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ENERGY DEPOSITION ON THE INNER SURFACES OF A HALL EFFECT THRUSTER FOR SATELLITE

Hall effect thrusters are used for space propulsion. The energy deposition on the inner surfaces of Hall effect thruster is analysed. Using a PIC MC 1D-3V model, the ion and electron exchanges of energy by bombardments are estimated in presence of a potential sheath near the surfaces and an electron secondary emission. Morever, simple expressions are deduced from the classic theory of non collisional potential sheath but without electron secondary emssion. A 3D ray-tracing method to determine the radiation energy deposition on the wall from visible and VUV optical ranges is presented.

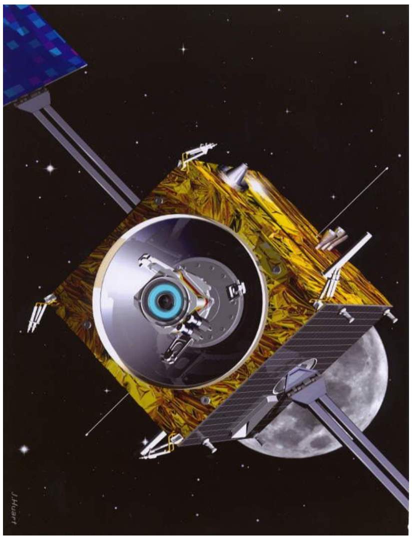
Key words: *satellite, propulsion, Hall effect thrusters, plasma propulsion.*

Introduction

The analysis of the thermal behaviour of the inner surfaces of a Hall effect thruster is performed with different approaches. A PIC-MC model is developed for the energy deposition from electron and ion and a tracing-ray method is proposed for the prediction of the spectral-dependent radiative fluxes impacting the surfaces. These two analyses are under development. First results are presented.

1. Hall Effect Thrusters (HET)

A Hall effect thruster HET is a electric thruster. The propellant is ionized by electron emitted by an external cathode and trapped by an external and radial magnetic field. Only electrons are magnetized and a quasi axial electric field is generated by the fall of electron mobility in the region of the chamber where the magnetic field is maximum. The HET is characterized by a E x B sustained plasma discharge. The propellant (Xenon) is injected through the bottom of the chamber and the ions (Xe^+) are extracted by the electric field. In presence of the crossed ExB field, the electrons present an azimuthal drift velocity. HET delivers a high specific impulse due to the velocity of the ions (15-20km/s) and then allows a minimization of the propellant consumption, but the level of thrust is not very large and the time required for the change of orbit is long. The performances as specific impulse (around 1800s) are well adapted to maintain the satellites in geostationary orbits and also in future for interplanetary missions.



ESA Crédit

Fig. 1. Smart-1 ESA mission with a PPS1350-G (Snecma - Safran Group)

SMART 1 was successfully sent to a Lunar orbit (Sept.2003-Nov.2004) thanks to a PPS1350G (T=88mN, Isp=1650s) from Snecma-Safran Group, France) with a propellant (Xenon) consumption of only 80kg.

2. Ion and electron energy deposition (PIC-MC model)

The energy deposition at the probe surface was studied in a system with cylindrical symmetry, related to an infinitely long cylindrical probe, $2r_p$ in diameter, immersed in a continuum, electro-positive plasma [6]. For the sake of simplification, the whole plasma volume is separated into two different zones: Sheath-Pre-Sheath (SPS) zone and a ring-shaped volume around it (referred to hereafter as plasma bulk zone) – see Fig.2. The motion of charged particles in both zones is described by the MC trajectories.

The concentration of charged particles in the plasma bulk zone is kept constant by assuming that the particles reflect specularly at the boundaries i.e. at the boundary with the SPS zone and at an external boundary given by r_b (radius of plasma bulk zone). Maxwell distributions were generally assumed as the initial conditions, but other distributions may be easily introduced as well. As the simulations continue, the charged particle distribution changes drastically. Initially, the charged particles are uniformly distributed in the whole considered space, i.e. plasma bulk and SPS zones. Later, the charged particle densities begin to decay in the close vicinity of the probe, due to the constant flux towards the probe and absorption (followed by recombination) or secondary electron emission (see next chapter) on the probe surface. On the other hand, there is a continuous thermal influx of charged particles from the plasma bulk zone to the SPS zone. This flux is simulated by the creation of a particle entering the SPS zone, with the same velocity as the particle from the plasma bulk zone which was reflected from the border with the SPS zone. When a particle is crossing the same boundary but from the SPS side, it is removed from the simulation.

