Understanding Plasma Thruster Dynamics and Thrust Assessment Using Impedans Semion RFEA

Published in the Journal of Applied Physics

Reference
M. R. Inchingolo et al, J. Appl. Phys. 135, 093304 (2024)
https://doi.org/10.1063/5.0186778

Introduction

Impedans provides advance Retarding Field Ion Energy Analyser (RFEA) technology designed to precisely measure ion energy and flux in various plasma or ion beam applications. These diagnostic tools play a crucial role in offering invaluable insights and precise control over processes driven by ion dynamics, spanning from semiconductor manufacturing to space propulsion industries.

A recent publication in Journal of Applied Physics features the application of Impedans "Semion" RFEA system in the development of a prototype plasma thruster. The Semion measurements proved instrumental in characterizing the thruster plume, estimating the thrust and providing an alternative to direct thrust measurement devices.

Experimental setup

The Electron Cyclotron Resonance Thruster (ECRT) prototype operated with Xenon is shown in Fig. 1. This device consists of a cylindrical source immersed in a static, quasi-axial magnetic field. Microwave power at 5.8 GHz is transported through a waveguide into the plasma chamber. The retarding field energy analyzer (Impedance-Semion system) was used to assess the ion energy distribution function (IEDF), and ion mean energy, in the far plume. It was positioned at 350 mm in front of the thruster as shown in Fig 1.

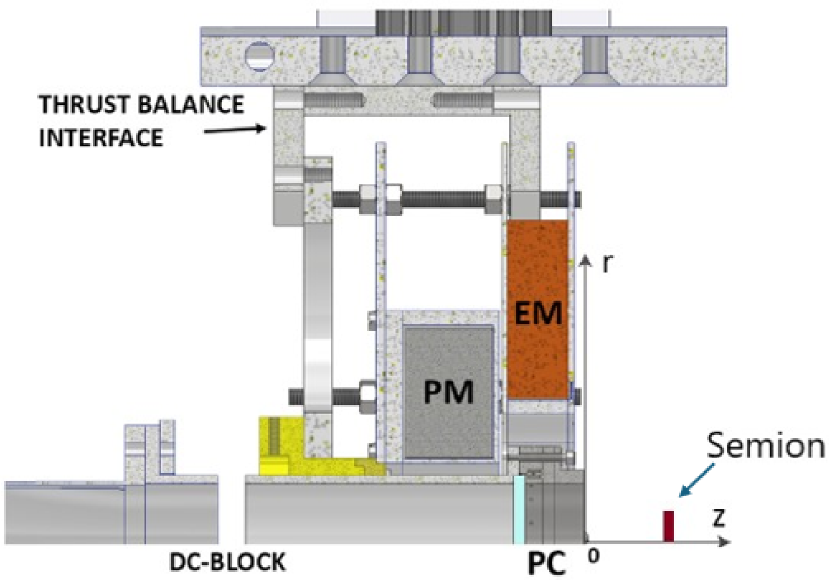

Figure 1 Cross section of the thruster assembly. PM stands for permanent magnet, EM for electromagnet, and PC for plasma chamber. Placement of Semion on axis is also shown.

Results

On axis RFEA scan were taken at different mass flow rates, power and azimuth angles for fixed axial position at 350 mm. The obtained IEDFs are shown in Fig. 2 for the three mass flow rates (2, 4 and 8 sccm) and power levels (80, 175 and 250 W). Analyzing at the shape of the IEDFs [panels (a)–(c)], the increase of power at constant mass flow induces a wider spread of the ion energies. Figure 2(d) shows the mean ion energy Ei for the different working points. Fig. 2(e) suggest that Ei barely depends on the azimuth angle.

