Development of a Caesium Free Hydrogen Negative Ion Source Based on a Pulsed ICP Discharge

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Introduction

H- ion sources currently used (and planned) for particle accelerators and fusion utilise magnetic filters to lower collisional negative ion losses, and use caesium to lower the chamber surface workfunction and enhance the production of negative ions on the plasma grid of the extraction system. However it has been suggested [1] that for DEMO/commercial fusion reactors that a similar Cs injection rate to ITER is likely to lead to NBI operational problems during the reactor lifetime. Fusion NBI ion sources of the future will need to either use Cs with much greater efficiency to dramatically reduce their consumption rate, or will require alternative materials to Cs to enhance the surface production of H-/D- ions.

Temporally filtered plasma sources have been used for efficient negative ion generation for plasma and neutral beam etching of semiconductor devices[2, 3]. Time modulation of the input power deposited into the plasma and the variation of the pulse duty cycle (power on to power off fraction for each pulse), the discharge and afterglow can be tailored to optimise negative ion production and extraction.

During the activeglow phase, power is deposited into the plasma and rovibrationally excited molecules are produced through collisions with high energy electrons, and through the interaction of neutral species with the walls. A small population of negative ions is generated during this phase of the pulse through dissociative attachment, but they are confined to the centre of the discharge due to the much more mobile electrons moving to the chamber walls [4].

The high energy tail of the electron energy distribution (EEDF) rapidly decays in the afterglow of the RF pulse, reducing collisional detachment losses of existing negative ions and promoting increased volume production of negative ions as the dissociative attachment cross section increases for thermal electrons. The decay of the plasma potential in the afterglow also means the negative ion population is no longer restricted to the centre of the discharge, which allows for extraction of ions from the plasma volume [5].

The aim of this work is to evaluate the performance of a Cs free RF inductively coupled ion source, operated in a pulsed regime to generate a high density of volume produced negative ions, as well as assess the performance of some Cs alternative plasma grid materials in the discharge.

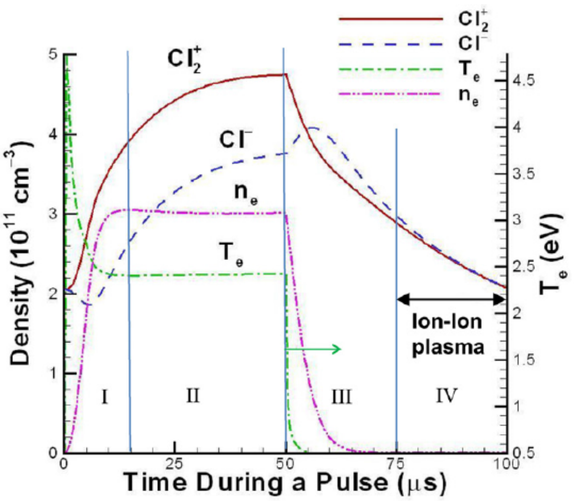


Figure 1: Time evolution of charged species in a 10kHz 50% duty factor chlorine ICP discharge in a GEC reference cell[6].

Experimental Set-Up

The University of Liverpool's negative ion source, shown in figure 2, uses a two turn planar copper coil which is separated from the steel cylindrical vacuum vessel with a quartz window. A bias-able extraction grid is positioned at the base of the chamber 9cm below the quartz window. Up to 1.2kW of RF power is supplied to the coil through a matching network, with a frequency of 13.56MHz. Time modulation of the power is carried out using a digital pulse generator which screens the output of the power supply when the voltage achieves a certain threshold. Measurements of the plasma parameters were carried out using two cylindrical Langmuir probes: one positioned in the centre of the chamber 4.5cm below the coil, and another situated approximately 1cm away from the extraction grid. All measurements were conducted with the plasma in the high density inductive mode (H mode).

