Caesium influence on plasma parameters and source performance during conditioning of the prototype ITER neutral beam injector negative ion source

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Abstract.
Systematic Langmuir probe measurements were performed during the caesium (Cs) conditioning of the IPP prototype negative hydrogen ion source. Conditioning consists of slowly injecting caesium into the source in order to increase the extracted negative ion current and minimize the co-extraced electrons. This process usually takes several days. Measurements were taken near the plasma grid where the majority of the extracted negative ions are created. A clear transition between a poorly conditioned (volume dominated H^- production) and a well conditioned (surface dominated H^- production) source was seen. By following the plasma parameter variations, an overall decrease of the plasma potential, the floating potential and also the electron saturation current was observed. However, the ion saturation current remained constant. Consequently, near the plasma grid where negative ions are generated and extracted, a transition occurred in the space charge balance (quasineutrality): the space charge is balanced by electrons when the source is poorly conditioned and by negative ions when the source is well conditioned.

1. Introduction

The ITER neutral beam injection system is based on the acceleration and neutralization of negative hydrogen ions. Caesium seeded RF driven negative hydrogen ion sources [1, 2, 3] are developed at IPP in order to achieve the ITER requirements. Most of the efforts are dedicated towards: obtaining more stable and reproducible parameters, the enhancement of the extracted beam current density during long pulse operation [4], the optimization of the magnetic filter field (FF) for beam homogeneity purposes and the reduction of the number of co-extracted electrons. However, a better understanding of the involved physics, especially the caesium dynamics, will lead to a further optimisation of the source performance.

Source conditioning is an important aspect of negative ion sources that uses caesium to enhance negative ions production. Conditioning consists of slowly injecting caesium into the source, to improve the amount of extracted negative ions and simultaneously reduce the co-extracted electron current to a managable level. The H^- (or D^-) are primarily generated from the conversion of H^0 and H_x^+ (x = 1...3) on all the source surfaces. However, only the negative ions formed on the plasma grid (PG), can be extracted because of the short survival length of negative ions (typically a few centimeters) [5]. Conversion on the PG surface can be enhanced by reducing the surface work function through deposition of caesium. Already shown was a clear correlation between the work function of a surface, the negative ion generation yield plus co-extracted electron suppression [6, 7, 8].

A campaign of systematic Langmuir probe measurements was performed to study the influence of caesium and the produced H^- on the plasma parameters (plasma and floating potentials, electron temperature, electron and ion saturation currents) during source conditioning on the BATMAN testbed [1].

Conditioning usually takes several days at the BATMAN testbed. Due to limitations in pumping capacity, the BATMAN testbed can only operate with short plasma pulses and negative ions are extracted during the last 4 s of a 6 s shot. The time between each pulse is on the order 200 - 300 s. Caesium is evaporated both during and between pulses. The time between pulses is necessary to deposit caesium onto the PG during conditioning. At the very beginning of an experimental campaign, despite the fact there is almost always some caesium remaining from the previous campaigns, the surface produced negative ion density is low and the source is more or less operating via volume production. Volume production corresponds to the dissociative attachment of a thermal electron to a rovibrationnally excited H_2 molecule in the ground electronic $X^1\Sigma_g^+(v)$ state [9, 10]. During this time, the source is 'poorly conditioned' and the source performance is poor: a low H^- current density and a high electron to negative ion current density ratio j_e/j_{H^-}.

Extraction of negative ions invetably leads to the co-extraction of electrons and the amount of extracted electrons has to be minimized to reduce the power load on the extraction grid (EG). Typically, a few shots are needed every morning to recover the

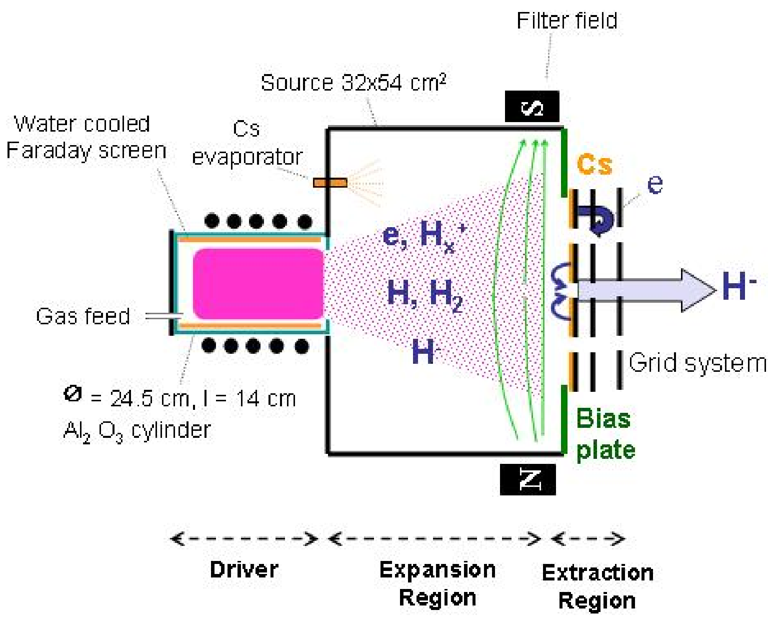

Figure 1. Schematic representation of the IPP RF source.

source performance of the previous day. This is due to the contamination of the surface by impurities during the night (base pressure is in the order of mid 10^{-7} mbar). Over a period of days, the source slowly switches from "volume" to "surface" production, as more and more caesium is added to the source. This can be seen due to the extracted current of negative ions slowly increasing, while j_e decreases.

