Properties of a constricted anode plasma source

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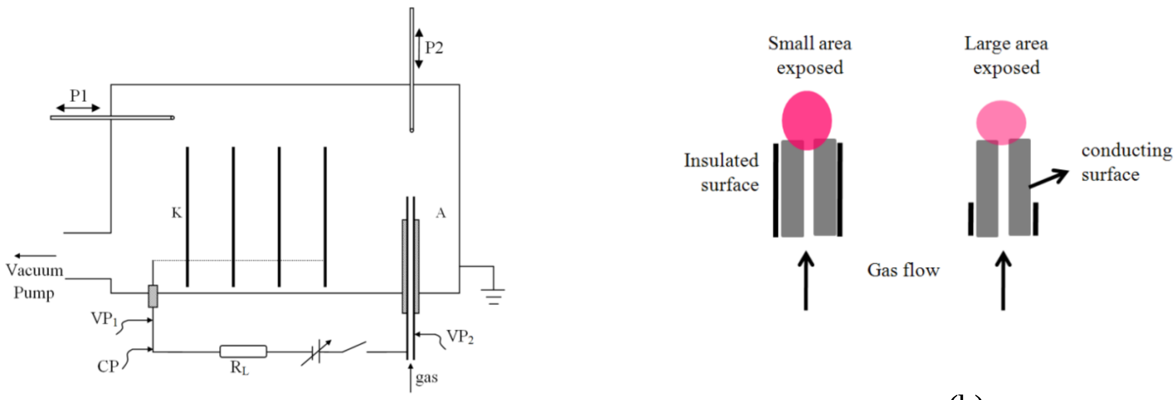
The neutral beam injection system of ITER requires a negative ion plasma source which can produce uniform plasma density (5×10^{18} m^3) over an area of 0.2 m^2 in front of the extraction grid of negative ions while the recommended chamber pressure should be below 0.3 Pa for avoiding breakdown between the extracting grids. The current sources based on surface production of negative ions rely on interaction of plasma with low work function surfaces [1]. For this Cs gas is fed along with the working hydrogen gas where Cs deposits on the stainless steel chamber walls and provides the active low work function surface. However, Cs can migrate along with negative ions through the extraction grid. This has serious consequences as some negative ions are produced in between the accelerator grids and their energies are significantly lower than the major component of negative ions extracted from the plasma. This leads to a poor optics of the beam and consequent beam divergence and therefore enormous amount of heat loading on the wall of the accelerator column. In order to address these specific issues, our objective is focused on developing a Cs free negative ion source, i.e. to create conditions that are favorable for the production of negative ions. Typical features of our source consists of (1) local production of negative ions in front of the extraction region, thereby minimizing the losses caused by ion-ion and ion neutral interactions, (2) active species generated locally which enhance the chemistry for the volume production of negative ions, (3) a low electron temperature region which minimize the destruction of negative ions that are produced.

The source comprises of equidistance parallel plates (annular or semicircular discs) acting as cathode while the anode is a constricted stainless tube whose outer surface is insulated from the plasma (figure 1). The exposed area of the anode can be varied by adjusting the length of the insulating ceramic tube covering the outer surface of the anode. The gas (Ar/N_2/He) is flown through the anode and pumped outside the chamber where the cathode is situated. A cylindrical Vacuum chamber is grounded and both anode and cathode are floating with respect to chamber and the discharge is created by applying a DC bias to the floating electrodes.