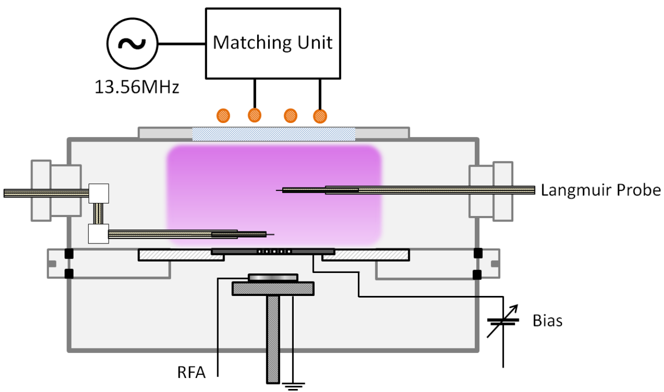
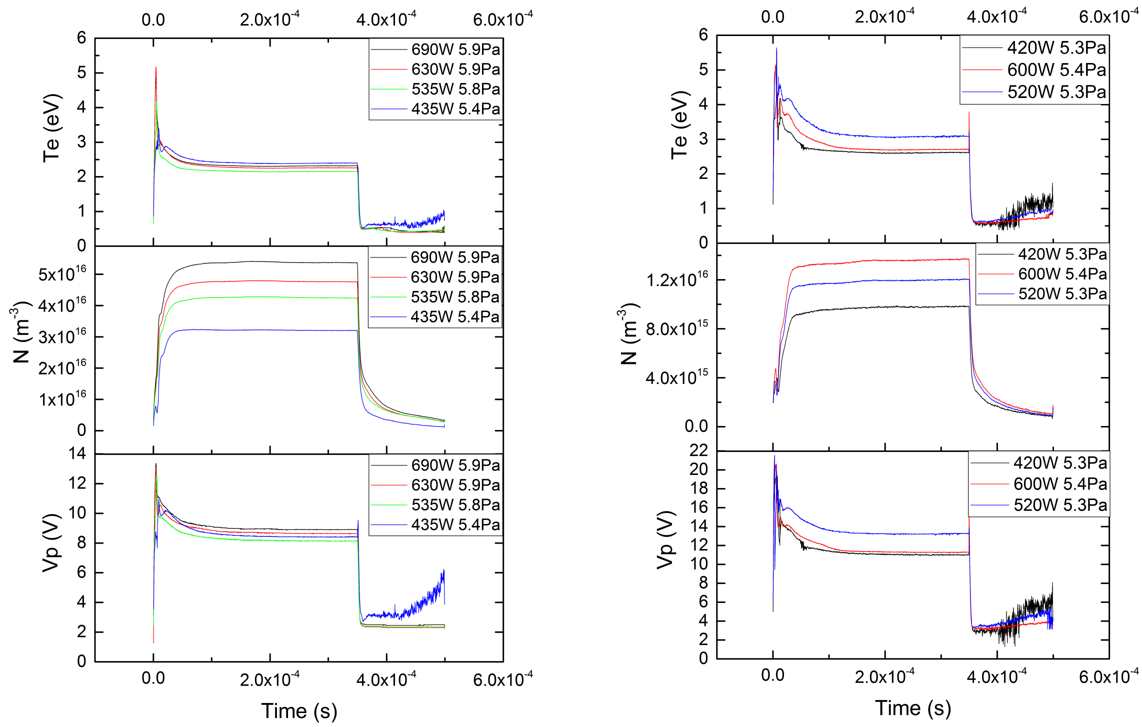


Figure 2: Schematic of the experimental set-up.

Results and Discussion

The plasma source was characterised by taking measurements of the electron temperature T_e , the plasma density, and the plasma potential V_p. Figure 3 shows the plasma parameters measured with changing input power in the centre of the discharge and near the extraction grid. The evolution of the plasma density, electron temperature and plasma potential followed the expected trends: a large overshoot of the electron temperature and plasma potential during the early stages of the pulse due to the heating of the initially low density of electrons [7], followed by the plasma parameters achieving their quasi-steadystate values after around 100μs, and a rapid decay during the afterglow as high energy electrons are quickly lost to the walls. As the electron temperature and plasma potential are only weakly coupled to the power deposited into the plasma, they remain unaffected by the increase in RF power. As expected the density of the discharge increases with power, with larger a larger density of charge carriers recorded in the centre of the plasma compared to those observed near the extraction grid for similar RF powers. The same plasma parameter measurements were also made whilst varying the pulse frequency, duty factor, and gas pressure to map out the parameters within the operational range of the ion source.



(a) (b)

Figure 3: Plasma parameter measurements in a hydrogen ICP discharge with a pressure around 5.4Pa, pulse frequency of 2kHz and duty factor of 70%. 3a) represents measurements taken in the centre of the discharge, whilst 3b) contains measurements taken near the extraction grid.

An retarding field energy analyser (RFA) was used to conduct measurements of the ion energy distribution function (IEDF) and ion velocity distribution function (IVDF) in the plasma bulk. The observed distributions were comprised of a single peak representing ions accelerated through the sheath and again through the electron repulsion bias within the RFA. After taking the additional acceleration into account the sheath potential found agrees with the plasma potential measured by the Langmuir probe diagnostic.

With source characterisation complete the RFA will be positioned approximately 8mm underneath the extraction grid to analyse the energy spectrum of ions extracted from the bulk plasma when a bias is applied. These measurements can then be compared with those taken with a ring of Cs alternative material boron-doped diamond surrounding the extraction apertures in order observe the affect of the material on the extracted ion energy distributions throughout the activeglow and afterglow.

References

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