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High Flux of Magnetised Plasma in Magnum-psi

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1. Introduction

In the divertor region of ITER particle fluxes of about 10^{24} $m^{-2}s^{-1}$ at a temperature of about 1 eV in magnetic fields up to 5 T are expected. It is necessary to study the behaviour of different materials used in divertor components under these conditions. But such investigations are usually difficult to carry out on big machines *in situ* because of the limited diagnostic access. Magnum-psi (Magnetised Plasma Generator and Numerical Modelling for Plasma-Surface Interaction Studies) is a pilot project designed to show that such conditions can be reproduced on a smaller scale, with good diagnostic access.

2. Experimental set-up

Magnum-psi is a linear device consisting of a cascaded arc plasma source (CAPS), a vacuum vessel for plasma expansion and magnetic coils (Fig. 1). The CAPS (Fig. 2a) was developed at the Eindhoven University of Technology [1]. It consists of a cathode part with three cathodes of thoriated tungsten 2 mm in diameter, fixed at 120° to each other and 45° to the CAPS axis, several copper cascaded plates 5 mm thick with a central 2-4 mm discharge channel, and an anode plate with a nozzle. All components are water-cooled. The plates are electrically insulated from each other and from the cathode part and the anode with boron-nitride plates 1 mm thick. The working gas (Ar, H_2) continuously flows into the CAPS at a pressure of 1-2x10^4 Pa and is ionised there. Usual discharge parameters are the following: gas flow rate 1-3.5 slm, and arc current 50-80 A. The arc voltage ranges from 40 V for pure argon plasma to 140 V for pure hydrogen plasma .

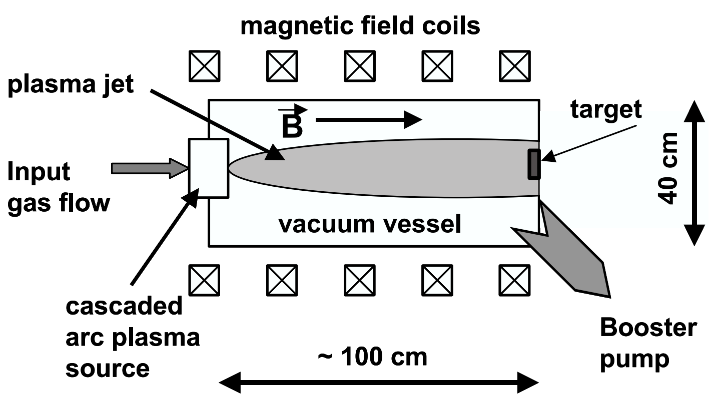

Fig. 1. Scheme of the experimental set-up

To prevent quick erosion of the tungsten cathodes in a hydrogen plasma and to increase the density of produced plasma a new CAPS design (Fig. 2b) was tested. The channel diameter in the first two cascaded plates was decreased to 2 mm, and an extra plate with radial inlet for hydrogen inflow was inserted between the second and the third plate.

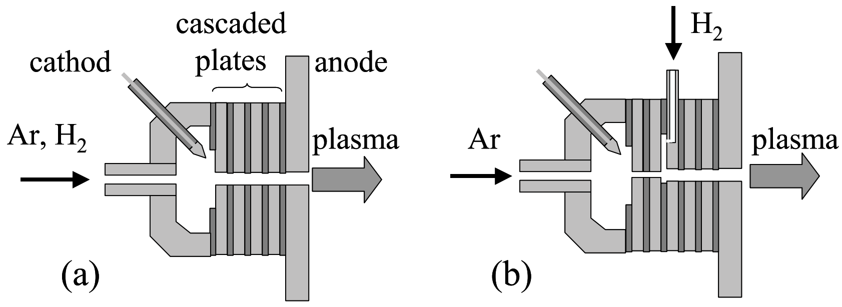

Fig. 2. Old (a) and new (b) design of cascaded arc plasma source

The plasma produced in the CAPS supersonically expands into the vacuum chamber, which is evacuated by booster pump with the pumping speed up to 4500 m^3/hour. By controlling the rotation velocity of the pump the pressure in the vessel can be kept constant at a value between 4 and 200 Pa.