The aim of this paper is to track the influence of caesium on: plasma parameters (potentials, electron temperature and saturation currents) in the vicinity of the PG and source performance (extracted negative ions and co-extracted electrons) during the conditioning process. Another goal of this paper is to determine when and why a correlation exists or not between the total injected Cs amount and the source performance. Additionally, when good Cs conditioning is achieved, an ion-ion plasma is formed. It either forms at the top, or in the bottom part of the PG (depending on the filter field (FF) orientation). The properties of this particular kind of plasma will be discussed.

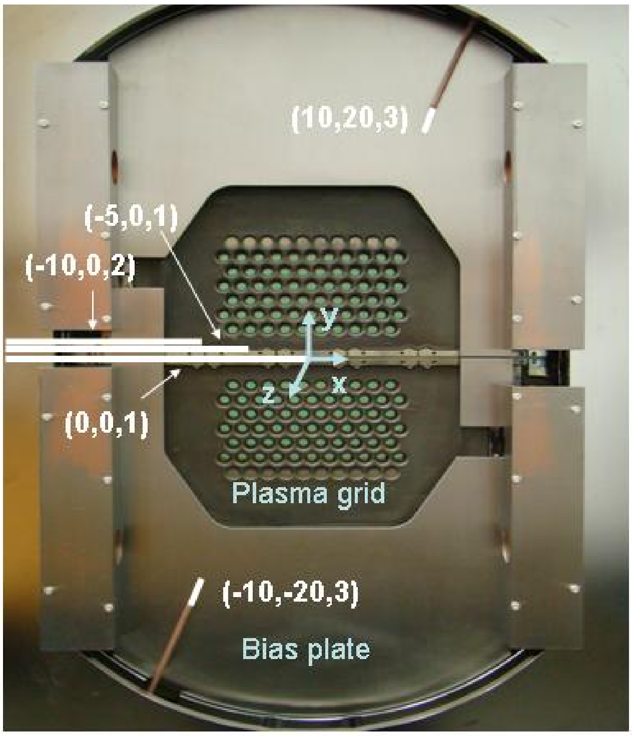

Figure 2. Picture of the PG. The location of the five pin probes is indexed by their position (in centimeters), the associated direct referential is in orange.

2. Experimental setup

Figure 1 shows a sketch of the IPP RF prototype source (P_{max} = 150 kW, f = 1 MHz). In order to achieve a high extracted negative ion current, caesium evaporation in the source is mandatory, with the evaporation rate being on the order of 10 mg.h^{-1} [11]. The cesium oven is located in the upper part of the source. The source can be divided into three parts: the driver where the plasma is generated, the expansion chamber and the extraction region where the negative ions are produced and extracted. The driver consists of an alumina cylinder with a water cooled RF coil connected to a 1 MHz generator. An internal Faraday screen protects the alumina from the plasma. The plasma then diffuses into the expansion chamber and reaches the extraction region. The latter two zones are separated by a magnetic filter field (FF) whose strength near the extraction area is approximately 7 mT. The main purpose of the FF is to reduce the electron temperature in order to reduce the destruction of negative ions by electron collision and to lower the amount of co-extracted electrons. The dominant destruction processes of negative ions are: electron stripping (e + H^- $\rightarrow$ 2e + H), which is very effective for a few electron-volts electron temperature; mutual neutralization (H^- + H^+

→ H + H), which slightly depends on ion temperature; associative detachment (H + H^- → e + H_2) and the non-associative detachment (H + H^- → e + H + H) both of which depend on the atomic hydrogen temperature. With the FF reducing the electron temperature to below 2 eV, the stripping of negative ions by electrons is minimized and the other mechanisms dominate.

The extraction system is comprised of three grids (see [1] for full details). The first grid is the plasma grid and is electrically isolated to allow it to be positively biased with respect to the source body. For optimum performance, its temperature has to be in the range of 100 - 200°C. Only a part of the PG is used to extract negative ions, the extraction surface being roughly 70 cm^2 at BATMAN. In order to have an optimum bias effect, a bias plate that borders the plasma grid area is connected to the body of the source. The bias plate is separated axially from the PG by 1 cm. The influence of the bias plate on extracted currents, and especially the reduction of co-extracted electron amount, is shown in ref. [3]. The extraction grid hosts permanents magnets (different from the ones generating the FF) in order to deflect the co-extracted electrons out of the beam.

