Cathode-less gridded ion thrusters for small satellites

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3 classes of Electric Propulsion systems

- Electrothermal thrusters
  - Energy source: (Sun)
  - Electrical energy
  - directed kinetic energy
  - Resistojet
  - Arcjet
  - Isp ~ 300 – 600 s

- Electromagnetic thrusters
  - Magneto Plasma Dynamic thrusters
  - Pulsed Plasma thruster
  - Isp ~ 800 – 1200 s

- Electrostatic thrusters
  - Gridded Ion thrusters
  - Hall thrusters
  - Isp ~ 1500 – 4000 s

- Energy source
- Electrical energy
- Directed kinetic energy

- F=JxB
- F=qE
Out of 1168 active satellites, 236 runs with EP systems

Data from Aerojet Rocketdyne (IEPC-2013-439)
Miniaturization possibilities

**Electrothermal thrusters**
- Heater
- Expansion
- Gas

**Electromagnetic thrusters**
- Anode
- B
- Arc current
- F=JxB
- Cathode
- Gas
- Plasma
- Anode

**Electrostatic thrusters**
- Neutralizer
- e⁻
- Xe⁺
- F=qE
- Gas
- Plasma
- Grids

Cold gas thrusters
Never used in space and systems with magnetic fields are difficult to downscale
Electrospray thrusters
Gridded ion thrusters
Hall thrusters
Miniaturization of gridded ion thrusters

Solar arrays

Xe propellant storage

Power Unit (PPU)

Flow Control Unit (XFU)

Gas discharge

Acceleration

Neutralizer

Electrostatic thrusters

F = qE

Gas

Neutralizer

Plasma

Xe+

Grids
Miniaturization of gridded ion thrusters

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Power Unit (PPU)

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Gas discharge

Acceleration

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Electrostatic thrusters

Gas

Neutralizer

B

Plasma

Xe+

F=qE

Grids

Initiate the discharge is difficult

\[ \lambda_{iz} = \frac{1}{n_g \sigma_{iz}} \]

Efficiency decreases by more electron losses to the walls
Miniaturization of gridded ion thrusters

**Solar arrays** → **Power Unit (PPU)** → **Flow Control Unit (XFU)** → **Gas discharge** → **Acceleration** → **Neutralizer**

**Electrostatic thrusters**

Initiate the discharge is difficult

\[ \lambda_{iz} = \frac{1}{n_g \sigma_{iz}} \]

Efficiency decreases by more electron losses to the walls

Grid separation scales inversely with applied acceleration voltage
Miniaturization of gridded ion thrusters

**Solar arrays** → **Power Unit (PPU)** → **Flow Control Unit (XFU)** → **Neutralizer** → **Gas discharge** → **Acceleration** → **Electrostatic thrusters**

**Initiate the discharge** is difficult \[ \lambda_{iz} = \frac{1}{n_g \sigma_{iz}} \]

**Efficiency** decreases by more electron losses to the walls

**Grid separation** scales inversely with applied acceleration voltage

**Neutralizer** cannot easily be downscaled
The NEPTUNE thruster
A new promising thruster with strong technology heritage

One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

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One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

C = ε₀A/d such that C₁ > C₂ and V₁ << V₂
Blocking capacitor C_B charges up to ensure that I_e = I_i

Rectification of the applied RF voltage

One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

Rectification of the applied RF voltage

One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

RF source (ICP)

RF biased grid

Blocking capacitor

RF

A^+

e

RF bias rectification to a DC bias

\( V_{DC} \approx 0.80 \ V_{RF} \)

Rectification of the applied RF voltage

One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

The space charge limited current is:

\[ J_{CL} = \xi \left( \frac{2e}{M} \right)^{1/2} \frac{V^{3/2}}{d^2} \]

\[ \xi_{DC} = \frac{4}{9} = 0.44 \quad \xi_{RF} = \frac{200}{243} = 0.82 \]

Rectification of the applied RF voltage

One Radio-Frequency power source for plasma generation, ion acceleration and electron neutralization

RF bias rectification to a DC bias

High ion energies and low anisotropic electron energies

The NEPTUNE thruster is promising for miniaturization

Advantages:
• No additional cathode
• PPU simplified – only one RF power supply
• Propellant flexibility
• Scaling flexibility
• Beam current can be x2 the one for a DC system
• Emitted net charge is always zero
Thank you for your attention

This work was supported by a Marie Curie International Incoming Fellowships within the 7th European Community Framework.
The PEGASES thruster promising for miniaturization?

Plasma Propulsion with Electronegative Gases - Accelerates positive and negative ions to generate thrust

Advantages:
• No additional cathode
• Plume with almost no electrons
• Control of the emitted net charge
• Solid propellant (Iodine)

Disadvantages:
• Need magnetic fields
• Need square voltage waveforms
• Electronegative gases are chemically reactive

PEGASES state-of-the-art

Proof-of-concept combining experiments, simulations and analytical models

High density ion-ion plasma

Alternate ± ion beams

Generalized CL law for alternate acceleration

Full space charge compensation in the beam