Five cooled coils can create a magnetic field of 0.4 T inside the vessel during 2 minutes and a magnetic field of 0.8, 1.2 or 1.6 T during 2 seconds.

An auxiliary ring-shaped electrode was installed coaxially with the plasma to draw extra ion (electron) current to the target.

A double Langmuir probe [2] was installed at about 30 cm from the nozzle and could be moved perpendicularly to the plasma axis to obtain radial profiles of the electron density and temperature. The probe consists of two tungsten wires of 4.5 mm length and 0.2 mm in diameter.

3. Experimental results

Measurements with the double Langmuir probe were carried out for different arc currents and different background pressure in the vessel for argon and hydrogen plasma. In every case a scan along the plasma radius was done. The electron temperature and density were calculated [2] from the double probe characteristics at every point of the scan. For a wide range of conditions the electron temperature was found to vary from 0.2 to 0.3 eV for an argon plasma and from 0.1 to 0.2 eV for a hydrogen plasma. The plasma density grows with the arc current because the extra power delivered to the plasma gives extra ionization. When the background pressure grows, the plasma profile becomes narrower, the plasma density increases in the center and decreases at the plasma edge. This can be explained by the fact that the collision frequency increases and the plasma expansion is confined. But at the same time the recombination rate grows, especially for a hydrogen plasma, and at a certain pressure the density starts to decrease (Fig. 3). A comparison for a hydrogen plasma at an arc current of 60 A, a flow rate of 3 slm, and a background pressure 7 Pa shows that the plasma density with the new CAPS design is approximately 1.5 times higher then that for the old design (Fig. 4). In the beginning of the arc argon atoms are ionized and in the middle of the arc the resonant charge exchange with hydrogen molecules and the following recombination of hydrogen ions gives a big amount of atomic hydrogen:

$Ar^+ + H_2 \rightarrow Ar + H_2^+$, $H_2^+ + e^- \rightarrow H + H$ or $Ar^+ + H_2 \rightarrow ArH^+ + H$, $ArH^+ + e^- \rightarrow Ar + H$. The atomic hydrogen can be ionised in the last part of the arc much easier than the molecular hydrogen. A disadvantage of this design is that a small flow of argon (at least 0.1 slm) should always be present.

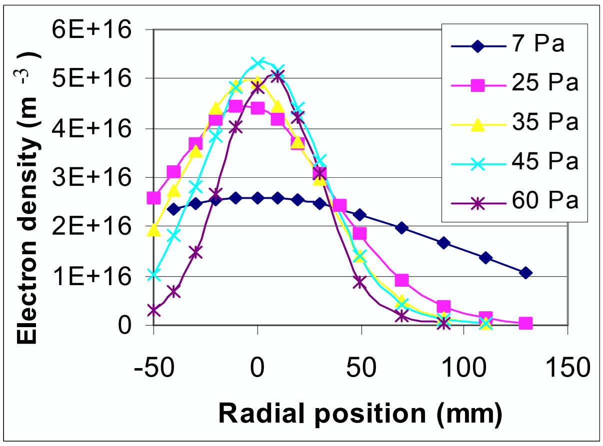

Fig. 3. The electron density profiles for hydrogen plasma at the position of about 30 cm from the nozzle at different background pressure.

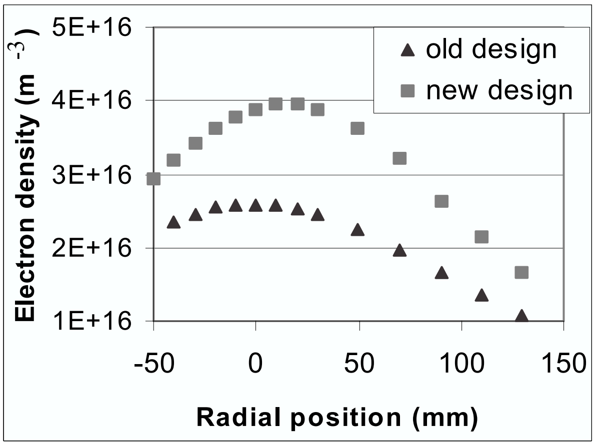

Fig. 4. The electron density profiles for a hydrogen plasma at the position of about 30 cm from the nozzle for the old and new designs at a background pressure of 7 Pa.