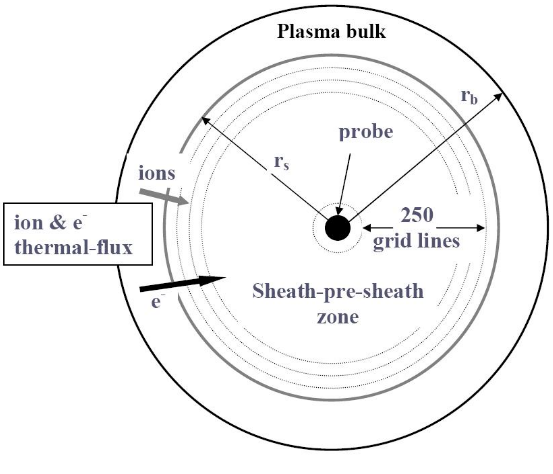


Fig. 2. Scheme of the considered zones in the PIC-MC model; 250 radial grid lines are presented by dotted circles

Hence, the charged particles are specularly reflected at the $r = r_b$ boundary in the bulk plasma zone. Whenever a particle from the bulk plasma zone approaches the $r = r_s$ boundary it is specularly reflected back to the zone but the twin-particle continues also itsmovement in the SPS zone i.e. an additional particle is generated in that zone. The particles are neglected when approaching the $r = r_s$ boundary from the SPS side. The described procedure makes it possible to keep the charged particle density (ionization degree) in the plasma bulk zone constant, and it also enables us to determine the thermal flux from the plasma bulk to the SPS zone.

The charged-particle MC trajectories in the SPS zone are determined by the Newtonian equations for particles motion in electric and magnetic fields. It is possible to take into account both the axial-field of the DC plasma column (if such exist) as well as the radial field generated by the probe-bias and the space-charge density (through the Poisson equation evaluated in 250 grid points) – see Fig. 1. The potential is derived from the integral form of Poisson equation:

$$E_i \cdot S_i = 4\pi \sum\nolimits_{n=1,i} [Q_{+n} - Q_{-n}], \qquad (1)$$

where E_n - the radial field value at the n-th grid point,

$S_n = 2\pi r_n l$ - the surface of the n-th grid element of radius r_n;

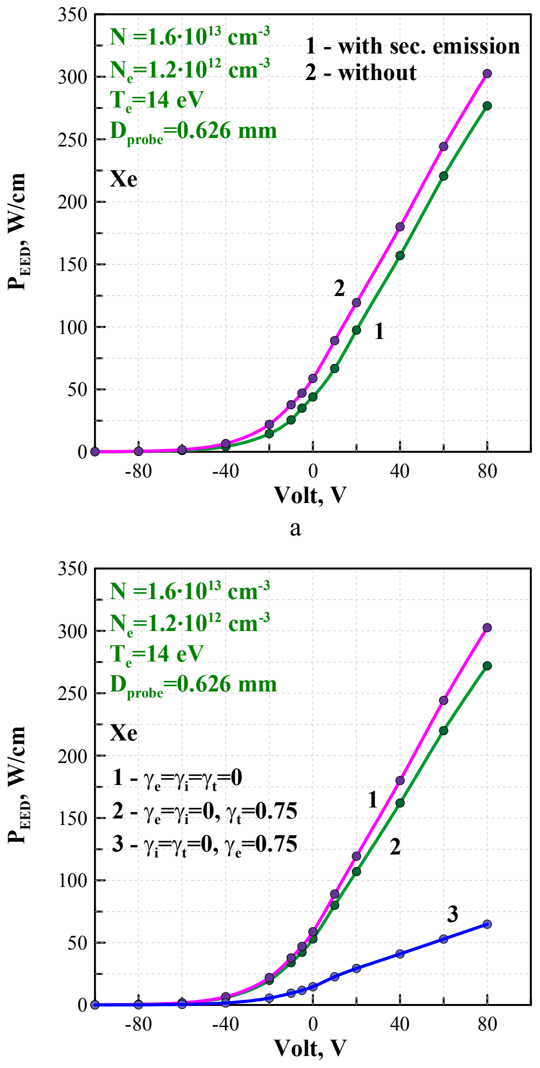
Q_{+n} (Q_{-n}) - the ion (electron) charge accumulated in the n-th grid element.

It should be noted that the surface S_n the charges Q_{+n} and Q_{-n} as well as other extensive quantities are calculated per unit length in the model.

The electrons on their way to the probe take part in different collision processes with the Xe atoms. Cross section for the elastic collisions are from Hayashi [3], for the excitation processes from Sydorenko [2] and for the step ionization from Phelps [4]. The electron-electron collision processes are ignored. The process of secondary electron emission was described using the general phenomenological model of SEE described by Sydorenko [2].