For generating the standard filter field, permanents magnets were installed in the diagnostic flange. However, in the present campaign, the permanent magnets were located on the sidewall of the vessel. During this study, the permanents magnets were located as closely as possible to the plasma grid. The resulting field differs slightly, in terms of field intensity, from the field that was previously generated by the magnets inside the diagnostic flange. The main difference between the configurations, is that the maximum intensity field, which previously was located close to the PG is now shifted 15 cm away from the grid towards the driver. The experiments were performed in an hydrogen plasma, at a pressure of 0.3 - 0.6 Pa and with a typical applied RF power of 40 - 80 kW. An extraction voltage of between 4 and 9 kV and an acceleration voltage varying from 8 to 14 kV during the conditioning process were used.

For this study, five fixed Langmuir probes were available. The Langmuir probe analysis system was previously described in great detail [12]. In this study; however, the Langmuir probes were not RF compensated. Three of the probes were located above the PG with exposed tungsten wires dimensions of: 25 μm radius and 0.5 cm length. The two probes above the bias plate dimensions are: 125 μm radius and 1 cm long. The analysis system is the PlasmaMeter developed at the School of Physics and Technology of the K.N. Karazin Kharkov National University, Ukraine [12]. Figure 2 shows the probe positions.

For convenience, the probes will be labelled in the following discussion only by their coordinates. A referential centered in the middle of the PG with a 1 cm unity was chosen to determine the location of the probes. The three probes near the PG have coordinates of (0,0,1), (-5,0,1) and (-10,0,2). These probes allow for plasma parameters to be collected from the edge to the middle of the PG. The two other probes are located at (10,15,3) and (-10,-15,3).

It is known that a magnetic field can reduce the electron current collected by the probe due to the electrons following the magnetic field lines [13]. However, a simple estimation for $T_e = 1\,\text{eV}$, $n_e = 10^{17}\,\text{m}^{-3}$ and $B = 3.6\,\text{mT}$ (value of the magnetic field computed in the vicinity of (0,0,1) probe) shows that the electron gyroradius ($950\,\mu$m) is greater than both the probe radius and Debye length ($23\,\mu$m) [12]. The magnetic tube surface area for a radius equal to the electron gyroradius greatly exceeds the probe surface area. Consequently, the influence of the magnetic field on the electron saturation current of the probes is likely negligible. This is true for all probes except the (-10,0,2) probe. That probe is located near the diagnostic flange and is the closest to the permanent magnets. The field intensity, at this location, is estimated to be 15 mT. The poor signal to noise ratio for this particular probe was due to the magnetic field as the IV curves of the three probes superimpose when no magnetic field is present. As the IV curve is distorted compared to the others no results obtained from this probe will be presented in this paper. Despite being as close to the flange as (-10,0,2), the probes located at (10,15,3) and (-10,-15,3) are much less influenced by the magnetic field. This is because these probes are located beyond the magnet frame and are thus in the fringe field of the permanent magnets. During measurements the probe tip temperature increases beyond 1000 K, therefore probe contamination by Cs is not considered probable. Finally, as the probes are uncompensated, densities will not be calculated and only the saturation currents will be discussed in order to minimise the errors due to RF distortion, especially in the electron branch.

The 852 nm line of Cs and the H_β Balmer line are monitored by a low resolution survey spectrometer ($\Delta\lambda_{FWHM} = 1$ - 1.8 nm, $\lambda = 200$ - 870 nm, 100 ms time resolution). The line of sight for the spectroscopy is parallel to the grid and 2 cm above it. This particular line is one of the most intense neutral caesium line (CsI) and is a resonance line of the electronic state 6p $^2P_{1/2}$, with an excitation energy of 1.45 eV [14]. Caesium evaporation from oven during conditioning leads to Cs coverage of all surfaces. This caesium can be desorbed during the discharge, and Cs neutrals then enter the discharge where they are ionised. As the ionisation energy of caesium is very low (3.89 eV), more than 90 % of the caesium in the plasma is ionised [15, 16]. It was previously shown that when the source was well conditioned, a direct correlation sometimes existed between Cs emission and the extracted negative ion amount.

One of the goals of this paper to clarify when and why this correlation exists or not. It will be shown that during the conditioning phase a correlation exists (only on the trends) between the 852 nm line and the extracted negative ion density, at the very beginning of the conditioning process. The source performance in this situation is low and little caesium has been evaporated from the oven. This correlation leads to an understanding of the variation of the PG work function: it is reasonable to assume when more negative ions are extracted that this is caused by a decrease of the PG work function. This correlation vanishes when conditioning proceeds further. Although the work function of the PG surface depends on the Cs coverage, it seems that the amount of desorbed Cs, when the source is well conditioned, does not drastically change the work function of the PG surface, mainly because the pulses are short (see [17] for long pulse operation at

MANITU testbed). Again this correlation is only valid during the conditioning process, since, when the source performance is high, it can be run without Cs evaporation (or little) for days (not shown here) with a high extracted negative ion current density and low electron to ion ratio. This suggest that when good Cs conditions are achieved, a stable layer is formed and can remain so for several days.

