A differentially pumped hollow cathode constricted anode plasma source for the production of negative ions

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The negative ion source for Neutral Beam heating system of ITER is required to deliver 40 A of D^-/H^- negative ion current though 0.2 m^2 grid. This demands high density (~$5\times10^{18}/m^3$) plasma in front of the extraction grid at low operating pressure of 0.3 Pa pressure. The existing negative ion sources for neutral beams injection heating (NBI) are based on tungsten filament type Kamaboko-III source and the advanced RF modular type ion source [1]. These sources rely on Caesium for efficient surface production of negative ions. However Cs can migrate into the extractor region along with negative ions and can lead to the divergence of the beam, dumping enormous power on to walls of the acceleration chamber. Therefore Cs free negative ion source for ITER NBI and future fusion devices is a high priority of research.

For addressing the above limitations, we are currently investigating on a new concept source based on the local volume production of negative ions using the principle of constricted anode plasma source originally developed by Anders in 1995 [2]. As shown in figure-1, the device comprise of an enclosed cylindrical hollow cathode having surface area exceeding several orders in magnitude than the anode. The anode is a small tube placed outside the hollow cathode. The hollow cathode and the anode region are separated by a floating stainless steel electrode having a 6.0 mm hole. The gas is injected from the back of the hollow cathode while pumped through hole which creates a differential pressure as high as 10 Pa inside the hollow cathode as compared to the 0.1 – 1 Pa outside the floating electrode where the anode is situated. By adjusting the gas flow rate a suitable electron neutral ionizing mean free path can be achieved for breakdown. The discharge is sustained with dc power supply at modest operating powers up to 400 W to obtain downstream plasma of density 10^{16} – 10^{17} m^{-3}. The neutral pressure near the anode is lower however bright plasma can be sustained near the anode as the electric field is concentrated over a small volume. The differential pressure helps to push the plasma outside the hollow cathode region as a jet of plasma sustained at a low pressure.

The condition near the anode is favorable for the production of negative ions. The negative ions are formed by a two step process, (1) by excitation of molecular gas followed by dissociation; (2) attachment process leading to the formation of negative ions. The dense plasma in front of the anode falls dramatically away from the anode resulting in the formation of a plasma double layer. The electron temperature drops significantly which reduce the destruction rate of negative ions. In this paper we investigate the spatial properties of the plasma near the anode using a resonance probe for measuring electron density [3] and an ion flux probe for positive ions density. Comparison of the ratio of electron to negative ion density is studied for pure electropositive argon gas and with the 50 % Ar/ O_2 mixture, where O_2 is electronegative in nature. The plasma potential and electron temperature is estimated using a floating emissive probe [4]. These point measurements are carried out relative to the edge of the anode glow, d = 0 mm as shown in figure-1(b).

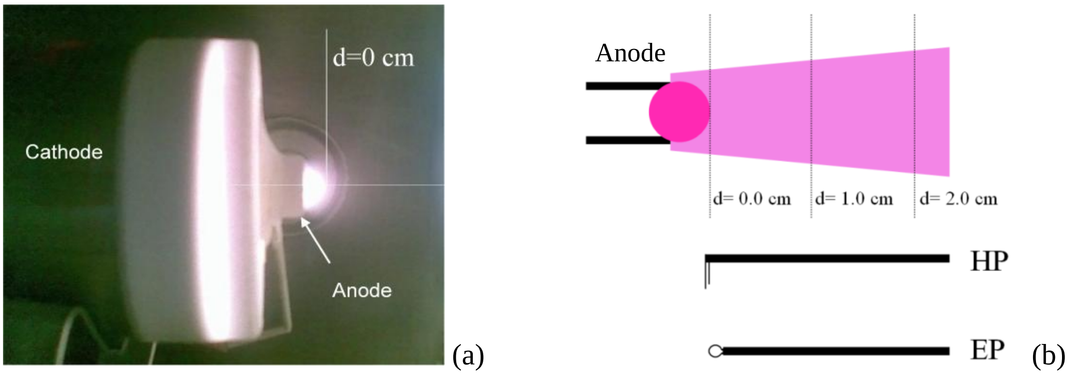


Figure -1 (a) Constricted Plasma source, Spatial plasma parameters are measured from the edge of anode glow. (b) HP: Hair pin probe and EP: Emissive probe

Experimental results and discussion

In figure-2, the spatial electron density at different operating powers (200 W, 300 W and 400 W) away from the edge of the anode glow shows over 50 % drop in n_e with in a distance of 5.0 mm. The drop in electron density is a result of ambipolar diffusion of positive ions in the expanding beam plasma. The electron density also drops as a result of very low ionization. The spatial behaviour of the plasma potential in figure-3 is monotonically decreasing with the distance from the glow. This suggests that the electron temperature is rapidly cooled in the expanding plasma.

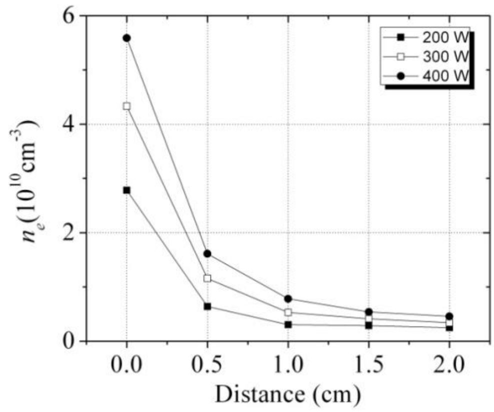


Figure -2 Graph of electron density versus axial distance along the plasma jet at 200w – 400 w power for Argon-Oxygen gas at 0.65 Pa

