Abstract

PEGESAS is an ion-ion thruster concept developed at LPP for over ten years. The neutralization of the plume by alternate negative and positive ion extraction leads to a thruster design where no external neutralizer is required anymore. First 0D fluid models - or global models - of plasma thrusters were developed for DC ion thrusters operated with Xenon [1]. The model was extended to RF gridded thrusters including more complex molecular iodine chemistry [2]. Recently, neutral gas heating by ion acceleration in the sheath was added to the model, which has a very large influence on the neutral power balance.

Following the description of collisionless heating in inductively coupled RF plasma provided in [3], stochastic heating was also taken into account both through an effective collision frequency, and a heating term in the electron power balance. Refining the global model leads to a better predictability of the thruster efficiency. Both numerical PIC simulations and experiments are in progress to validate the analyses that were conducted here.

From conventional gridded thrusters... ...to the PEGASES thruster

Global model

Mean parameters of the plasma and global thruster performances are estimated by fast numerical solver.

- Particle balance for each species
- Gas heating
- Electron power balance

Neutral gas heating by ion acceleration in the sheath

A kinetic model was developed to simulate the iodine chemistry, including RF power injection, power loss to the walls, and grid extraction.

Stochastic heating in an inductively-coupled plasma

- Transverse electric field gradient in the skin depth of an inductive discharge
- RF perturbation of the electron velocity distribution function at small space scales induces collisionless heating
- Induced surface power flux depends on the skin depth $\delta$:

$$\frac{m_e}{e} \frac{E_{\text{skin}}^2}{\delta^2} \sim 2 \langle \alpha \rangle$$

- Equivalent collision frequency

$$\nu_{\text{equiv}} \approx \frac{C_e \langle \alpha \rangle n_e}{4 \pi}$$

- The skin depth accounting for collisionless heating was calculated iteratively
- Plasma resistance rises by a factor 3 due to stochastic heating

Neutral gas heating with $n_e (1.6 \times 10^{13} \, \text{m}^{-2})$ and $
u = 13.56 \, \text{MHz}$

2D PIC simulations

- 2D PIC code modified to run with any noble gas type propellant (Xe, He, Ar, Kr, I electropositive)
- 1D capacitively coupled discharge benchmark validated
- After validation by the global model, simplified iodine chemistry will be implemented in the code
- Magnetic barrier of PEGASES can be simulated with argon and iodine, for which many experiments were conducted.
- Complex geometry of acceleration grid will be implemented in the future

Future magnetised global model

Improvement of the global model to take into account electron confinement by the magnetic field.

- 3 regions:
  - RF heating
  - Electron attachment
  - Downstream extraction and acceleration
- Thermal fluxes connect the 3 regions together
- A longer effective distance for electrons in region
- An RF heating

PIC/GM connections

- Extended iodine chemistry
- Empirical modeling of the electron mobility in the magnetic barrier
- Code development
- Negative ions
- RF power injection

References