During conditioning, the discharge parameters (discharge pressure, injected power, extraction voltage and PG current) are changed in order to optimize both the extracted negative ions and electron to ion ratio. When the source is in the ‘poorly conditioned‘ state, a large amount of electrons are extracted. Consequently, the source is initially operated with a slightly higher pressure and lower RF power. Additionally, the extraction voltage has to be lowered to prevent damaging the EG by the heat load caused by electrons. Typically, when the source is ’poorly conditioned’ discharge parameters are 0.5 - 0.6 Pa, 60 kW and 4 - 5 kV extraction. Day after day, the source parameters are slowly increased to their nominal value, namely 0.3 Pa, 60 - 80 kW, 9 - 10 kV extraction.

3. Results and discussion

3.1. Influence of the Cs during the conditioning process on plasma parameters and source performance

Figure 3a) follows the evolution of the plasma potential of the (-5,0,1) probe during five operation days, while figures 3b) and 3c) shows the (electrically measured) co-extracted electron current density and the extracted negative ion current density respectively. Due to the probes being uncompensated, the error in the plasma potential evaluation was of ± 1 V (difference between the maximum and the minimum of the second derivative). The data in these three graphs are plotted versus the emissivity line ratio $\epsilon_{Cs(852nm)}$ / $\epsilon_{H_\beta(Balmer)}$ in order to emphasise the influence of caesium. The H_β (Balmer) line depends on the electron temperature, electron density and the excitation cross section. Since in this case the electron temperature is constant and low, independent of the source parameters, this line is related to the electron density for the a constant discharge pressure. The $\epsilon_{Cs(852nm)}$ / $\epsilon_{H_\beta(Balmer)}$ ratio allows a direct comparison of the volume Cs emission to the plasma emission. The source conditioning started on 23/11/2009 and caesium was injected daily, during the whole conditioning period of the source. Figure 3b) when compared to figure 3a) clearly shows a variation of the plasma potential in parallel to the co-extracted electron current density, with the exception of the first day of conditioning.

In the first two days the plasma potential decreases as the $\epsilon_{Cs(852nm)}$ / $\epsilon_{H_\beta(Balmer)}$ line ratio increases. The source performance was poor as the extracted negative ion current density (around 10 mA.cm^{-2} on figure 3c) is low and there exists a high co-extracted electron current density (between 40 and 50 mA.cm^{-2} on figure 3b). During the very first day of conditioning (23/11/2009), an increase of both the co-extracted electrons and extracted negative ions is observed. Several hypothesis may explain the

