Development of Neutralizer with Carbon Nanotube Cathode for Small Scale Ion Engine

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Yoshiyuki Takao*, Akihiro Kugimiya† and Shinobu Nagai‡
Oita National College of Technology
1666 Maki, Oita City, 870-0152, Japan

Naoji Yamamoto§ and Hideki Nakashima**
Kyushu University
Kasuga, 816-8580, Japan

Abstract: Experimental studies were carried out to examine adaptability of a cathode with carbon nanotubes to a small scale microwave discharge ion engine. Two types of carbon nanotube cathodes are tested. One is a cathode of single walled carbon nanotubes bonded on a copper plate (SWCNT cathode). The other is a cathode of CNTs generated directly on a carbon disk (CD cathode) by arc discharge. The electron current density of 18mA/cm^2 at applied voltage of 380V was attained with the SWCNT cathode and the cathode is applicable to the neutralizer for the small scale ion engine. Electrons are extracted at high applied voltage from the CD cathode. The improved surface treatment must be investigated for better performance of the CD cathode.

I. Introduction

The ion thruster is one of electric propulsion systems that have advanced features and make some attractive missions possible. As the thruster generates thrust by emitting ions accelerated with electrostatic grids, it has high performances of high specific impulse and high propellant utilization efficiency. The ion thruster of microwave discharge type is one of ion thrusters and produces ions by ionizing propellant with high-energy electrons accelerated by microwave in a magnetic field of its discharge chamber. The magnet field can be produced by using permanent magnet such as SmCo or Nd magnet. Since the thruster utilizes no cathodes for plasma production, it is relieved from the cathode heater failure that results from the degradation of the cathodes. The thruster has very simple structure and needs only one microwave power supply to produce plasma and quick ignition without any preheating sequence is possible. These features as well as very simplified power supply units will assure longer lifetime and higher reliability as compared to conventional DC discharge thrusters with cathodes such as hollow ones.[1.]

In the past, several ion engines have been developed and used for the artificial satellite on a geostationary orbit or planetary exploration.[2.] A series of small-scale satellites are recently expected to use instead of traditional large-

* Associate Professor, Department of Electrical and Electronic Engineering, takao@oita-ct.ac.jp
† Student, Department of Electrical and Electronic Engineering
‡ Student, Department of Electrical and Electronic Engineering
§ Assistant Professor, Department of Advanced Energy Engineering Science
** Professor, Department of Advanced Energy Engineering Science

scale satellites for reducing launch cost and risk. As the microwave discharge ion engine has the great advantages of its simple structure and power units to minimize its scale, we developed a small scale microwave discharge engine[3-4] and needs suitable neutralizer for the simple thruster.

Carbon nanotube (CNT) is recently used as one of nanotechnologies in many industrial fields. CNT has many advanced features such as high mechanical strength, high thermal resistance, high chemical resistance, and geometric form of very thin figure. Therefore, CNT is expected to use for field emission cathodes of light source or electric gun.

In the present study, two types of CNT cathodes are tested to develop a neutralizer for the small scale microwave discharge ion engine. One is a cathode of single walled carbon nanotubes (SWCNT) bonded on a copper plate(SWCNT cathode), the other is a cathode of CNTs generated directly on a carbon disk (CD cathode).

II. Experimental

A. SWCNT Cathode

SWCNT cathode is shown in Fig.1. SWCNTs used in this work were produced at Toyohashi University. The copper plate of 20x20x10 cm^3 has a cylindrical hole (diameter of 2mm, depth of 0.5 mm) at the center of it. The hole was filled with SWCNTs and electrically conductive bond.

B. CD Cathode

CD cathode is a graphite disk (diameter of 2mm) that is dug into a same size copper plate of SWCNT cathode (Fig. 1) and CNT is generated on the surface of the disk by arc discharge directly, because bonding and orienting of CNTs on the cathode is difficult. The schematic diagram of the arc discharge system is shown in Fig.2. The CNT generation conditions are shown in Table 1. Two CD cathodes were made on various discharge conditions. The graphite disk was set below a graphite rod (tip diameter of 1mm) as an electrod and the distance of both graphite electrodes is about 0.5mm. By adding high voltage, arc discharge is generated between the both electrodes and CNTs are generated in cathode and/or anode spot on the disk surface. CNTs generated in cathode spot were observed by a FE SEM and is shown in Fig.3.

