Operating a magnetron sputtering electric propulsion device with a pulsed gaseous water propellant

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The number of small satellites represented by CubeSats has significantly increased in the last few decades. The key technology to success missions using small satellites is realization of a small electric propulsion system (EP) for their attitude and orbit control, de-orbit, and so on [1]. Many types of small EP devices have been investigated in industrial and scientific fields, being represented by pulsed plasma thrusters, gridded ion thrusters, vacuum arc thrusters, and so on [2-4]. They have a common technical challenge for their size and power limitation (~ a few tens of watts).

Magnetron sputtering has been widely used in semiconductor manufacturing. Applications of gasless or bipolar-voltage-applied magnetron sources to EP have been proposed [5]. A recent study with a dc magnetron sputtering (DCMS) has demonstrated the thrust generation by exhausting the metallic target material, where the argon gas is fueled to sustain the discharge. As the sputtered and exhausted particles are electrically neutral, a neutralizer-free EP system can be achieved [6]. When operating with high power impulse magnetron sputtering (HiPIMS), the thrust decreases because ionized sputtered atoms go back to the cathode and are not ejected from the system, which is a phenomenon called self-sputtering [7]. Furthermore, a water-fueled magnetron sputtering source has also demonstrated the thrust generation [8]. While the thrust in the water-fueled operation is lower than that for an argon-fueled source due to the power consumption for dissociation of water molecules, it does not require a high-pressure gas tank for propellant storage and would meet the criterion for compact EP. Various kinds of liquid and solid propellants have been investigated owing to their advantages in developing a compact thrust system. In addition, water is one of the most suitable propellants in terms of its safety, abundance, and the ease of use [9].

A propellant gas feeding system, which requires smaller size besides accurate control of mass flow rate, also plays an important role in a small EP device. In the authors' previous study, water-propellant is introduced by a mass flow controller constantly [8]. In the present study, to minimize the size of the gas feeding system, a mass flow controller is substituted by a pulsed valve, and the quantity of the introduced propellant gas is controlled by a pulse width of the gas valve as shown in Fig.1. A previously reported target technique is used to assess the impulse bit [10].

A constant dc voltage (500-1000 V) is supplied between the anode and cathode through a resistor of 1 kΩ. When the water vapor is introduced to the plasma source, a ring-shaped plasma is produced. The pulsed valve is opened

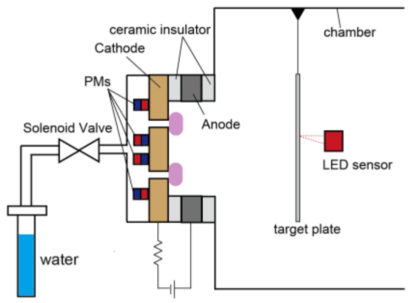

Fig.1 Schematic diagram of experimental setup.

for 5-15 msec and the discharge is sustained for 100-500 msec, which depends on the supply voltage at 500-1000 V. The target measurement shows the maximum impulse bit of 0.1 mN·s, where the impulse bit due to the rare water propellant is eliminated. The thrust-to-power ratio is roughly corresponded to that for mass flow controller operation.

A change in the discharge impedance, i.e., the discharge mode, is observed during the discharge pulse. To investigate the effect of the mode change on the thrust generation, a temporally resolved measurement of the impulse bit is performed. The result shows that the linear correlation between the impulse bit and the discharge power is confirmed. The detailed discharge characteristics, the measurement technique, and the assessed impulse bit will be presented.

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