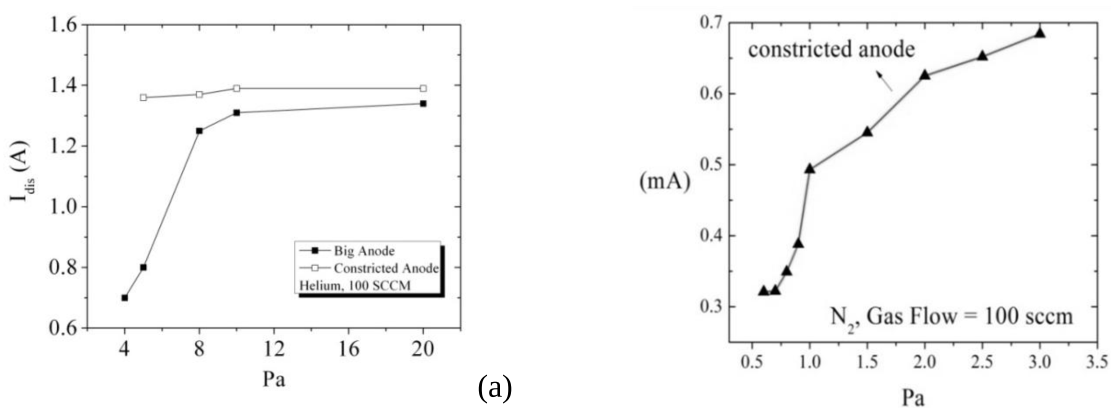
(a) (b)

Figure 1 (a) A constricted anode - hollow cathode plasma source; P1, P2: Hairpin probe / Langmuir probe; VP1, VP2: Voltage probe; CP: Current probe (b) Area of the anode exposed to the plasma is adjusted by the length of insulating material. Increase in anode area diminishes the intensity of the fireball.

Spatial plasma properties such as electron density and electron temperature are measurements by hairpin probe and commercial Langmuir probe. The discharge is characterized by a uniform plasma density of 10^{10}-10^{11} cm^{-3} and distinct electron temperature regions between inside and outside the parallel plates. Around the constricted anode intense electric field leads to the heating of the plasma electrons locally around the anode which facilitates ionization at low pressure. An intense plasma is formed around the constricted anode which is characterized by density over an order in magnitude higher as compared to the background plasma density near the cathode.

Results and discussion

Figure 2 (a) show the comparison of discharge currents obtained with two different anodes one of them having a relatively large area exposed to the plasma.



(a) (b)

Figure 2 Discharge current versus pressure (a) for Helium (b) Nitrogen at 400 W

As observed, the discharge current is higher in case of constricted anode and discharge current remians almost constant over a pressure ranege up to 4 Pa. A similar results is shown in figure 2 (b) for nitrogen discharge where the discharge sustains up to 5×10^{-3} mbar.

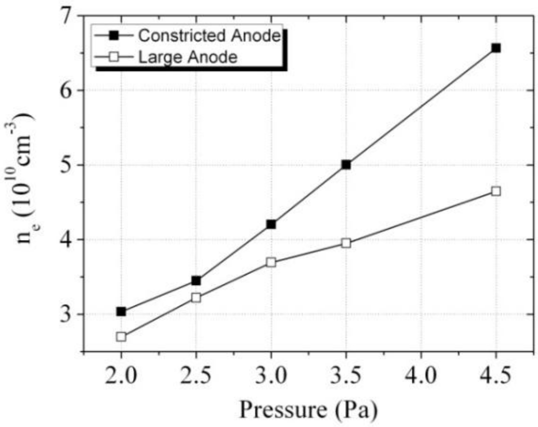


Figure 3 Electron density as a function of pressure for constricted and big area anode (N_2, 400 W)

The graph of electron density versus pressure (figure 3) at fixed power of 400 W shows the enhancement in the plasma density in the positive column in case of constricted anode as compared the the relatively large area anode.

The rise in the discharge current and plasma density in case of constricted anode can be correlated to the existance of intense anodic glow. The anodic glow evolves as a result of enhanced ionization of background neutrals by energetic electrons which are accelerated by double layer potential profile in the anode region [2,3].

