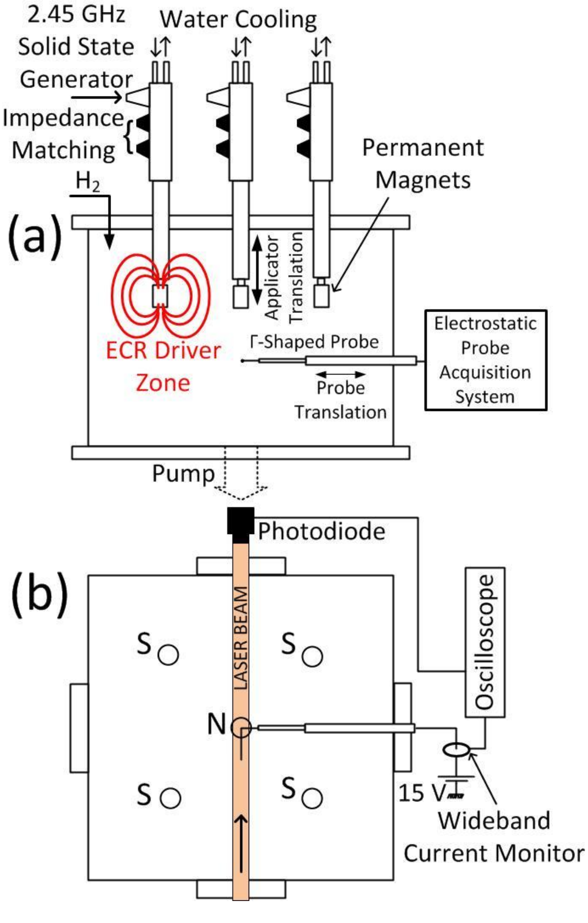

Fig.1 Diagram of the source Prometheus I.
a) Side view and b) Top View.

2. SOURCE CONFIGURATION

The conceptual diagram of the source is presented in Fig. 1. The plasma is generated by a two-dimensional network of five Electron Cyclotron Resonance (ECR) dipolar sources [3]. Each source works independently with a microwave power (2.45 GHz) up to 180 W. The power is generated by solid state components (Sairem®) instead of traditional magnetrons. It appears that such ECR sources are well suited for negative ion production [4] and they can overcome limitations arisen from the use of filaments. Their advantages lie in their ability to produce high density plasmas with both hot and cold electrons [5]. In Prometheus I, the permanent magnets used for the ECR-coupling form at the same time a first magnetic trap for a part of the hot electrons. Fig. 2 demonstrates the magnetic field configuration as it was simulated with the ACDC module of COMSOL Multiphysics® suite. The calculation is based on the magnetic flux conservation with the remanent magnetic flux of the Sm_2Co_{17} magnet (1.05 T) provided by the manufacturer. The length of each magnet is 30 mm.

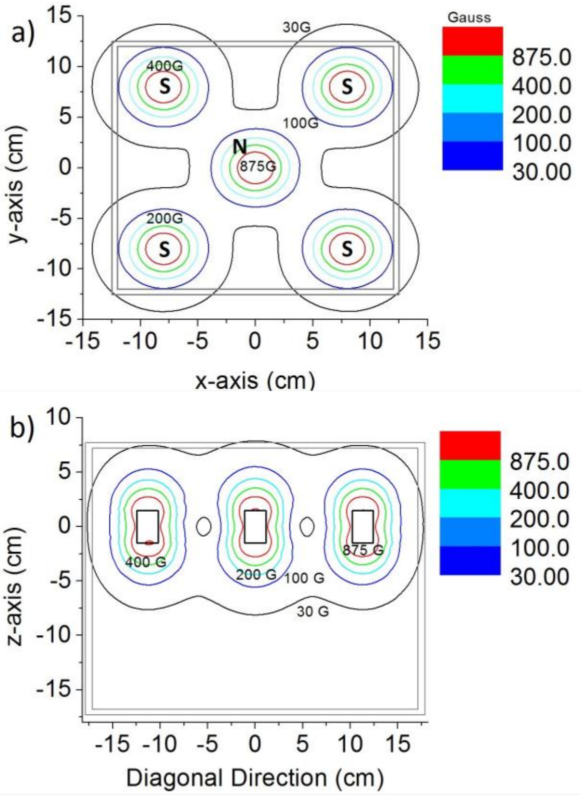

Fig.2 Contours of the magnetic field intensity on a) a horizontal plane placed 20 mm bellow the mid-plane of the magnets b) a vertical plane placed on the diagonal of the chamber.

