OPTOELECTRONICS AND ADVANCED MATERIALS – RAPID COMMUNICATIONS Vol. 4, No. 11, November 2010, p. 1826 - 1829

Experimental investigation of the microwave electrothermal thruster using metals as propellant

G. MOGILDEA*, M. MOGILDEA
Institute of Space Sciences, 409th *Atomistilor Street, PO Box MG-23, RO 077125, Magurele, Ilfov, Romania*

In this paper is presented the possibility of vaporization and ionization of the metal threads (in particular lead) during interactions with a microwave field (2.45 GHz frequency) from a cylindrical waveguide having TM_{011} propagation mode. The experiment is realized in vacuum conditions at 7 × 10^{-5} milibar pressure. In vacuum a teflon piece is heated and is created a plasma through decomposition of the teflon. Lead thread is vaporized and ionized of plasma teflon.

(Received September 12, 2010; accepted November 10, 2010)

Keywords: Vacuum conditions, Cylindrical waveguide, Electric propulsion, Microwave field, Lead threads

1. Introduction

In this paper is presented possibility of use of the lead threads as propellant for the feed an experimental microwave thrusters. In present are used for microwave thruster gaseous propellants such, He [1], Xe, Kr. When compared gaseous propellants with metals (Pb, Bi) as propellants we notice that metal have more advantages than gaseous propellants. These advantages such as: low ionization energy, low price, and small volume them make it well suited for the use as propellant in electric propulsion.

The researches realized in air at normal pressure and room temperature, showed that if a lead thread is inserted in high electromagnetic energy region of the microwave field from a cylindrical waveguide having propagation mode TM_{011} [2] or TM_{012} [3], the lead thread is vaporized and ionized. The goal of this work is to investigate the possibility of vaporization and ionization of the lead threads with a microwave field (2.45 GHz frequency) in vacuum conditions, using a cylindrical waveguide with the propagation mode TM_{011}. The lead threads used as propellant in this experiment have 0.5 mm diameter. Several experiments were realized in air at normal pressure and vacuum conditions at 7 × 10^{-5} milibar pressure. These experiments showed that the energy consumed for vaporization and ionization process of the lead threads in air and vacuum conditions is not same. In vacuum conditions it is necessary to use higher microwave power, but the main problem is that the lead quantity can not be controlled. The reason the use a little microwave power for the vaporization and ionization process of the lead threads in air can be explained through the ionization of the air molecules of lead thread. Because experimental researches showed that the air can not ionized by the microwave field from the cylindrical waveguide if we have not a metal thread, we can conclude that electric charge on the metal surface thread creates a very high electric field witch ionizes the air molecules. Then the metal thread is vaporized by air ions and ionized by the microwave field from the waveguide. To prove this concept we realized an experiment in vacuum conditions witch creates ions in the waveguide through decomposition of teflon. Then the lead thread is vaporized and ionized in the microwave field from the cylindrical waveguide. The teflon in our experiment was selected because when is it heated in vacuum condition it decomposes in gas [4]. The gas from teflon can be very easily ionized of the microwave field from the cylindrical waveguide. It is known that the teflon is used for the feed of pulsed plasma thruster (PPT) [5, 6]. In the PPT, a bar of solid propellant such as teflon is pushed by a spring in between a cathode and an anode and ablated, there after ionized in a plasma arc (about 20 kA for a few microseconds). The ionized material is accelerated subsequently by the Lorentz force in the exhaust. PPTs have a very low thrust efficiency but high exhaust velocity (a few tens of km/s) and have been successfully flown. The goal of the use of the Teflon in our experiment is to create plasma from teflon necessary for the vaporization and ionization process of the lead threads. The result of the experiments was to obtain same quantity of vaporized and ionized lead for same energy used in air.