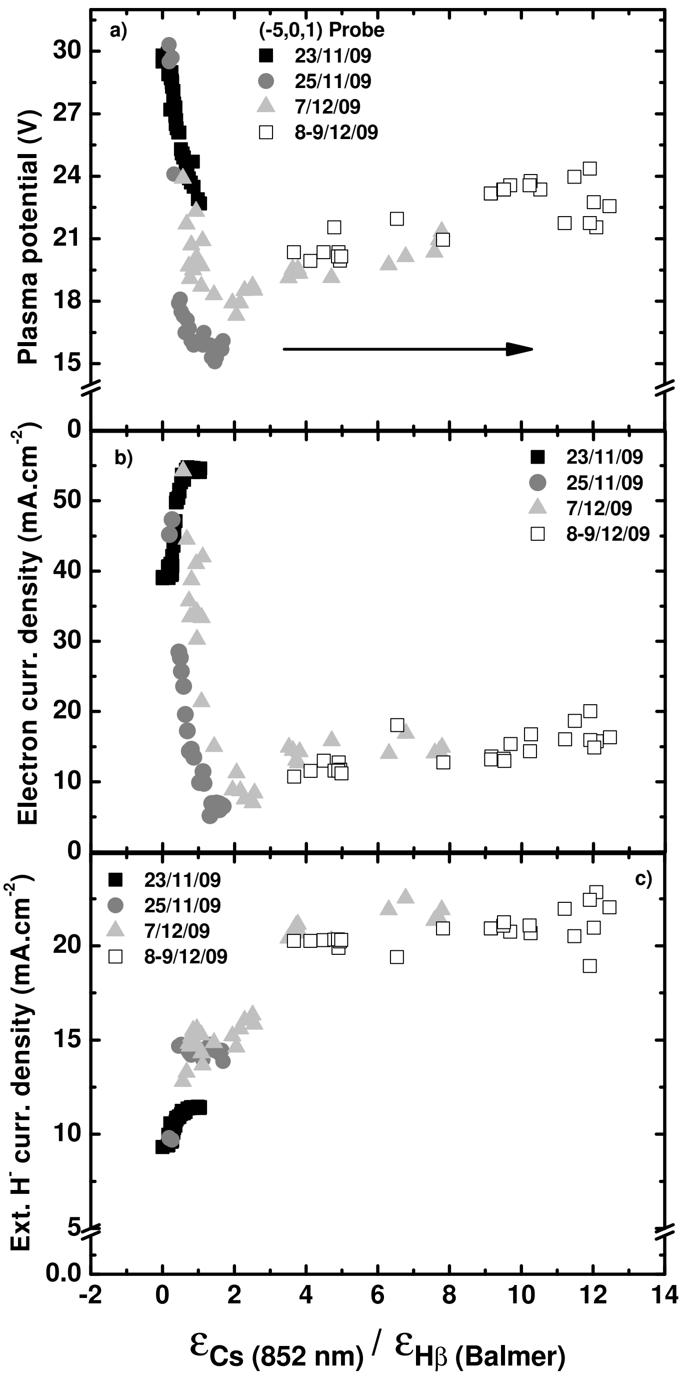

Figure 3. a) represents the plasma potential variation, b) the co-extracted electron current density and c) the extracted negative ion current density over days versus the spectroscopy emissivity line ratio. The arrow indicates the evolution over days

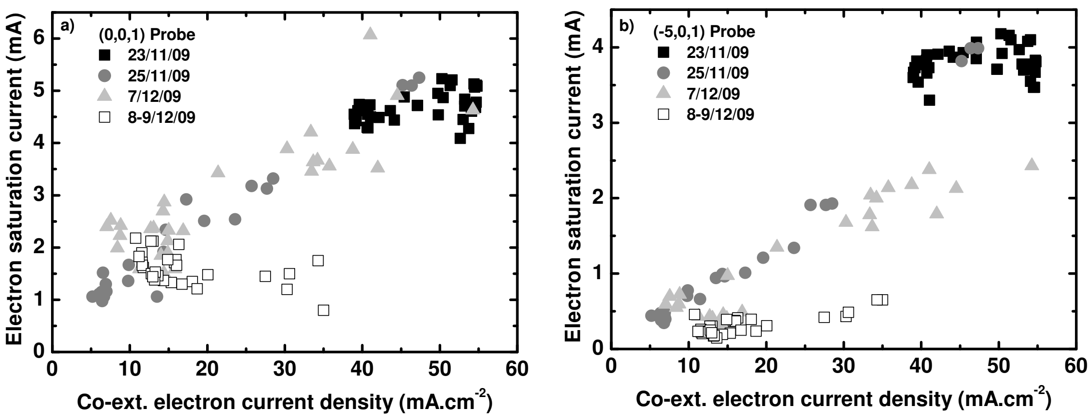

Figure 4. a) and b) show the variation of the electron saturation current with the co-extracted electron current density for the (0,0,1) and (-5,0,1) probes respectively.

unexpected increase of the co-extracted electron current density, since for this particular day, no change in the discharge parameters were made.

The first is that Cs starts to be evaporated into the source, and is almost completely ionised. It is likely the observed increase in the co-extracted electron current is due to bad beam optics. H^- ions are lost on the extraction grid and counted as electrons. Recent experiments at BATMAN demonstrated that bad beam optics results in an enhanced co-extracted electron current density because of H^- losses to the EG, especially with low extraction and acceleration voltage, which was the case on the 23/11/2009. During the following day (25/11/2009) there was a steady decrease in the co-extracted electrons and simultaneously a slow increase of the extracted H^-.

A drastic change occurs on the third day of conditioning (7/12/09). A strong drop in the co-extracted electron current density can be seen on figure 3b) while the amount of negative ions strongly increases, as indicated on figure 3c). During this day a transition occurred between a "poorly conditioned" and a "well conditioned" source. During this day, the extracted negative ion current density also slowly becomes independent of the total amount of evaporated Cs in the source. The source will remain in this state until the last measurement day (see figure 3c). In the same way, the variation of plasma potential and co-extracted electrons becomes poorly affected by the total quantity of Cs evaporated into the source. Over the next two days, the source performance is acceptable and essentially independent of the caesium density. However, the small increase seen on figures 3a) and b) for good source performance is within the error bars. The observation that the source becomes independent of the Cs amount once it is well conditioned is in agreement with the results of [15]. It seems that a steady state was achieved on the PG surface that leads to a more or less stable work function. Achieving this optimal Cs condition allows the source to be operated with high performance for several days without the need to further evaporate caesium. This is only possible because the source is pulsed with very short pulse length, the amount of desorbed Cs from the PG during the pulse being low enough not to lead to a significant change of the PG workfunction. Moreover, the base vacuum of the source being of mid 10^{-7} Pa contributes to the stability of the Cs layer as the impurities flux (O_2, H_2O, NO_x etc...) polluting the layer is low. The behaviour of the (0,0,1) probe during these five days is very similar to those previously presented on (-5,0,1) probe. Comparable behaviour was observed in filament driven sources operated in volume H^- production [18, 19].

