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# Plasma-materials interactions in spacecraft propulsion
# 宇宙機用プラズマ推進機におけるプラズマ-壁相互作用

Naoji Yamamoto
山本直嗣

*Kyushu University*
*6-1, Kasugakoen, Kasuga,Fukuoka, 816-8580, Japan*
九州大学　〒816－8580　福岡県春日市春日公園6-1

To understand interactions between plasma and the wall is important for space application, especially advanced propulsion system, electric propulsions. For example, the lifetime of the ion engines and Hall thrusters is limited by the erosion of the wall by the ion sputtering. The thrust performance in Hall thruster depends on the wall materials, that is, the plasma parameters were changed by the wall characteristics.

## 1. Introduction

This paper shows examples of the Plasma-materials interactions in spacecraft application. We focus on the topics in thermal protection system and electric propulsion, especially Hall thrusters and ion thrusters.

## 2. Thermal Protection System

When the space vehicle enter the earth from the space, the shock layer appears and rare atmosphere in the shock layer is dissociated and ionized and be weakly ionized plasma. From the shock layer, huge heat flux enter the space vehicle as convective, catalytic and radiative heat flux. The thermal protection system (TPS) is crucial technique at re-entry to the earth against severe aerodynamic heating [1-3]. For example, the re-entry speed of HAYABUSA mission is about 12 km/s, the estimated heat flux was 15 MW/m$^2$ for 30 seconds.

For the heat protection, several materials, ceramic tiles, C/C (Carbon/Carbon composite) materials CFRP ablative materials, etc., were used.

C/C materials can keep sufficient stiffness at high temperature, therefore, they apply structural parts. Ceramic tiles have features of low density and low thermal conductivity, they were adopted as a thermal insulator.

Ablative materials are used as a functional material. The principle is as follows [4]. If the temperature of the ablator increase due to the aerodynamic heating, pyrolysis reaction occurs in the resin of the ablator, a pyrolysis gas is generated and the resin is carbonized. The carbonized resin forms char layer and the gas goes through the layer. The pyrolysis gas brow to the hot shock layer gas and reduced the heat flux from the shock layer as convective heat flux. In addition the pyrolysis gas absorb heat from the char having passing through the char and cool down the vehicle. At Hayabusa mission, they used Tilt-layered and Lattice Layered carbon phenolic was used for the protection of the capsule.

## 3. Hall Thruster

Hall thrusters [5] are a class of electric propulsion device in which a propellant gas is ionized and accelerated to produce thrust. Hall thrusters show considerable promise for satellite station keeping and orbit transfer applications[6,7] since they offer an attractive combination of high thrust efficiency, exceeding 50%, with a specific impulse range of 1,000-3,000 s and a higher ion beam density than ion thrusters, due to the existence of electrons in the ion acceleration zone. This is because a moderate magnetic field is applied in the acceleration zone, causing the magnetization of the electrons and not the ions [8]. Several types of Hall thrusters are available, but they can be categorized into two general groups; the magnetic layer type and the anode layer type[9,10]. One example of the former type is the Russian “Stationary Plasma Thruster” (SPT). It has a ceramic wall and its acceleration channel length is longer than its channel width.

In the Hall thruster, the interactions between plasma and the acceleration channel wall were observed. One of the interesting interaction is concerned with the secondary electron emission effect of dielectric wall.

The thrust performance of the thruster depends on the wall material [11], and this dependency is due to the difference in the secondary electron emission coefficient. The increase in secondary electron emitted from the wall reduce the potential drops on the wall and the temperature in the thruster. The SEE coefficient has positive interaction with electron temperature[12], therefore, the wall keep the adequate electron temperature in the Hall thruster and the moderate potential drop on the wall and this contributes the adequate ion acceleration, that is high efficiency and long lifetime of the Hall thruster. Indeed, the thrust performance using low SEE coefficient ceramic wall, e. g., BN/ ALN is worse than that using high SEE coefficient BN.

This is one of the example of self-functional appearance by the plasma-materials interactions in a spacecraft propulsion.

It is interesting that the secondary electron emission leads to anomalous electron diffusion across the magnetic field, so-called near wall conductivity, and degrade the thrust performance, so the adequate SEE material, (BN/SiO2 or BN ceramic) is used as a wall material in Hall thrusters.

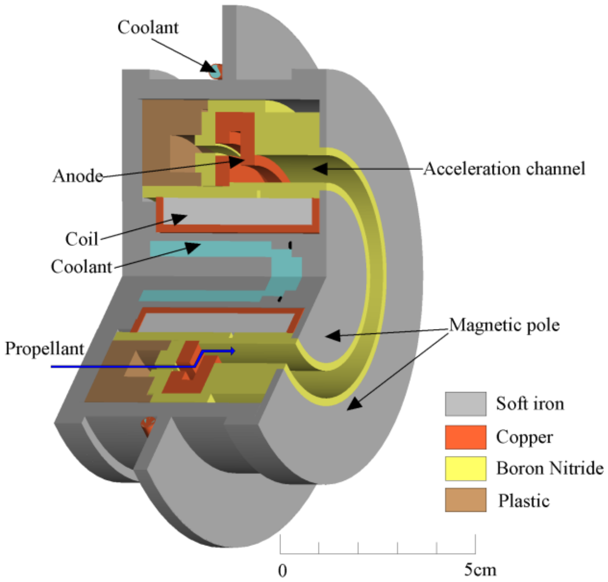


Fig.1. Cross-sectional view of a Hall thruster

## 4. Ion Engine

An ion engine works by pushing ions away from the spacecraft [13]. Ions in the discharge chamber plasma accelerates to 30,000-50,000 m/s(normal ion engine) by the strong electric field Ion thrusters show high energy transfer efficiency, exceeding 70%, with good specific propellant consumption. Therefore, ion thrusters have already been used extensively in space missions, such as Deep Space 1[14], HAYABUSA[15], and other missions[16].

A Neutralizer is one of the key component of ion engine, it emits electrons for neutralization. Lifetime limiter of the ion engine is lifetime of neutralizer, and the sputtered wall material deposition on the insulator would degrade the neutralizer performance. The reason why molybdenum wall was sputtered by the ions, though the potential drop on the wall is almost 20-30 V, had been unknown. However, several study [17,18] reveal that the double ionized ions would play an important role. And in Hayabusa 2, there are improved neutralizers and they will show the good performance.

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