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Evaluation Method of Hall Thruster's Lifetime by Using Multilayer Coating[†]

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KEY WORDS: (Hall Thruster) (Lifetime Evaluation) (Multilayer Coating) (Sputtering)

1. Introduction

A Hall thruster is one of the most promising propulsion devices in near-Earth missions for high thrust efficiency and high specific impulse. To achieve the missions, it requires a long lifetime of approximately 10,000 hours^{1, 2)} because of its low thrust which is common to electric propulsion thrusters. A primary lifetime-limiting mechanism is that the channel walls are eroded by ion bombardment inside the ion acceleration zone. In order to improve the lifetime performance of Hall thrusters, the development of an estimation method of its lifetime is very important. Although the lifetime has been measured in various ways^{1, 3, 4)}, there are not real-time, low-cost and accurate measurement methods.

In this study, a new evaluation method of the Hall thruster's lifetime by using a multilayer coating was proposed and its usefulness was examined by setting multilayer coating test plates in the plume from the Hall thruster.

2. Experimental

2.1 Hall thruster

A magnetic layer type Hall thruster developed in the University of Tokyo was used in this experiment. The inner diameter, outer diameter and length of an acceleration channel were 48 mm, 62 mm and 21 mm, respectively. Xenon gas was used as a propellant. The thruster was operated at typical conditions: discharge voltage and current, magnetic flux density and xenon mass flow rate were respectively 200 V, 1.8 A, 14 mT and 1.36 mg/sec. During the operation, the chamber pressure was maintained at 1.2×10^{-2} Pa.

2.2 Principle

Figure 1 shows the principle of lifetime measurement method by using the multilayer coating. A channel wall surface is coated with metal and with

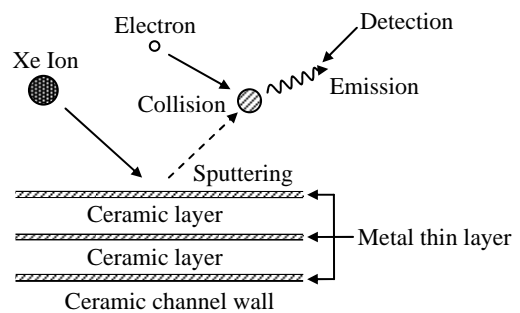


Fig.1 Lifetime evaluation method by using a multilayer coating.

ceramic alternately. Metal layers are the marker to measure the erosion rate of ceramic layers. Metal erosion is detected by emission spectroscopy. Metal layers must be thin enough to produce a sharp emission signal. The erosion rate is estimated from the interval time of periodic metal emissions. The fluctuation of the emission intensity has no influence on the accuracy in this method.

2.3 Multilayer coating

Silver (Ag) was selected as the metal layer material because of its availability and high sputtering yield. In addition, Ag is not used in the components of the thruster. Boron nitride (BN), which is the typical channel wall material of Hall thrusters, was selected as the ceramic layer material.

Four Ag layers and three BN layers were alternately deposited on an aluminum substrate of dimension 30mm×50mm×0.5mm. The Ag and BN layer thicknesses were respectively 20 nm and 300 nm, except that the bottom Ag layer thickness was 200 nm. An ion beam sputtering coating device was used. Argon was used as the working gas. Argon mass flow rate, accelerating voltage and chamber pressure were 0.12 mg/sec, 750 V

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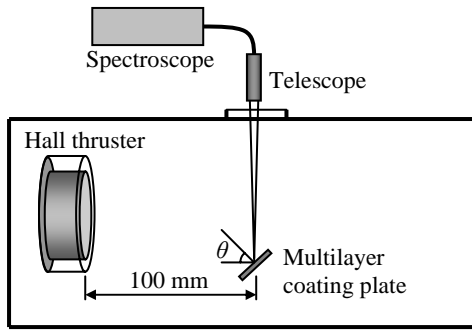


Fig.2 Schematic diagram of the measurement system.

and 7.9×10^{-3} Pa, respectively. These multilayer coatings were carried out at the Smart Processing Research Center of Osaka University.

2.4 Experiment

Figure 2 shows a schematic diagram of the measurement system. A multilayer coating plate with a coating area of $\phi 5$ mm was set at 100 mm downstream of the Hall thruster exit with an incidence angle θ . A telescope was focused on the front surface of the plate, and the history of AgI (338.4 nm) emission intensity was measured with the spectroscope. The angular dependence of sputtering yield was also measured and compared with the literature data.

3. Results and Discussion

Figure 3 shows the history of AgI emission intensity at $\theta = 0^\circ$. The first and second emission peaks were distinctly detected and the interval time was 16 sec, which corresponds to the erosion rate of 19 nm/sec. However, the third and fourth peaks became blunt. This would be due to the non-uniformity of BN layer thickness in the multilayer coating: when a plate with a coating area of 30 mm square was used, the second emission peak could not be detected. The profile will be improved by limiting the size of coating area, which is small enough to ignore the non-uniformity of BN layer thickness.

The interval time between the first and second emission peaks was 13 sec at $\theta = 30^\circ$ and 8 sec at $\theta = 60^\circ$. The sputtering yields were normalized by the sputtering yield at $\theta = 0^\circ$:

$$\frac{Y(\theta)}{Y(0)} = \frac{T(0)}{T(\theta)} \frac{1}{\cos \theta} \quad (1)$$

where T is the interval time of AgI emissions. The normalized sputtering yield increased with θ as shown in Table 1. This tendency agreed qualitatively with the literature data^{2,5)} for xenon ions at 300 eV.

Table 1 Normalized sputtering yield.

Incidence angle θ	The present study	Reference 2)
30°	1.4	1.2
60°	4.0	2.6

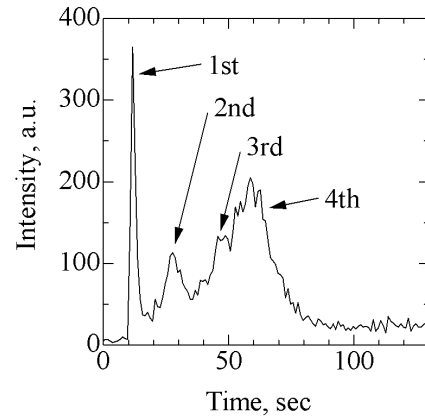


Fig.3 AgI (338.4 nm) emission intensity at $\theta = 0^\circ$.

If a multilayer coating is deposited on the channel wall of a Hall thruster, it enables us to estimate the lifetime of a Hall thruster with a given wall thickness by measuring the real-time erosion rate of the ceramic channel wall.

4. Conclusion

This study succeeded in the measurement of the history of AgI emission intensity when a multilayer coating plate was exposed to the ion beam of a Hall thruster. The angular dependence of BN sputtering yield was measured and the result agreed qualitatively with the literature data. From these results, it was concluded that this method is effective for evaluating a Hall thruster's lifetime.

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