The plasma density in the anodic glow can be estimated by equating the current at the cathode (I_c) and the current at the anode (I_a).

$$I_a = en_a A_a \left[\frac{2eV_a}{m_e}\right]^{1/2} = I_c = en_c A_c \left[\left(\frac{kTe}{M}\right)^{1/2} + \gamma\left(\frac{2eV_c}{m_e}\right)^{1/2}\right]$$

Where n_a and n_c are the plasma densities in the anode and cathode region respectively. After performing some algebraic steps we obtain

$$\frac{n_a}{n_c} = \frac{A_c}{A_a}\left[\gamma + \sqrt{\frac{m_e}{M}}\sqrt{\frac{kT_e/2e}{V_c}}\right]\sqrt{\frac{V_c}{V_a}}$$

If we put the known values of the parameters in above equation, we get $(n_a/n_c) \approx 100$ i.e. plasma density in the anode region is 1-2 orders of magnitude higher as compared to the plasma

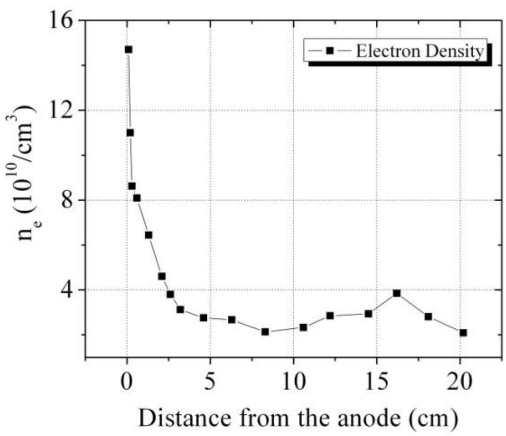


Figure 4 Spatial electron density measurement from anode and to cathode

density in the cathode region. The experimental data for Nitrogen gas at 2 Pa and input power of 400 W is presented in figure 4. The ratio of n_a and n_c from the graph is about 50 which matches reasonably well with the calculated value.

In figure 5 (a) spatial profile of electron density in front of the cathode plates is plotted. It can be seen that the electron density is uniform over the length of 20 cm and the density drops symmetrically outside the cathode region. In figure 5(b) the data for electron temperature shows a significant drop in the electron temperature outside the parallel plate as compared to the electron temperature inside the parallel plates.

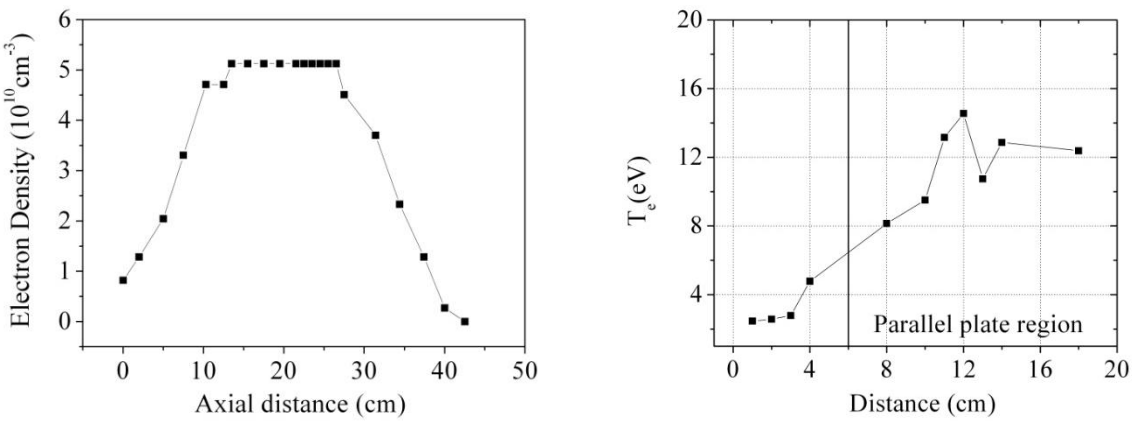


Figure 5 (a) Uniform axial plasma density in the cathode region and (b) Spatial electron temperature between and outside the parallel plate cathodes for N_2 gas at 2 Pa.

These distinct electron temperature regions in a single plasma device facilitate the production of negative ions by volume process. While low electron temperature in front of parallel plate cathode will help in minimizing the loss of negative ions by electron collisions, plasma uniformity in this region will be useful for maintaining uniform, high negative ion density plasma in front of the extraction grid.

Acknowledgement

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