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Compact ECR Plasma Source: its Physics and Application

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Electron Cyclotron Resonance plasma sources are of fundamental importance in plasma physics because of the attractive properties of these sources. They offer several advantages: 1) resonant absorption of microwave enables the operation of these sources at wide range of gas pressures; 2) high degree of ionization/ density can be achieved in contrast to the RF and DC plasma sources; 3) Electrodeless operation of these sources offers simple configuration and longer operational life. A Compact ECR Plasma Source (CEPS) has been developed at IIT Delhi, India [1] that is both portable and easily mountable on a target chamber of any size. It integrates the four standard components of an ECR plasma source namely plasma-source section (PSS; ID ≈ 9.1 cm and length ≈ 11.6 cm), an appropriately designed magnetic field configuration, a microwave coupler for feeding power to the PSS and a microwave source. Microwave (at 2.45 GHz, CW, up to 800 W) is launched through a quartz window into the PSS and propagates therein like a whistler wave. The PSS behaves like a plasma loaded waveguide which can support a number of guided plasma waves that are either resonant modes (atttain $\omega_{ce} = \omega$) or non-resonant modes (propagating through $\omega_{ce} = \omega$ layer) [2]. Also, these modes suffer a *reversal* of polarization along the radius (from right hand polarized to left and vice versa) so that both azimuthal modes $m = +1$ (RCP on axis) and $m = -1$ (LCP on axis) are absorbed with equal ease.

The CEPS uses NdFeB ring magnets that render the system both lightweight and compact. They produce two ECR surfaces, one of which is blocked out by the quartz window, while the other is formed within the PSS and aids plasma formation. *The field lines passing through the ECR surface inside the PSS resemble a magnetic mirror configuration, which trap electrons allowing them to cross the ECR surface multiple times and gain energy in each pass, enabling the formation of very high plasma density, high electron temperature and large plasma potential inside the CEPS.*

The efficacy of the CEPS for plasma production was confirmed by attaching it coaxially to a test chamber called the Small Volume Plasma System (SVPS, ID = 15 cm, Length = 37 cm) [3]. Plasma characteristics obtained downstream in the SVPS revealed unique and interesting properties of the plasma. It *was found that the bulk electrons obey the double-adiabatic equation of state (EOS) and follow an n/B = const. scaling along the axis over a wide range of argon pressure*. Typical bulk and warm electron densities, $n \approx 10^{11}$ cm^{-3} and $n_w \approx 10^8$ cm^{-3} respectively were measured using Langmuir Probe (LP) at 0.5 mTorr and 500 W of microwave power. Bulk and warm electron temperatures ($T_e \approx 2.5$ eV and $T_w \approx 50$-60 eV) were found to be uniform along the axis with the plasma potential dropping gently from $V_p \approx 27$ V to 18 V along the axis. The latter results confirm that the CEPS is an efficient plasma source and can be exploited for various applications.

This talk will discuss some of the above physics issues pertaining to the CEPS before focussing on its utlization as an electrodeless quasineutral plasma thruster as a special application.

The ability of the CEPS to serve as an efficient plasma thruster was assessed by analyzing the plasma characteristics inside the PSS. For this purpose, the CEPS was attached to a large expansion chamber namely, the Medium Volume Plasma System (MVPS, ID = 48.2 cm, Length = 75 cm) [4]. Unlike the SVPS, the MVPS plasma *does not obey* the double-adiabatic EOS nor the *n/B = const*. scaling.

The plasma parameters observed outside the CEPS are *very different* from those found inside the PSS. *Using special LPs, it was possible for the first time to measure the plasma parameters inside the PSS*. As expected, high plasma densities (≈ 10^{12} cm^{-3}), high bulk electron temperatures (15-20 eV) and high plasma potentials (≈ 100 V) were observed inside the CEPS, at ≈ 0.5 mTorr and 600 W. However, the most unique feature of the CEPS plasma is the *fall of almost the full plasma potential inside the CEPS within a short distance, close to its exit*, giving rise to strong ambipolar electric fields suitable for accelerating ions [4]. The computed thrust *due to the CEPS alone* was found to be ≈ 56 mN. The presence of highly energetic ions was also confirmed with RFEA measurements yielding 87 eV of ion energy at ≈ 2 cm in front of CEPS. Assuming uniform beam profile and taking into account the ion energy and density at that location gives ≈ 50 mN of thrust. The two results agree well. It is noted that the reported thrust values are at very moderate power and are *much higher in comparison to those obtained from existing thrusters like the helicon thruster* (≈ few mN). This opens up the possibility of developing CEPS into an efficient plasma thruster.

References

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