C. Current-Voltage Characteristics Measurement System

The schematic diagram of the current-voltage characteristics measurement system adopted here is shown in Fig.4. The measurement system comprises a cylindrical vacuum chamber (inner diameter of 35 cm and depth of 20 cm), high voltage power supply, cathode stand, and vacuum pumps. The high voltage is supplied by a feed-through from the power supply between the electrodes. Electrons emitted from the CNT cathode were collected by the anode of a copper plate and electron currents were decided from voltage drop of the series resistor of 1kΩ. The vacuum chamber is evacuated by a turbo molecular pump (250l/s) and a rotary pump as a auxiliary pump.

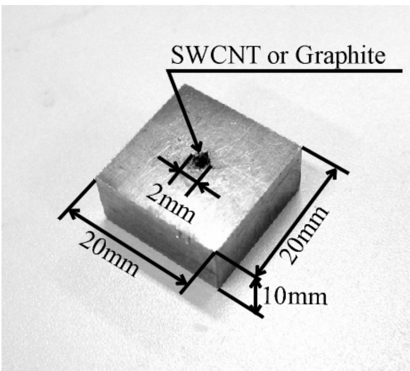

Figure 1. Dimension of SWCNT or CD cathode.

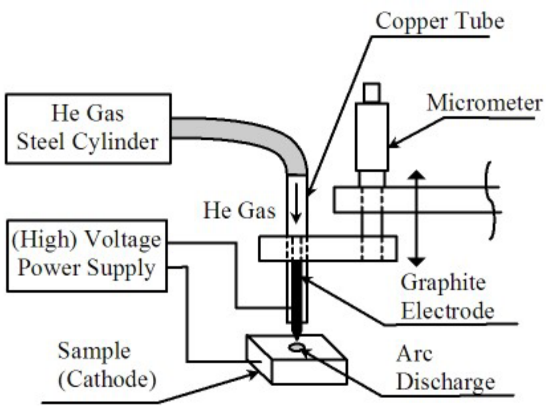

Figure 2. Schematic diagram of arc discharge system for surface treatment of CD cathode.

Table 1. Arc discharge conditions for CNT generation on the surface of CD cathode graphite disk.

Cathode number	1	2
Discharge current	3.5mA	10A
Discharge duration	60 min	30 sec
Discharge voltage	2.2kV	16V
Sample polarity to graphite electrode	−	+
Working gas	He	
Working gas flow rate (l/min)	1	10

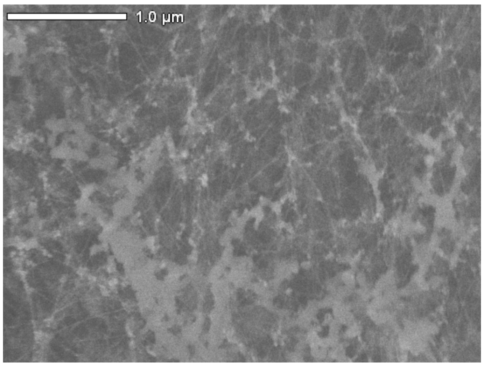

Figure 3. CNTs generated in cathode spot.

D. Electron Extraction Test

Electron currents extracted from the CNT cathodes were measured to estimate adaptability of the cathode to the neutralizer for the small scale microwave discharge ion engine. A SWCNT cathode was tested at the electrode intervals of 0.5 and 1mm. Two CD cathodes that were prepared at the arc discharge conditions shown in Table 1 were tested at electrode interval of 0.5mm. The pressure in the vacuum chamber was $<1 \times 10^{-3}$ Pa during electron extraction tests

III. Results and Discussion

Figure 5 shows the emitted electron current from the SWCNT cathode with applied voltage as the variable. Electron current was 0.48mA at applied voltage of 370V and electrode interval of 0.5mm. Applied voltage of 1200V was needed to extract the same amount of electrons at electrode interval of 1mm. Electrode interval is strongly affected values of electron current. Electron current was 0.56mA that corresponds to current density of 18mA/cm^2 at 380V and 0.5mm interval. This result indicates that SWCNT cathode is applicable to the neutralizer for the small scale microwave discharge ion engine as the electron density is about 3 times larger than ion current density of the