2. Experimental

A series of tests were done to determine the vaporization and ionization process characteristics of the lead threads in the microwave field from the cylindrical waveguide having TM_{011} propagation mode .The mean power of the microwave field from waveguide can be changed through modification of the pulses duration [2]. Testing was performed in a cylindrical vacuum chamber having the inner diameter 0.4 m and length 0.5 m. An operating pressure of 7 × 10^{-5} milibar was maintained while testing of the vaporization and ionization process of the lead thread. In Fig. 1 is shown the electrical scheme used for vaporization and ionization of the lead thread from the cylindrical waveguide. The diameter of the cylindrical waveguide is 10 cm and length 13 cm. As microwave source in our experiment is used a magnetron type 2M235 K having 800 W microwave power. The magnetron antenna is inserted inside of the waveguide. The power supply generates voltage pulses with 50 Hz frequency. The effect of changing the voltage pulse duration for feeding the magnetron anode is the modification of the mean microwave power of inside of the waveguide. An ampermeter connected between the line voltage and the power supply of the magnetron recording the current consumed by experiment. The copper pipe from inside of the cylindrical waveguide is used for the feed of the experimental microwave thruster using lead thread as propellant.

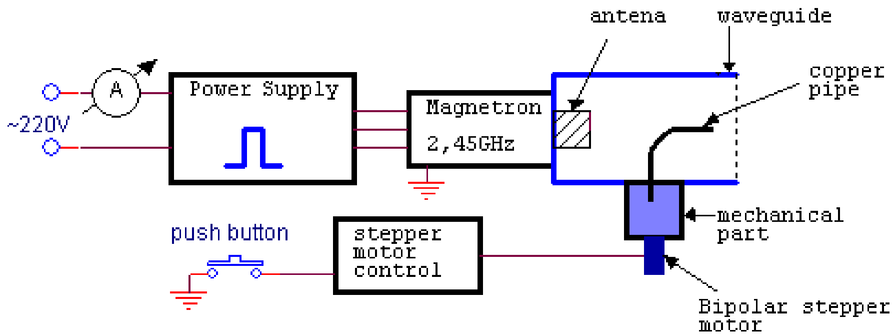

Fig. 1.

The use of a copper pipe has two mains advantages. First, the use the copper pipe at carry of the lead thread in high electromagnetic energy region is that the metal pipe transfer the electric charge of the lead thread. The electric charge is generated on the surface of the metal pipe due to the microwave field from cylindrical waveguide. Thus can be used any length of lead thread in the vaporization and ionization process. Secondly, when copper pipe is heat decomposes in gas the teflon piece. The mechanical part and the bipolar stepper motor push the lead thread in high electromagnetic energy region. This region is situated at 6.5 cm from magnetron antenna. The system stepper motor and mechanical part can be pushed in high electromagnetic energy region of the cylindrical waveguide of approximately 2 cm lead thread. When is used push button the stepper motor is move a step and the lead thread is pushed 0.3 mm.