Different processes are responsible for the changes in the plasma parameters normally observed when caesium is added into a hydrogen source. Bacal et al. [18], show that the addition of xenon (131.30 amu) to an hydrogen discharge increases the electron density and also causes the electron temperature to decrease. This work also showed that the addition of caesium (132.90 amu) produces a reduction of the electron temperature, the density, as well as the plasma potential. The difference between what was observed with xenon and caesium was due to the surface coverage by caesium decreasing the work function thus allowing new emission processes (electrons and negative ions) from the wall. The decrease of the electron density while observed is not explained in the paper of Bacal et al..

In the present work due to the filter field, the electron temperature in the vicinity of the probes is low ($T_e = 1 \pm 0.5$ eV) [12] and it is impossible to observe any clear decrease due to the addition of Cs. Figures 3a), 3b) and 3c) clearly show a correlation between the variation of the plasma potential, the co-extracted electron current density, and the extracted negative ion current density with the total amount of Cs injected into the source for the first two days. During the first two days of conditioning, the evaporated amount of Cs in the source was low (see $\epsilon_{Cs(852nm)}$ / $\epsilon_{H_\beta(Balmer)}$ ratio on figures 3a), b) and 3c); however, the influence on source parameters and performance was very strong compared to the following days.

During source conditioning, the electron saturation current is directly proportional to the co-extracted electron current density as can be seen on figures 4a) and b). When good conditions are achieved as on the last two days shown on figure 4a) and b), this dependence becomes unclear. The decrease in the electron current can only be interpreted as a decrease in the electron density as the electron temperature remains constant. In this particular investigation, it was observed that five points with low saturation currents and high co-extraceted current density were present. The reason for these points is still under investigation.

We will now discuss the influence of the presence of negative ions on the surface on the local plasma parameters. Recent calculations on H^- generation on a surface made by Wünderlich [20] suggest that the negative ions created on the PG surface repel the electrons from the bulk plasma. Figures 5a) and 5b), present the variation of electron and ion saturation currents obtained by the (-5,0,1) Langmuir probe as a function of the

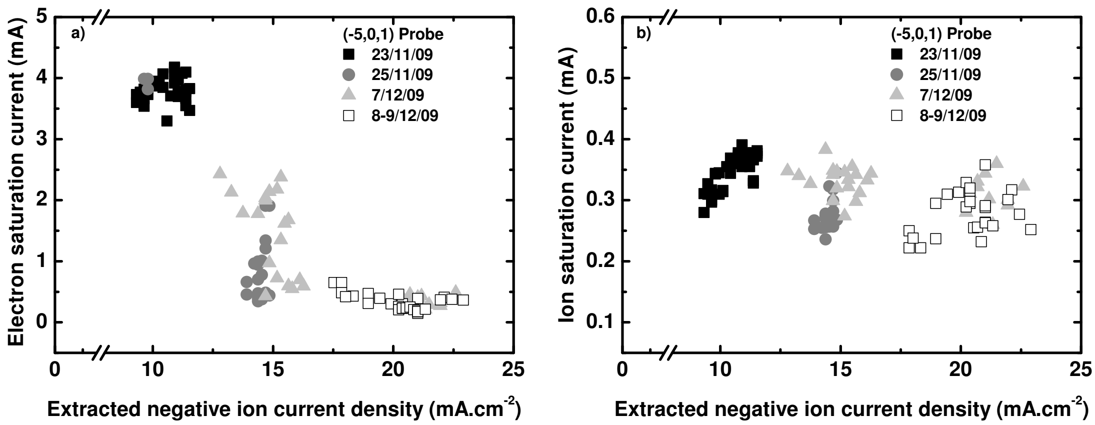

Figure 5. a) and b) present the evolution of the electron and ion saturation current of the probe as a function of the extracted negative ion current density.

extracted negative ion current density. In figure 5a) it can be seen that the electron saturation current decreases with increasing extracted H^-. In figure 5b) is shown that the ion saturation current is essentially independent of the extracted negative ion current density. Combining figures 5 with figures 4 prove that the charge balance (quasineutrality) is made by electrons when the source is "poorly conditioned" and by negative ions when the source "well conditioned". As shown in the calculations of [20], these results indicate that negative ions leaving the surface probably replace the electrons from the plasma, and that the charge balance near the grid is made by the negative ions when the source is "well conditioned".

3.2. Plasma properties in the PG vicinity

In this section will be discussed the differences on the plasma properties observed between the top and the bottom part of the PG.