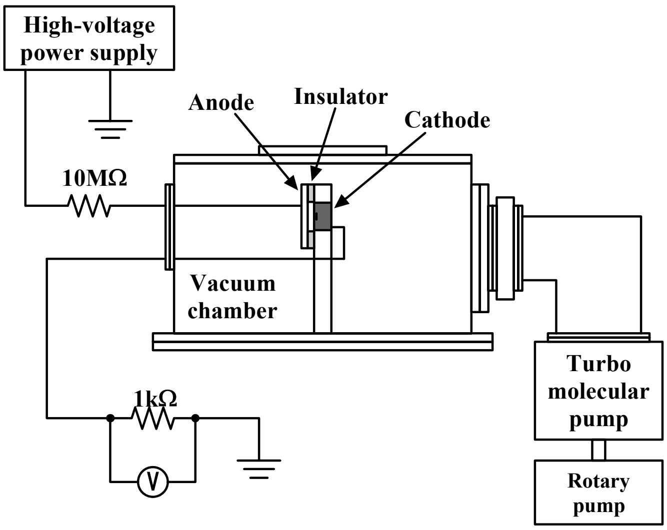

Figure 4. Schematic diagram of the current-voltage characteristics measurement system.

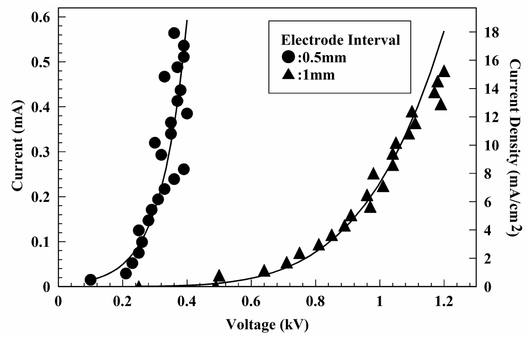

Figure 5. Current-voltage characteristics of SWCNT cathode at electrode interval of 0.5 or 1mm.

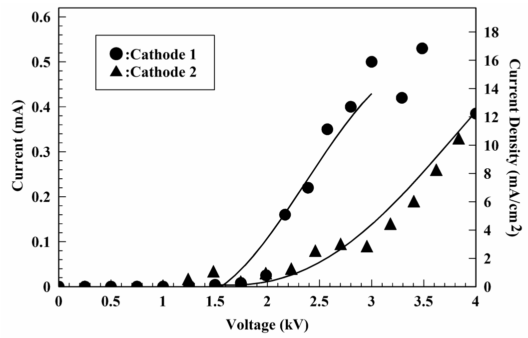

Figure 6. Current-voltage characteristics of CD cathodes.

ion engine.[5] However, the applied voltage of 380V must be reduced because of energy loss. Narrower electrode interval is effective for its reduction.

Figure 6 shows the emitted electron current from the CD cathodes with applied voltage as the variable. Electron currents were extracted at applied voltage of more than 1500V and this value is smaller than that of a graphite cathode that was not treated with arc discharge. The two cathodes were made with different discharge conditions as shown in Table 1 and both cathodes need to be improved in their performance. As arc spot is very small and often craters, these results were caused by short of CNT and increase of electrode interval. Optimization of discharge conditions is required.

IV. Conclusions

CNT cathodes were fabricated and tested to clarify adaptability of the cathode to the neutralizer for the small scale microwave discharge ion engine. The following results are obtained.

1) Electron current of 0.56mA was extracted from a cathode of single walled carbon nanotubes bonded on a copper plate at applied voltage of 380V and electrode interval of 0.5mm. As this electron current corresponds to current density of 18mA/cm^2, the SWCNT cathode is applicable to the neutralizer for the small scale microwave discharge ion engine.

2) Electrode interval is strongly affected values of electron current extracted from the SWCNT cathode.

3) Electron currents is extracted at applied voltage of more than 1500V from a cathode of CNTs generated directly on a carbon disk by arc discharge. This cathode needs to be improved in its performance for applying to the neutralizer.

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