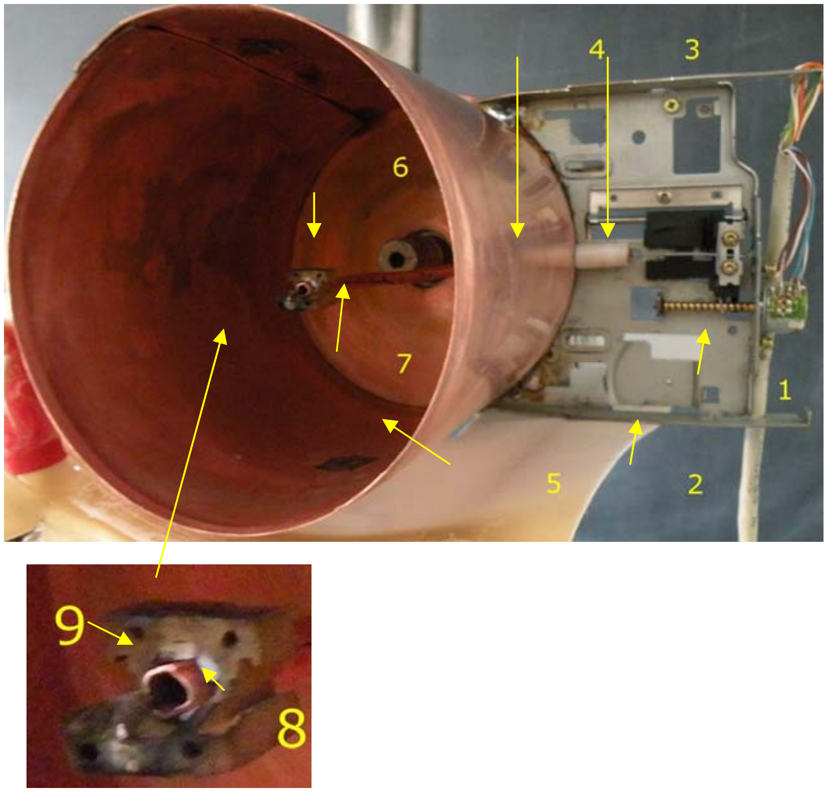

Fig. 2. 1-bipolar stepper motor, 2- mechanical part, 3 - lead thread, 4 – teflon tube, 5- cylindrical waveguide, 6-magnetron antenna, 7-copper pipe, 8- ceramic support, 9- teflon pieces.

In Fig. 2 we can see a picture of the system experimental microwave thruster witch use lead threads and teflon as propellant. In this experiment is used as propellant 5 % teflon and 95 % lead. The vaporization and ionization process of the propellants starting at the power total (anode power + power filament from magnetron) 700 W. After 3 -5 seconds the total power is reduced at 180 W. The teflon piece (Fig. 2) is heated of the end of the copper pipe located in high electromagnetic energy region of the cylindrical waveguide.

It is know that the Teflon in solid phase not absorbed the microwave field. The loss factor of the teflon at $25^\circ C$ temperature and 2.45 GHz frequency is $\varepsilon'' = 3.1 \cdot 10^{-4}$ [7]. According to H. Leidecker, when a piece of teflon (PTFE) is heated in vacuum conditions is decomposes into C_2F_4 (97%) and C_3F_6 (3%) [4]. The gases resulting from decomposition of the teflon are easy ionized of the microwave field from cylindrical waveguide. Thus, in high electromagnetic energy region is creating a plasma sphere having around 6 mm diameter. In this plasma is inserted the lead thread.

So, in high electromagnetic energy region are created teflon ions then the teflon ions vaporize the lead thread. The lead vapors are ionized by the microwave field. Because the waveguide is connected to the ground, the ions (lead and teflon) are attracted at the walls of the cylindrical waveguide. The teflon tube is used as electrical isolator between the copper pipe and waveguide walls. The cylindrical waveguide is realized from copper. During vaporization and ionization of the propellants (lead + teflon) the ceramic support is heated and maintained a constant temperature of the Teflon. Thus the gas flow generated through depolymerization of the teflon will be constant. It was found experimentally when ceramic support is failing the vaporization and ionization process of the propellants can not be controlled.

The rate of depolymerization of the heated Teflon, in vacuum is described by the Arrhenius equation. (1)

$$w = \rho \cdot B \exp\left(-\frac{E}{R \cdot T}\right) \tag{1}$$

w is the rate of decomposition;
B is the collision number, $B = 3 \times 10^{19}\ \sec^{-1}$;
E= is the activation energy of the reaction, E=347.8 kj/moll;
R is the gas constant, $R = 8.3145 J \cdot K^{-1} \cdot mol^{-1}$;
T is absolute temperature (K)
ρ is the density of teflon