Following Fig. 1, the five plasma sources are mounted on the top flange of a cubic (edge length 240 mm) high vacuum stainless steel chamber, which brings CF flanges for viewports and installation of the diagnostic techniques. On the bottom flange a turbo-molecular pump (Adixen^{TM} ATP80) is adapted yielding a base pressure of $2x10^{-7}$ Torr. Using digital mass flow controllers (MKS 1179B), hydrogen (N50) is introduced and the working pressure is accurately monitored with an absolute pressure transducer (MKS Baratron 627D). For the present study the working pressure is 1-20 mTorr and the MW power up to 180 W/source.

3. DIAGNOSTIC TECHNIQUES

A custom electrostatic probe is placed on the source symmetry axis, 65 mm bellow the mid-plane of the central permanent magnet, and it is oriented perpendicularly to the vertical component of the magnetic field. The horizontal component of the magnetic field at this level is practically zero due to symmetry (see Fig. 2a). The probe consists of a tungsten wire (Ø 0.25 mm) housed in dielectric tubes (alumina/quartz) of a telescopic configuration. The exposed part of the wire is 15 mm and it is L-shaped in order to be aligned with the beam of the laser used for photo-detachment measurements (Fig. 1). The tracing of the V-I curves is accomplished with a home-made system described elsewhere [6]. Since, a cold electron population, i.e. steep current trace, is expected, it is essential that the voltage step is low (in this work 97.5 mV). Averaging 8192 (2^{13}) samples at every point of the curve is found to be adequate to reject the plasma-induced noise. Probe data are processed with a customized Matlab^{TM} program.

For the determination of the negative ion densities, the laser photo-detachment technique is used [7]. The laser beam is generated from a Q-switched Nd:YAG 1064 nm laser (Quantel, Brilliant Eazy, 5 ns pulse width, max 330 mJ/pulse). The diameter of the beam (6 mm) is appropriate for this technique, since it is greater than the collecting radius of the probe [8]. Following calibration experiments, 70 mJ cm^{-2} energy density is chosen for sufficiently stripping all H^- of their extra electron in the laser-illuminated space. During photodetachment measurements the probe is biased to +15 V, i.e. 5-10 V above the plasma potentials measured here. It is experimentally confirmed that the above conditions ensure saturation of the photo-detached electron current pulse. For the acquisition of this pulse a current monitor is used (Pearson Electronics, 6585) instead of traditional de-coupling circuits [7] (Fig. 1b). The output of the current monitor is connected to a LeCroy WaveSurfer 104Xs-A digital oscilloscope (1 GHz - 5 GSamples/s). The acquisition of the signals is triggered by the reference signal provided from a fast photo-detector (FPS-10 OPHIR) facing the beam of the laser through optical filters (Fig. 1b). Noise rejection of the photo-detached electron current pulse is achieved by averaging 512 waveforms and limiting the oscilloscope channel bandwidth to 20 MHz.

3. RESULTS AND DISCUSSION

In this section, indicative results on the plasma of the source are given and discussed. In Fig. 3, a typical graph of the electron current (as it is extracted from the probe V-I curve by subtracting the ion current) is shown. Clearly there are two electronic populations, i.e. one cold (0.84 eV) and a second hotter (13.4 eV).

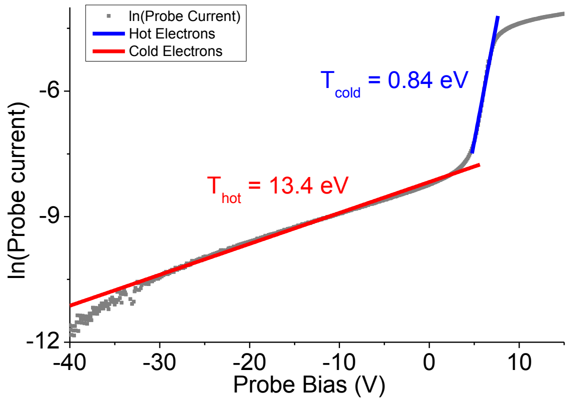

Fig.3 Indicative electron current extracted from a V-I curve of the probe (120 W/source and 13 mTorr).