In this work an energy deposition at the probe surface immersed in the Xe plasma of the ion thruster under conditions described in [5] and the effect of various secondary electron emission (SEE) is investigated (see also [6]). Figure 2 presents the power deposited per probe length of 1 cm, with various (elastic, true and total) and without SEE processes. One sees that SEE processes lead to decrease of energy deposition. The elastic processes are more efficient in the power reduction.

The axial magnetic field also leads to substantial reduction of deposited power – see Fig.4. Electrons deflected on their route to the probe collide with its surface significantly less frequently. This research will be extended for an analysis of the plasma energy deposition on the insulated walls of the channel of Hall thrusters.



a

b

Fig. 3. Electron energy deposition on probe surface (a) with (for surface covered by boron nitride ceramics) and without secondary electron emission; (b) for elastic and true SEE processes

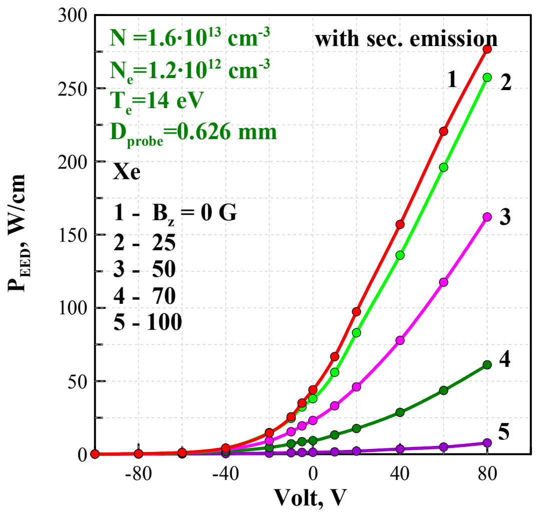


Fig. 4. Influence of axial magnetic field on electron energy deposition on probe surface

2. Ion and electron energy deposition (Langmuir model)

A simple model of energy deposition on the inner surfaces of a HET is based on a non collisionnal potential sheath and a Mawellian distribution of the charged particles (electrons and ions). No secondary electron emission by electron impact and complete neutralizations of electrons and ions at the surface are assumed. Morever and in order to simplify the description, a plane surface and a uniform plasma (out of the sheath) is considered. Then, the energy deposition by unit of surface and time of a charged particles j is expressed as:

$$\phi_j = \int_{v_x}\int_{v_y}\int_{v_z} v_z \frac{1}{2} m_j v^2 f(v_w)\, dv_x dv_y dv_z, \quad (2)$$

with $v^2 = v_x^2 + v_y^2 + v_z^2$, v_x, v_y are varying from $-\infty$ to $+\infty$ and v_z from a minimum value which is function of the electric charge of j, potential of the surface and plasma potential. The z axis is normal to the surface. A two temperatures model is assumed (T_e,T). For a positive surface potential, the energy deposition ϕ_e from electrons is:

$$\phi_e = \frac{1}{2\pi^2} n_{e0} m_e \left(\frac{2\pi k T_e}{m_e}\right)^{3/2} \left(\frac{e\Phi}{2kT_e} + 1\right), \quad (3)$$

and for a negative surface potential:

$$\phi_e = \frac{1}{2\pi^2} n_{e0} m_e \left(\frac{2\pi k T_e}{m_e}\right)^{3/2} e^{\frac{e\Phi}{kT_e}}, \quad (4)$$

Φ is the difference between the potential of the surface and the plasma potential. This energy deposition has been calculated with n_{e0} (plasma density outside the plasma sheath) from [7].

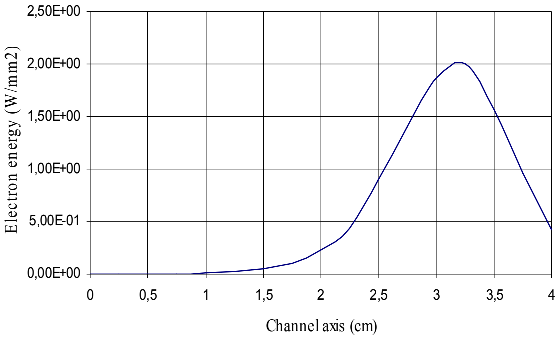


Fig. 5. Energy deposition from electrons along the channel axis

3. Radiative fluxes

Electronic levels and transitions for neutral Xe and ionized XeII (NIST atomic spectra database) have been introduced in the line-by-line code SPARTAN (IST

Lisbonne). This code allows the calculation of radiative properties of Xe in thermal non equilibrium at low-pressure and high temperatures assuming in a first step a Boltzmann distribution at a characteristic temperature. The spectra is calculated (see Fig.6 with an apparatus function of 10 Å for a better visualization of the spectrum lines) using the plasma parameters at the channel exit of a PPS100-ML HET (n_n = 5.5 x 10^{12} cm^{-3}, n_i = = 2.8 x 10^{11} cm^{-3}, T_e = 11.5eV [7]). The neutral xenon is mainly in the VUV range (1000-2000Å) with a line at 7200 Å (near-IR range). However, there is today a lack of data for a part of the VUV range. The Xe^+ emission is mostly in the visible region (4000-7000 Å).