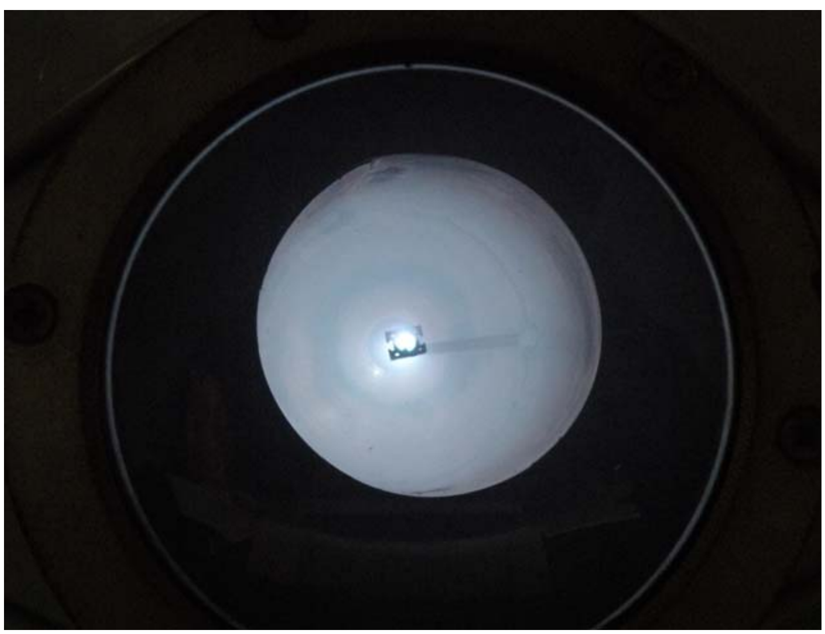

Fig. 3. Experimental Microwave Thruster in vacuum conditions.

In Fig. 3 is showed the experiment realized in vacuum conditions at 7×10^{-5} milibar pressure of the experimental microwave thruster using lead and teflon as propellant. For 180 W power total (anode power + power filament from magnetron) were vaporized and ionized 1.2 mg/s lead.

3. Discussion

All components used in this experiment are commercially type with lower efficiency. Power supply used for feed of the magnetron has 60 - 70 % efficiency.

The efficiency of the magnetron is around 73%. We can say that the power microwave generated of magnetron is around 50 % from electrical power. By changing commercial power supply of the magnetron from our experiment with a switching power supply the total electrical power can be reduced. A better specific impulse of the propellant is possible if a grid system at the waveguide exit is used.

4. Conclusions

Experiments realized in vacuum condition at 7×10^{-5} milibar pressure, led to the conclusion that the lead threads can be vaporized and ionized in combination with teflon.

References

[1] M. Micci, Low-Power Solid-State Microwave Thruster Systems, Third International Conference, Cannes, France, 2000.
[2] G. Mogildea, M. Mogildea, Optoelectron. Adv. Mater. – Rapid Commun., **4**(3), 352 (2010).
[3] M. Mogildea, G. Mogildea, J. Optoelectron. Adv. Mater. **12**(5), 1157 (2010).
[4] H. Leidecker, The thermal decomposition of Teflon, http://misspiggy.gsfc.nasa.gov/tva/issfoc/iss/docs/.
[5] Keidar, M. Boyd, I. D. Beilis, I. I., Electrical discharge in the Teflon cavity of a coaxial pulsed plasma thruster, Plasma Science, IEEE Transactions on, **28**, 376 (2000).
[6] Takefumi Saito, Hiroyuki Koizumi, Hitoshi Kuninaka, Pulsed Plasma Acceleration Using Powdered Propellant, Journal of Plasma and Fusion Research. SERIES, Vol. **8**, (2009).
[7] Roger Meredith, Engineers' Handbook of Industrial Microwave Heating, The Institution of Electrical Engineers, London, 1998.
[8] Alex Kieckhafer, Lyon B. King, Energetics of Propellant Options for High-Power Hall Thrusters, Proceedings of the Space Nuclear Conference 2005, San Diego, California, June 5-9, 2005.
[9] Cody C. Farnell, John D. Williams, Ion Thruster Grid Design Using an Evolutionary Algorithm, Journal of Propulsion and Power, **26**(1), (2010).

*Corresponding author: georgemogildea@yahoo.com