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Exploring the Potential of an ECR Source for Large-Area Hydrogen Negative Ion Production in Fusion Applications

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Abstract: Hydrogen negative ions (H^-) are a key species in hydrogen plasma, with applications in plasma-based material processing, environment and biomedical applications, accelerator physics, and, most importantly, thermonuclear fusion [1, 2]. In fusion research, H^- ions are crucial for heating and current drive in magnetically confined fusion reactors [3]. Currently, most fusion-based H^- ion sources use inductively coupled plasma (ICP) systems driven by radio frequency (RF) at around 800 kW. These systems rely on collisional power coupling, which is less efficient than resonant coupling techniques. Electron cyclotron resonance (ECR) provides a more efficient alternative, yet its potential for large-area, high-current sources remains largely unexplored.

This paper presents investigations into an ECR-based large-volume plasma system through plasma characterization using Langmuir probe and molecular beam mass spectrometer (MBMS). The experiments were conducted in a cylindrical expansion chamber, known as ECR based Large Negative Ion Beam Source (ELNIBS), with a height and diameter ~ 1 m. Plasma was generated using a compact ECR plasma source (CEPS) [4], that was mounted on the top dome of the chamber. The magnetic field configuration of the source decays exponentially into the plasma expansion chamber aiding plasma expansion. Plasma characterization was performed under varying operating conditions of microwave power (400 - 600 W) and gas pressure (1 - 3 mTorr). Axial and radial Langmuir probes (LP) were used to measure plasma parameters, while positive and negative ions mass as well as energy spectra was obtained using a low-pressure plasma sampling probe (PSM) of Hiden HPR-60 quadrupole MBMS [Fig. 1].

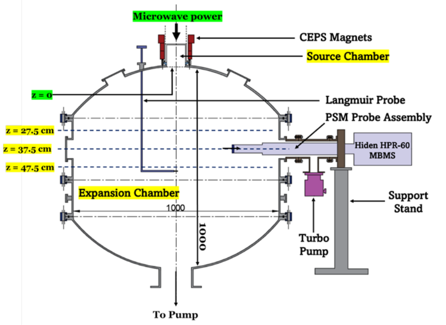

Figure 1. Experimental setup with plasma diagnostics

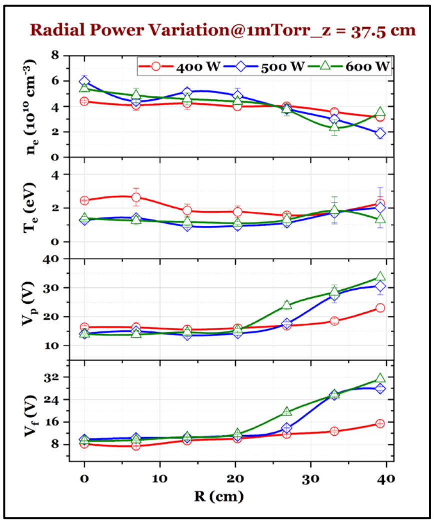

Figure 2. Radial variation of plasma parameters (a) plasma density, n_e [10^{10} cm^{-3}], (b) electron temperature, T_e [eV], (c) Plasma Potential, V_p [V], Floating Potential, V_f [V] for different input microwave powers (400 W (red line, circle symbol), 500 W (blue line and rhombus symbol) and 600 W (green line, triangle symbol)]

Experiments were performed under the conditions of the plasma source facing the PSM probe and the probe mounted in the transverse direction. The LP results indicate that a uniform plasma was produced, with $n_e \sim 10^{11}$ cm^{-3} and a low electron temperature of $T_e \sim 1$ eV [Fig 2]. These results indicated favorable conditions for volume production of H^- ions and those were detected using MBMS. The relative concentrations of H^+, H_2^+ and H_3^+ ions were also studied, which indicates that H_3^+ ions tends to be more dominant for the operating conditions in these experiments. The effect of plasma conditions along with the energy distribution of the positive ions on H- mass spectra and energy spectra will be presented in more detail.

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