Radiative transfer towards the inner walls is treated according to the ray-tracing approach taking into account the symmetry over the zenithal angle of the annular channel of the thrusters. The length of each ray is calculated and for each ray path the equation for radiative transfer is solved with emission and absorption in the plasma discharge.

The figure 7 presents the rays (3D) impacting a point in the external channel wall.

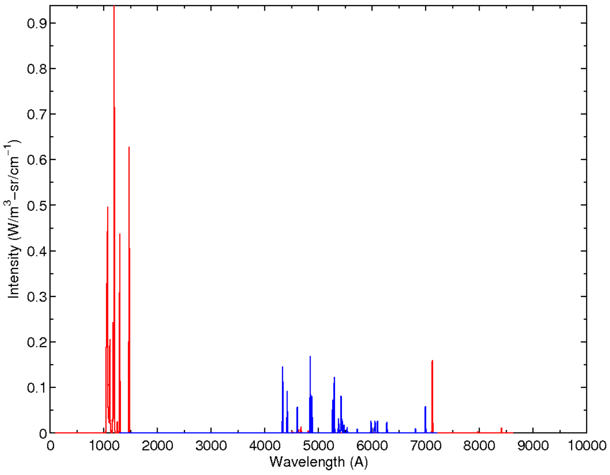


Fig. 6. Spectra from neutral Xenon (red) and ionized Xenon (blue) at the exit of a PPS100–ML

The ray tracing method has been used to determine the energy deposition on the inner surface in first using the assumption of a Boltzmann distribution [8]. The flux of energy will be calculated without this assumption of equilibrium.

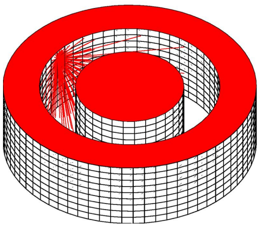


Fig. 7. 3D representation of the rays impacting a point at the external HET channel wall

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Conclusion

It was shown that the discussed PIC MC model described in Ref. 1 and verified using measured IV characteristics of Langmuir probe immersed in the well described plasma can be applied to study plasma under conditions close to that in ion thrusters. It was found that SEE processes lead to decrease of energy deposition. The elastic processes are more efficient in the power reduction. It was observed that the axial magnetic field influences probe characteristics and power deposition more significantly than radial field. The axial field deflects all electrons approaching probe and leads to substantial reduction of deposited power.

Ray tracing method is a powerful method for the determination of the radiative flux on surfaces. It will be used for the calculation of the flux of energy on the inner surfaces in VUV-visible optical range using a 3D method and non equilibrium conditions.

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ЭНЕРГЕТИЧЕСКОЕ ВОЗДЕЙСТВИЕ НА ВНУТРЕННИЕ ПОВЕРХНОСТИ ХОЛЛОВСКОГО УСКОРИТЕЛЯ

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Двигатели, принцип работы которых основан на эффекте Холла, используются в качестве двигательных установок для космических аппаратов. В работе анализируется выделение энергии на внутренние поверхности Холловского ускорителя. Используя метод крупных частиц (модель 1D-3В), моделируется взаимодействие электронов и ионов с учетом вторичной электронной эмиссии в пристеночных границах. Для определения распределения радиационной энергии в видимом и ультрафиолетовом оптических спектрах на стенки ускорителя использовался метод 3D-трассировки лучей.

Ключевые слова: спутник, двигательная установка, Холловский ускоритель, плазма.

ЕНЕРГЕТИЧНИЙ ВПЛИВ НА ВНУТРІШНІ ПОВЕРХНІ ХОЛЛОВСЬКОГО ПРИСКОРЮВАЧА

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Двигуни, принцип роботи яких заснований на ефекті Холла ,використовуються як рухові установки для космічних апаратів. У роботі аналізується виділення енергії на внутрішні поверхні Холловського прискорювача. Використовуючи метод великих частинок (модель 1D-3В), моделюється взаємодія електронів та іонів з урахуванням вторинної електронної емісії в пристінкових кордонах. Для визначення розподілу радіаційної енергії у видимому й ультрафіолетовому оптичних спектрах на стінки прискорювача використовувався метод 3D-трасування променів.

Ключові слова: супутник, рухова установка, Холловський прискорювач, плазма.

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