The continuous decrease of the electron saturation current leads to the onset of an ion-ion plasma either in the upper or the lower part of the PG. The exact location is dependent on the orientation of the filter field. The onset of an ion-ion plasma was previously reported (see [1] and the discussion in [21] for more details). Figures 6a) and 6b) are Langmuir probe characteristics obtained during this campaign from the (-10,-15,3) and (10,15,3) probes respectively. In contrast to the results showed in [21], where the (-10,-15,3) probe curve was symmetric and (10,15,3) probe had a regular Langmuir probe shape, figure 6 shows the (-10,-15,3) probe characteristic is a regular Langmuir probe shape while (10,15,3) probe is symmetric. The magnetic field direction was reversed between the campaigns in this paper and in [1]. Recent measurements

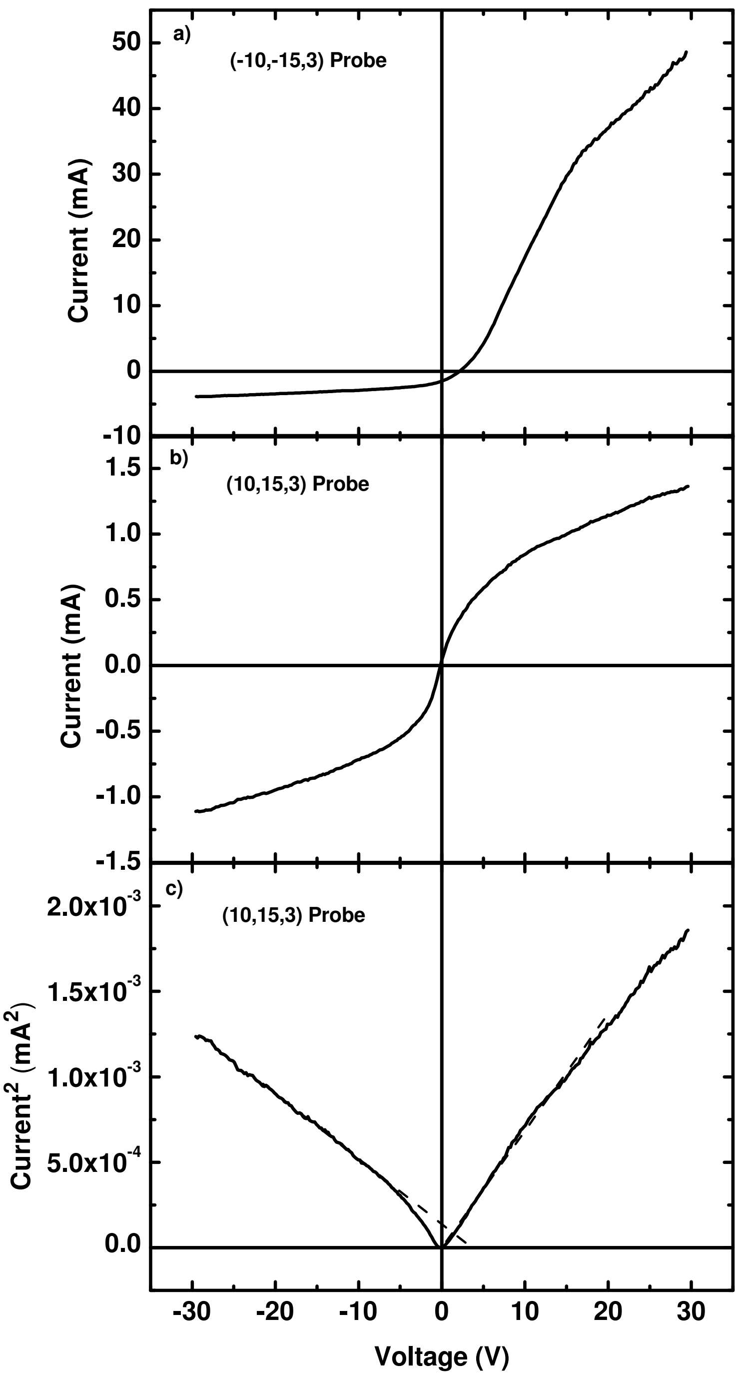

Figure 6. a) present a Langmuir probe characteristic recorded by the (-10,-15,3) probe, b) is the (10,15,3) probe characteristic, while c) is the i^2 against V plot of the b figure.

were made with a Langmuir probe from the driver neighbourhood up to the PG vicinity show that the plasma potential slowly decreases as the probe moved away from the driver [22]. Moreover, density and pressure measurements are lower in the driver than in the expanding chamber due to neutral depletion induced by the high RF power used [23]. As a consequence, the presence of an **E**x**B** and/or ∇**P**x**B** drift is the probable explanation for the differences observed between the top and bottom part of the PG.

The curve in figure 6b) is almost perfectly symmetric. In this particular case: $V_p = V_f = 0$ V. The plasma is composed of H^+, H_2^+, H_3^+, Cs^+ and H^- ions. The Cs^{2+} ion population can be neglected as the ionization energy is 23.15 eV, and is much greater than the electron temperature. Consequently, since the curve is symmetric, negative and positive fluxes to the probe are equal.