It is reminded that, the presence of cold electrons, having temperature kT<1 eV, are necessary for negative ion production through the dissociative attachment reaction [2]:

$$e(<1\ eV) + H2(v''\geq 5) \rightarrow H^- + H \qquad (1)$$

On the other hand it appears that a part of the hotter electron population does escape from the ECR magnetic filter.

The production of negative ions is confirmed by the photo-detachment signals obtained (Fig. 4), with forms in agreement with the bibliography [7,9,10]. Depending on the plasma operating conditions, two forms of signals are in general observed: signals with a well-distinguished "plateau" which follows the first "peak" of the signal (Fig. 4a) and signals where this "plateau" is not evident (Fig. 4b). In order to compare all the acquired signals under various working conditions, the peak value of the current pulse is herein considered for estimating the negative ion H^- density. In this way, a weak overestimation of the negative ion density might be introduced.

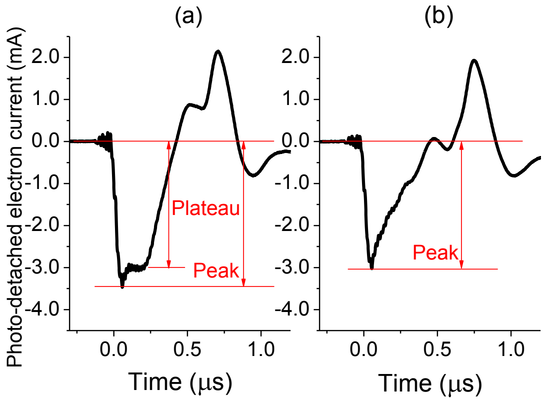

Fig 4 Indicative current pulses produced by the laser photo-detached electrons at different plasma conditions: a) 180 W/source at 19 mTorr and b) 180 W/source at 12 mTorr.

The above mentioned experimental processes provide an idea about the negative species densities in Prometheus I. Fig. 5 represents the electron (n_e) and negative ion (n_{H-}) densities as a function of the working pressure. The latter is measured before the plasma ignition.

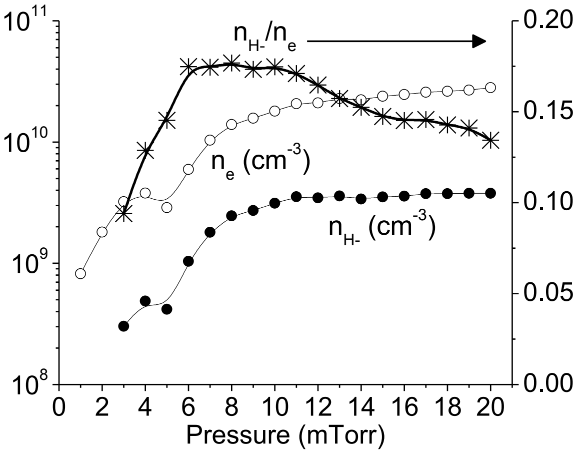

Fig 5 Negative ion and electron densities versus the working pressure. The density ratio is shown as well (180 W/source).

Quasi-saturation is obtained for both quantities, for a pressure higher than about 8 mTorr, while the negative ion to electron density ratio (n_{H^-}/n_e) exhibits an optimum of 0.18 close to 8 mTorr. It is underlined that the optimization of the ion production in this source is in progress and thus the results presented here are just indicative.

4. CONCLUSIONS

This experimental study showed on the example of the source Prometheus I that the use of a two-dimensional network of electron cyclotron resonance dipolar sources produces plasmas with suitable electron energy distribution function for negative hydrogen ion production. The use of Langmuir probe and laser photo-detachment diagnostic techniques allowed the determination of the temperature of the two electron populations and the negative ion density, respectively. The pressure dependence of the negative ion and electron densities was established in the pressure range 1 to 20 mTorr (180 W/source), and an optimal pressure at 8 mTorr was unveiled for maximizing the ratio of the first to the second density. Wide parametric study has been scheduled for this source.

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