Potentials on the cascaded plates at I_{arc}= 60 A, a flow rate of 3 slm, and p_{vessel} = 7 Pa were measured for both the old and the new design of the CAPS (Fig. 5). The discharge voltage is lower for the new design of the CAPS, so at the same arc current less power is put into plasma but the plasma density is higher showing the higher efficiency of the new design.

An extra ion current up to 3 A or electron current up to 10 A can be drawn to the target with the auxiliary ring-shaped electrode to increase particle flux density to the target.

A hydrogen plasma, produced in the CAPS has been studied recently in a magnetic field up to 0.045 T [3]. The results, obtained with the Langmuir probe method, are influenced by a magnetic field. The electron and ion Larmor radii r^B_e and r^B_i should be much larger than the Debye lenght λ_D for the method to be valid. The criteria for using this method are still valid for a magnetic field of about 0.4 T. The method shows that the electron densities for a hydrogen plasma in a magnetic field of 0.4 T are higher by two orders of magnitude (Fig. 5). A hydrogen plasma recombines fast by dissotiative recombination [4], but in a high magnetic field the plasma expansion is confined and thus the recombination is limited. The electron temperature in hydrogen plasma is found to be about 1 eV in a magnetic field of 0.4 T. It is higher than in the case without a magnetic field probably also because of the expansion confinement. In a hydrogen plasma the particle flux density to the target is of the order 10^{20} $m^{-2}s^{-1}$ without a magnetic field and 10^{22} $m^{-2}s^{-1}$ in a magnetic field of 0.4 T. So using the auxiliary electrode to draw extra current to the target the required particle flux density exceeding 10^{23} $m^{-2}s^{-1}$ can be reached in a higher magnetic field (1.6 T).

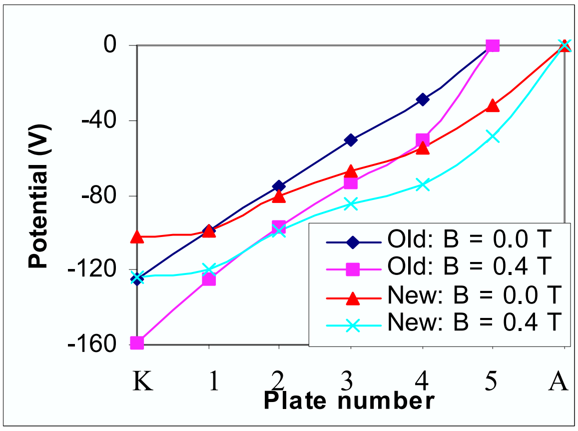

Fig. 5. The potential distribution at the cascaded plates of the CAPS for the old and new designs without a magnetic field and in 0.4 T magnetic field.

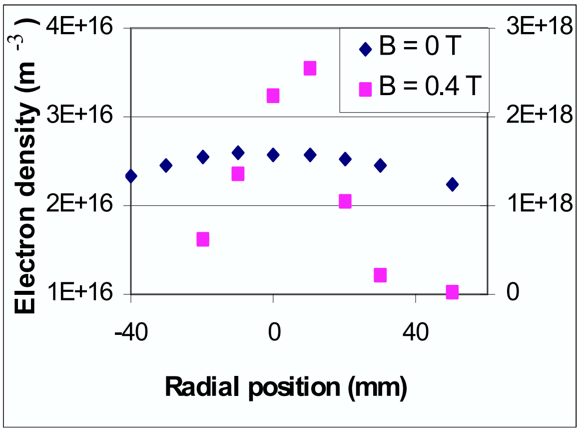

Fig. 6. Electron density profiles of a hydrogen plasma at the position of about 30 cm from the nozzle without a magnetic field (left scale) and in a 0.4 T magnetic field (right scale)

4. Conclusions

A downstream hydrogen plasma with an electron density of about 10^{18} m^{-3} at an electron temperature of about 1 eV in a magnetic field of 0.4-0.8 T was created. The particle flux under these conditions is about 10^{22} $m^{-2}\cdot s^{-1}$. The desired divertor-relevant particle flux density of 10^{24} $m^{-2}\cdot s^{-1}$ comes within reach using an auxiliary electrode to draw extra current to the target in a magnetic field of 1.2-1.6 T.

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