In the following, the implications of the presence of an ion-ion plasma for the ionic species will be discussed in detail. The H^+ ions are generated by the dissociation of hydrogen molecule followed by the ionization of the atoms. The atomic hydrogen atoms gain half the Franck-Condon energy (2.24 eV) [24] during the dissociation process. Due to collisions with background neutrals, spectroscopic measurements showed their temperature is 0.8 eV in the vicinity of the PG [25]. The H^+ temperature can be estimated to be within the range of $0.8 < T_{H+} < 2.24$ eV. The background gas temperature (H_2) was also obtained by the evaluation of the molecular hydrogen emission [26]. The measured gas temperature is roughly 1300 K (0.1 eV), thus the H_2^+ and H_3^+ temperatures are likely to be the same. The caesium ion temperature can be estimated to be also equal to the gas temperature i.e. 0.1 eV. However, due to a lower density compared to the other ionic species (see [15] for an estimation of the Cs^+ density, which is roughly 1 % of n_e) and especially due to a much higher mass, the Cs^+ flux to the probe can be neglected. As a consequence, even if the H_2^+ and H_3^+ densities are on par or even larger than the H^+ density, the positive flux to the probe will still be largely determined by the H^+ flux.

In order to experimentally determine if H^+ dominates the positive ion flux, the probe current squared plotted against probe bias for the (10,15,3) probe (see on figure 6c)). Dashed lines over the positive and negative branches show a deviation to the linear law only for the negative branch and only near 0 V. This deviation is likely be due to the presence of low temperature electrons. Woolsey and colleagues [27] have used the ratio of the slopes to determine the ratio of the positive / negative masses. In order to avoid the deflection caused by the electrons near the plasma potential, the slopes were taken between -10 V and -15 V for the positive ion branch and between 10 V and 15 V for the negative ion branch. This results in a m^+ / m^- ratio of $1.7 \pm 20\%$ where m^+ is the positively charged species mass and m^- the negatively charged species mass.

The species distribution in the plasma was estimated to 40% H^+, 40% H_2^+ and 20% H_3^+ [28]. It is difficult to estimate the temperature of the H^- ions. There must be two negative ions populations present in the plasma: the H^- generated in the volume whose temperature is assumed to be equal to the H^+ temperature and the H^- coming from the surface. The negative ions coming from the surface gain the energy from the sheath potential voltage drop (the plasma potential is generally 1 or 2 V higher than the bias voltage of the PG). For this assumption the resulting H^- temperature is rather low (around 1 or 2 eV). A temperature of 0.8 eV is assumed for the H^- ions in the following calculations, the electron population is neglected, as their density is low. Using the previously assumed positive ion proportion, the H^- temperature of 0.8 eV and taking two H^+ temperatures, it is found that:

- the mass ratio is 1.9 for a 0.8 eV H^+ temperature and 0.1 eV H_2^+ and H_3^+ temperature,
- the mass ratio is 1.5 for a 1.5 eV H^+ temperature and 0.1 eV H_2^+ and H_3^+ temperature.

In spite of not knowing exactly what the H^+ and H^- temperatures are, the results are in reasonable agreement with the experimental value. As electrons are present, though with a low density, the m^- mean mass should also be reduced. However, the observation of the symmetric probe trace and the good agreement between the evaluation of the (10,15,3) probe result with the simple estimation confirms that a dominantly ion-ion plasma is located in this part of the PG. In this case the flux to the probe are mainly made by H^+ and H^- ions. Due to their similar mass it is reasonable to assume that both have a similar temperature. In contrast, a plasma composed of positive, negative ions and electrons is located in the other part of the PG as shown by the (-10,-15,3) probe trace. This non-unifromity of the plasma could have some influence on the uniformity of the extracted beam.

4. Conclusion

The aim of this paper was to track the influence of the caesium on source performance and the plasma parameters measured by Langmuir probes during source conditioning. A campaign of systematic Langmuir probe measurements was performed in order to follow the shot to shot evolution of the plasma parameters.

During Cs injection, the following effects were observed: the plasma potential decreased, the co-extracted electron current decreased, and the extracted negative ion current slowly increased. However, the analysis of the probes saturation currents showed a decrease of the electron saturation current while the ion saturation current remained unaffected by the addition of Cs. These observations indicate strongly that the space charge balance near the PG was made by electrons when the source performance was poor, and by negative ions when good source performance was achieved. This confirms that a substantial H^- production will result in a depletion of the electrons in the vicinity of the production surface as was predicted in [20] and assumed in [1].

Finally, the continuous decrease of the electron saturation current leads to the onset of an ion-ion plasma. This onset is only observed in the top or the bottom part of the source (depending on the direction of the applied filter field) and not in the middle part of the PG. Using the estimates of the positive ion temperatures, a very simple estimation showed that the flux to the Langmuir probe was governed by H^+ and H^-. Other species and especially the Cs^+ ions could be neglected. This evaluation of the positive and negative fluxes enabled the calculation of the positive to negative mass ratio. This ratio was then compared to the one obtained by taking the ratio of the slopes of the I^2 vs V curve. A reasonable agreement is found between the experiment and the calculation, despite some uncertainties in the temperature of the species and their proportions. However, the exact mechanism or mechanisms combinations leading to the presence of an ion-ion plasma in a part of the plasma grid and a more conventional plasma in the other part, depending on the FF orientation, are still under investigations.

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