

**PhD Thesis Title:** Experimental and Theoretical Study on Compact ECR Plasma Source for Thruster Application

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## *Abstract*

Electric thrusters are used for altitude control and station keeping of small satellites in low earth orbits, orbit raising of medium and large platforms to geostationary earth orbits or deep space exploration missions. However, the use of high voltage ion acceleration grids and beam neutralizers limits the life of an electric thruster since they are prone to erosion. Electrodeless thrusters have distinct advantage over the conventional ones that avoids erosion problem thereby enhancing their active life. Accordingly, a novel plasma thruster using Compact ECR Plasma Source (CEPS) is proposed as a competitive candidate, satisfying the electrodeless condition since microwave power is coupled to the plasma through a dielectric window as opposed to via an immersed electrode. Quasineutral plasma containing energetic ions is expelled outwards to impart momentum to the vehicle omitting the requirement of neutralizers.

The CEPS is a novel ECR plasma source (patented by IIT Delhi) employing a unique magnetic field configuration created by a set of NdFeB ring magnets. This design promotes not only high density plasma production but offers very efficient electron heating leading to the development of plasma potential drop near CEPS exit which leads to ion acceleration suitable for thrusters. In order to determine the propulsive performance of CEPS, it was attached to a large expansion chamber. A series of experiments and theoretical modelling were performed at different operational parameters. Specially designed and in-house fabricated Langmuir probe

and ion energy analyzer were used to specify evolution of plasma parameters and assess the thrust attainable from CEPS.

LP measurements reveal high-density argon plasma ( $\approx 10^{12} \text{ cm}^{-3}$ ), with high bulk electron temperatures ( $\approx 20 \text{ eV}$ ) and plasma potentials ( $\approx 100 \text{ V}$ ) at very modest microwave power ( $\approx 600 \text{ W}$ ) over a wide range of pressures (0.3 to 1 mTorr). A potential step forms within CEPS near the exit and provides advantage as a means to accelerate the escaping ions. Energy analyzer reported the ion energies as high as 87 eV in-front of CEPS at 0.5 mTorr.

In order to effectively describe the plasma behaviour in expanding geometry, we developed a zero dimensional, 2-zone global model of the plasma flow, where zone-1 and zone-2 represent the CEPS and expansion chamber respectively. The model considers the balance of particle density, momentum and energy in the two zones and predicts the thrust attainable from the CEPS. The computed thrust under actual space-like conditions for xenon and argon are  $\approx 80 \text{ mN}$  and  $\approx 45 \text{ mN}$  respectively at 600 W of microwave power. It is shown that CEPS has the potential to be developed into a novel thruster technology.