4th Asia-Pacific Conference on Plasma Physics, 26-31Oct, 2020, Remote e-conference

Direct measurement of a thrust induced by sputtered materials in magnetron-type plasma sources

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Electric propulsion is one of the important technologies for space missions by spacecrafts and artificial satellites. These days, small satellites called CubeSat packed in about 10x10x10 cm^3 cubic unit have attracted much attention. When the space mission is accomplished, the small satellites have to be removed from the Earth orbit, inhibiting the increase in Earth orbit. The increasing number of space debris has been recognized as a serious problem, because they collide with other spacecrafts and break them. Therefore development of a compact electric propulsion device mountable on the small satellite is required to prevent them from getting space debris and to maintain the sustainable space activities. It would be useful to eliminate a high-pressure gas tank for the propellant storage, yielding the compact system. An ion gridded thruster operated with water propellant has been proposed and under development [1]. Here a new concept of the compact electric propulsion device using a metallic propellant is proposed, where the thrust is generated by mass ejection due to sputtering of a metallic material. This experiment is preliminarily performed with argon gas for plasma production and the thrust imparted by sputtering of target material is demonstrated.

"Sputtering" is a phenomenon that occurs when ions in plasmas impinge target surface. The ions give their momentum to target material and the metallic particles are released from the target surface with a certain kinetic energy. As the thrust is equivalent to the momentum flux exhausted from the system, the ejection of the sputtered material is expected to contribute to the thrust generation. A well-known magnetron sputtering system is chosen here for the sputtering system since the high density plasma is confined. Since the charged particles are confined by the magnetic field lines terminating the target surface in the magnetron source, it is expected that the plasma itself has only small contribution to the thrust generation. Furthermore, two different power supplies are tested in the present experiment; being the Direct Current Magnetron Sputtering (DCMS) and High Power Impulse Magnetron Sputtering (HiPIMS). Since the HiPIMS can supply a high power in a few tens of microsecond, a current magnitude in the HiPIMS is typically about 500 times greater than that in the DCMS. When the HiPIMS is used, sputtering of the target by the ionized target material often occurs, which is called as "self sputtering"[2].

The magnetron sputtering source shown in Fig.1(a) is attached to a pendulum thrust balance installed in a 26-cm diameter and 73-cm long vacuum chamber evacuated by a turbo-molecular pumping system. The thrust balance consists of two flexible plates suspended from the top side of the chamber; this structure enables the plasma source to move axially with a pendulum motion[3]. A displacement induced by the plasma production and sputtering is measured by using a commercial displacement sensor. By taking a calibration coefficient relating the displacement to the force before pumping down the chamber, the absolute value of the thrust can be obtained.

The thrust obtained with a copper target and a DC power supply is about 400-600 μN for the discharge power of 40-60 W as shown in Fig.1(b), while the thrust is undetectable for a carbon target even for the similar discharge power (not shown here). Under the same conditions with the HiPIMS, the obtained thrust is about 200-300 μN. The thrust reduction for HiPIMS can be attributed to self sputtering. Since the sputtered particles are ionized and are accelerated to the target in the self-sputtering process, the exhausted particles decrease. These results demonstrate that the thrust generation by the mass ejection accompanying with the sputtering. The detailed discussion will be shown in the presentation.

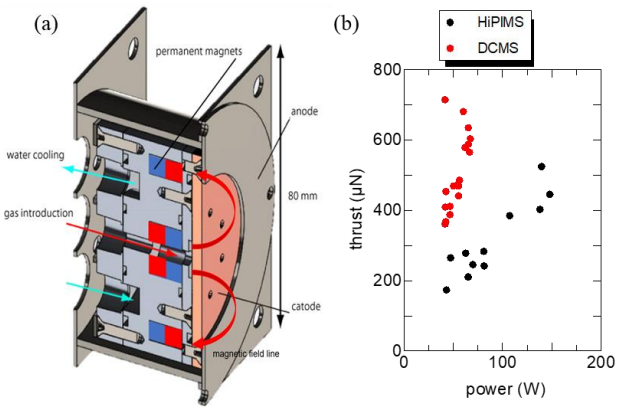

Fig.1(a) Schematic diagram of the magnetron sputtering source.(b) Measured thrust with a Cu target for the DCMS (red dots) and the HiPIMS (black dots).

References

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[2]Andre Andres,*Journal of Appl Phys.,* **121**, 171101 (2017)
[3] K.Takahashi, *Rev. Mod. Plasma Phys.,* **3**,3 (2019).