Numerical simulation of a low-pressure electrodeless ion source intended for air-breathing electric propulsion

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Air Breathing Electric Propulsion (ABEP) systems offer a promising solution to extending the lifetime of Very Low Earth Orbit (VLEO) missions by using residual atmospheric particles as a propellant. Such systems would operate in very low-pressure environments where plasma ignition and confinement prove challenging. We employed advanced numerical simulations to explore the capability of our laboratory ion source in overcoming these challenges.

In this contribution, we present results of a Global Plasma Model (GPM) of a plasma burning in very low-pressure air mixture. The results are validated by experimental measurements acquired using a laboratory electrodeless ion source utilizing a resonator for plasma ignition. The device is specifically designed to operate within low-pressure environments as it holds potential applications in ABEP systems for Very Low Earth Orbit (VLEO) missions. Parametric studies were carried out via GPM to investigate the resonant behavior and its implications. The possibility of the model serving as a predictive tool is assessed through experimental validation against measured data, mainly the extracted ion current.

Parametric studies of resonant plasma are conducted using the GPM, which can describe plasma systems with complex physics and reaction kinetics. Since the GPM calculates volume-averaged quantities, it can serve as a fast and efficient tool for computing plasma properties. The numerical results are compared to experimental measurements while changing the operational pressure in the discharge chamber, input power and the external magnetic field. Our model includes a kinetic scheme, which contains over 600 reactions and processes. The model can replicate the resonant behavior with respect to varying magnetic field observed in the experimental data, as seen in the following figure:

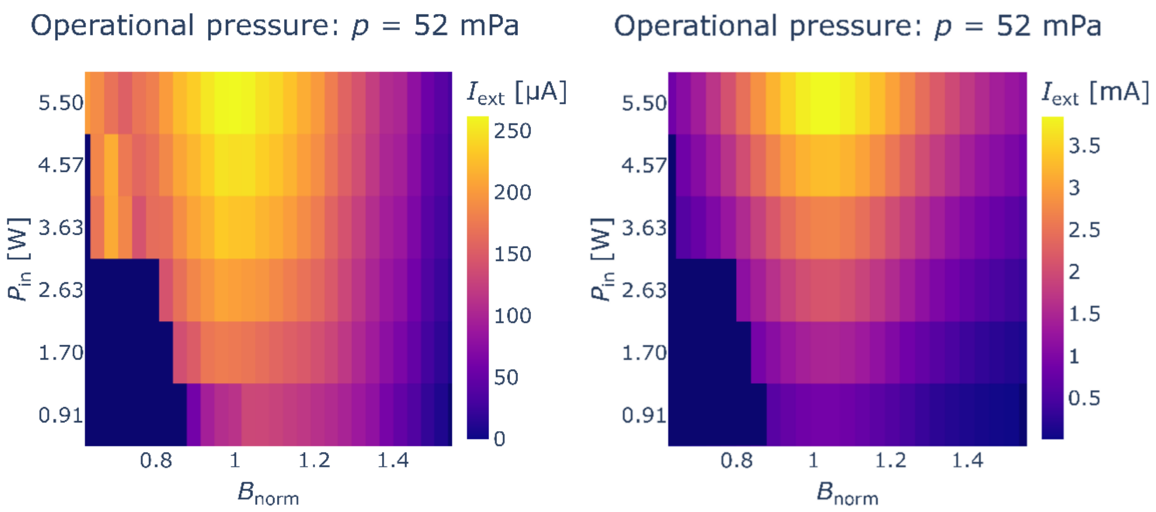

Fig. 1: Comparison between 2D graphs of extracted ion dependencies on normalized magnetic field (where $B_{\mathrm{norm}} = 1$ represents resonance) and input power.
(left: experimental results, right: GPM, $p = 52$ mPa).

The experimental values of extracted ion current differ from the predicted results by an order of magnitude, signaling potential for improvement. Using the GPM, we stand to better understand the underlying plasma processes and use this knowledge to improve the extraction efficiency of the device.

The verified model is further utilized in extrapolating additional information about the plasma such as ion composition, mean mass of ions or a degree of ionization.

The improved ion extraction in our prototype directly translates into producing larger thrust, which is imperative for VLEO operation due to significant drag. Deciding whether the thrust is net positive by direct comparison of the two variables should lead to better understanding the feasibility of the ABEP concept. Apart from further improving the device, our current research gravitates towards ensuring reliable thrust estimation as well as conducting additional plasma diagnostics.

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