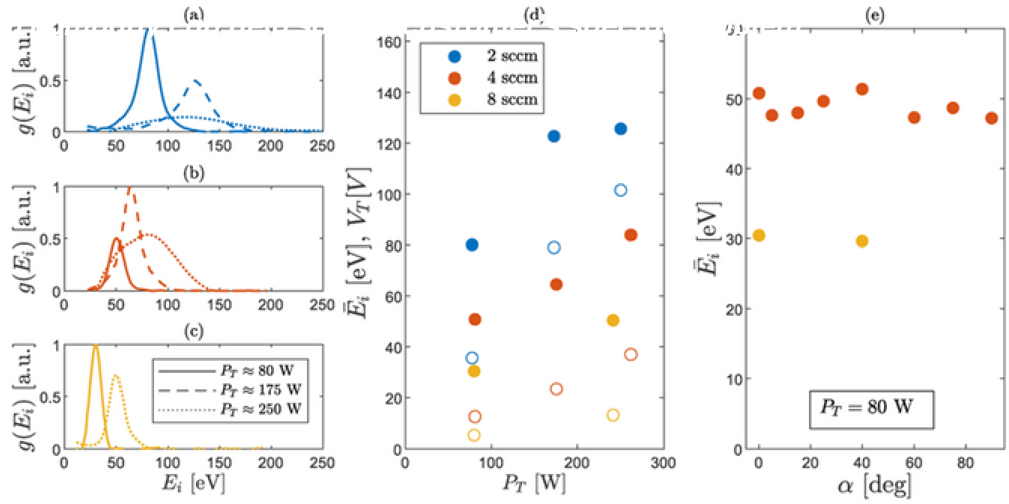

Figure 2 Retarding Field Energy analyzer measurements. (a)–(c) Ion energy distribution function (IEDF) for different mass flow rate 2, 4 and 8 sccm (blue, red, and yellow, respectively). Solid, dashed, dotted lines indicate 80, 175, and 250 W, respectively. (d) Mean ion energy Ei (filled dots) based on the IEDF results, and thruster floating potential VT (empty dots). (e) Mean ion energy Ei at different azimuth angles only for 4 and 8 sccm (red and yellow) at 80 W.

RFEA measurements also confirmed the presence of superthermal electrons (> 300 eV) in thruster plume. In the absence of electrons within the probe, negative collected currents (IC < 0) are representative of ion currents and should tend to zero as VG2 is increased and all the ions are repelled. Interestingly, for VG1 > - 300 V, and VG2 sufficiently large to repel all the ions, IC is positive as shown in Fig. 3(a) confirming the contribution from electrons. The performed test allows for estimating the amount of electron current reaching the collector depending on VG2. The electron to ion collected current ratio, Ie/Ii is provided in Fig. 3(b).

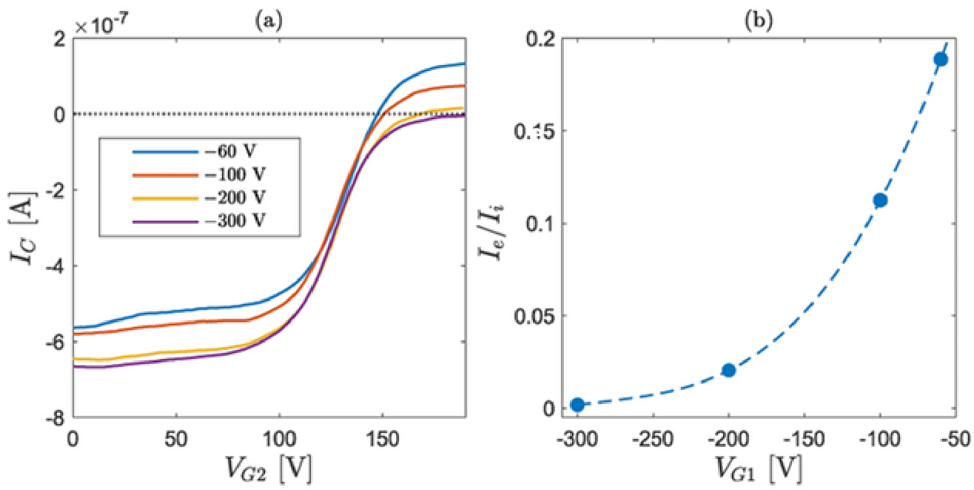

Figure 3 (a) RFEA characteristic IV curves at four different biases of the primary electron repelling grid G1 (60, 100, 200, 300 V). (b) Ratio of the electron to ion currents collected by the RFEA. (a) and (b) have been obtained for one single operating point, PT = 175 W and 2 SCCM flow rate. The RFEA settings for the rest of the grids and collector are: G0 is floating and used as a reference potential, VG2 =0–190 V, VG3 = VC -10 V and VC = VG1 V.

Summary

The RFEA-IEDF measurements provided insights into two important phenomena. Firstly, an increased dispersion of ion velocity with increasing power, indicating an expansion of the ionization region scaling with power. Secondly, the presence of an energetic electron tail in the plume up to 300 eV was identified. These plume measurements allowed for the indirect assessment of thrust including the contribution of ions and super thermal electrons, thereby reducing the disparity between the direct and indirect thrust estimations.

Thrust measurement in plasma thrusters can present challenges due to the unique nature of these propulsion systems. Plasma thrusters operate by ionizing gas and accelerating the resulting plasma using electric or magnetic fields to produce thrust is often a complex process. Impedans' Semion RFEA measurements enable indirect assessment of thrust generated by the plasma thruster. Semion offers insights into the underlying physics crucial for optimizing thruster design and enhancing its performance.

To know more about Impedans Semion RFEA *click here*