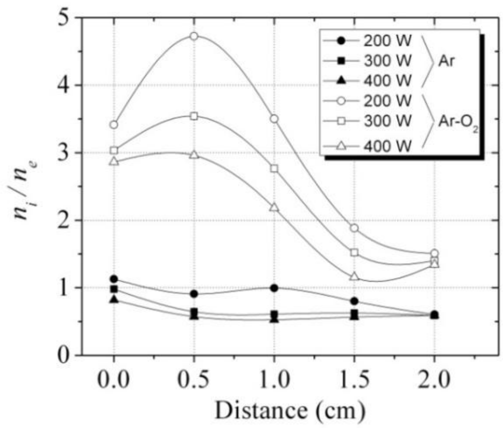


Figure - 3 n_i/n_e versus distance from the anode for Ar and Ar-O2 gas mixture at 0.65 Pa

On the other hand in figure-4 the behaviour of electron density to positive ion density ratio for 50% Ar-O_2 mixtures shows some peculiar characteristics when compared with pure argon. In the case of pure argon the ratio is typically close to 1 at all positions from the anode glow. This is expected for pure electro-positive plasma ($n_e \sim n_+$). Whereas with 50% Ar-O_2 plasma, the positive ion density exceeds the electron density by 3 – 5 times at d = 5.0 mm and remains overall higher up to a distance of 0 – 10.0 mm.

The excess positive ion density observed in the above case (figure-4) for the Ar-O_2 plasma suggests direct violation of the plasma quasineutrality unless compensated by the presence of negative ions. Since the behaviour of the plasma potential is similar for pure argon and

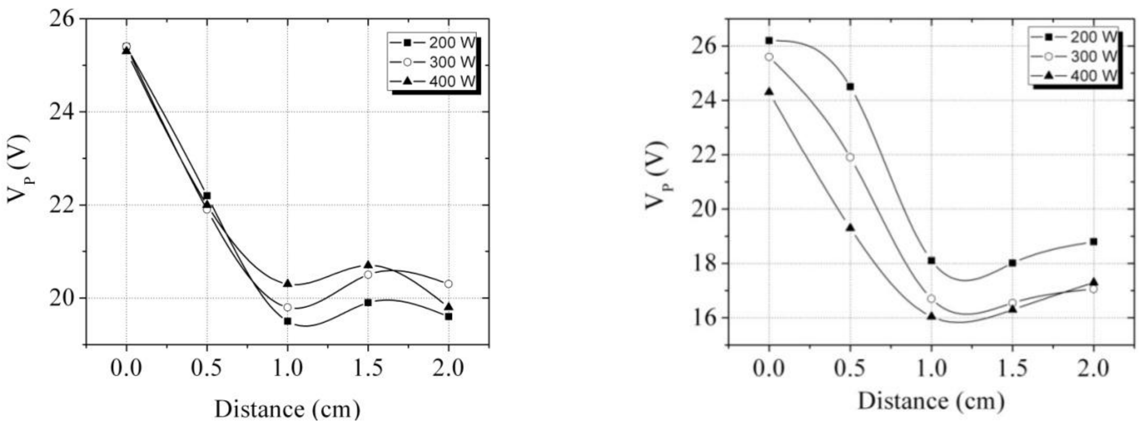
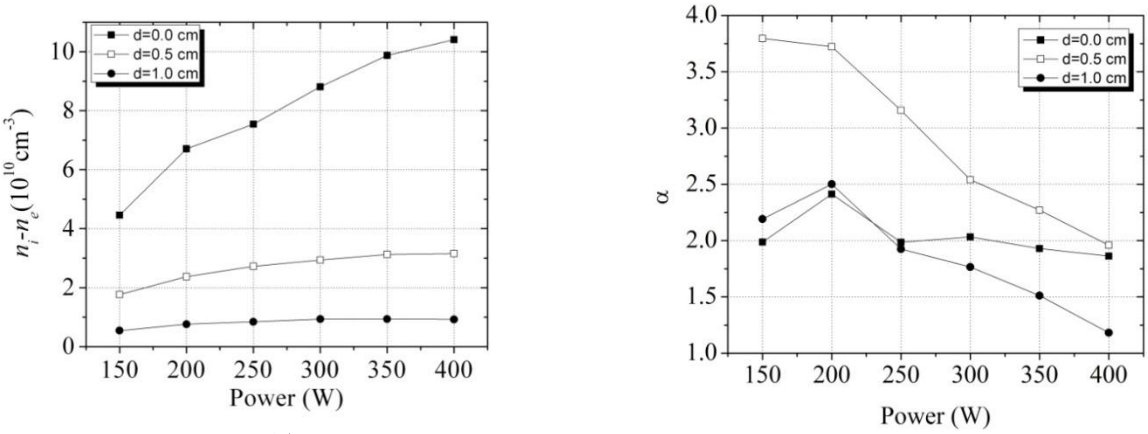


Figure -4 (a) Pure Argon 3(b) Ar/O_2 mixture: Plasma potential versus axial distance for Ar O_2 gas mixture at 0.65 Pa

Ar-O_2 mixture, it ignores the possibility of a space charge of positive ions over the range of 0 – 20 mm outside the luminous glow region around the anode. Therefore we can conclude that the conditions are favourable for the creation if negative O_2 ions at specific distance, in this case d = 5.0 mm, outside the anode. Using this simple diagnostic we obtained the plots of negative ion density as a function of operating powers between 150 W up to 400 W as shown in figure 5. The background neutral pressure near the anode was 0.65 Pa.



(a) (b)

Figure-5 (a) Difference between ion density and electron density as a function of input power; (b) The ratio α=n_ / n_e is plotted against input power

As expected the negative ion density is found to increase with power as a result of increased electron attachment favouring creation of negative ions. Whereas the relative ratio $\alpha = n_-/n_e$ falls with the electron impact dissociation as the electron density increases with the power.

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