B/TI MULTILAYER REACTIVE IGNITER FOR MICRO SOLID ROCKET ARRAY THRUSTER

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ABSTRACT

In this study, reactive B/Ti multilayer igniters were investigated for the noncontact ignition of a micro solid rocket array thruster in vacuum. When current is supplied to the B/Ti multilayer igniter, the chemical reaction: 2B + Ti → TiB_2 + 1320 cal/g occurs, and high temperature plasma is discharged to a distance of several millimeters or more. The B/Ti multilayer igniters with 3 sizes were fabricated, and tested in 6 configurations of solid propellant. Although one rocket with ignition charge was ignited successfully, the noncontact ignition of the solid propellant was not achieved.

INTRODUCTION

Down-sizing of spacecrafts is advantageous in reducing the cost and time of development and the risk of launching failure. 10 kg class or smaller manmade satellites are referred as microsatellite, and mainly used for scientific or technological purposes. For the microsatellites, MEMS technology is useful to miniaturize a variety of components including sensors, actuators and thrusters.

Recently, several types of microthrusters, for example, cold/hot gas jet thrusters [1], vaporizing thrusters [2, 3], bi-propellant thrusters [4] and solid rocket thrusters are developed using MEMS technology. We are developing the micro solid propellant rocket array thruster for simple attitude control of a 10 kg class microspacecraft [5, 6]. The micro solid rocket array thruster is the array of many one-shot micro solid rockets on a substrate. This promising concept was first proposed by Lewis Jr. *et al.* [7], and several groups are developing this type of microthruster [5-9].

However, the reliable ignition and combustion of solid propellant at micro scale in vacuum is difficult. All groups including us used resistive microheaters to ignite the solid propellant, but uncertain adhesion between the microheater and the solid propellant is an inevitable critical problem. In this study, we applied B/Ti multilayer igniters to escape this problem.

EXPERIMENTAL SETUP

B/Ti Multilayer Reactive Ignitor

The B/Ti multilayer reactive igniter is originally used for air bags [10]. It has a bridge, in which 200–300 nm thick Ti and B layers are alternately stacked. When electric current flows through the bridge, the bridge is heated up, and then the following reaction occurs:

$$2B + Ti \rightarrow TiB_2 + 1320\ \text{cal/g}. \quad (1)$$

This reaction is exothermic, and produces high temperature plasma, which discharges to a distance of several millimeters or more. This high temperature plasma can ignite a solid propellant, even if the igniter makes no physical contact to the solid propellant in vacuum.

Figure 1 shows the structure of B/Ti multilayer igniters fabricated on p^{++} Si diaphragms in the first layer of the microthruster. Five 250 nm thick Ti layers and four 220 nm thick B layers are alternately stacked by electron-beam evaporation, and patterned by lift-off. The sizes of the fabricated bridges are 10 × 10 μm^2, 30 × 30 μm^2 and 100 × 100 μm^2. Boron evaporation must be carefully done with slow heating and cooling using a carbon hearth liner to avoid explosion. After that, Au/Pt/Ti electrical lines are formed by lift-off.

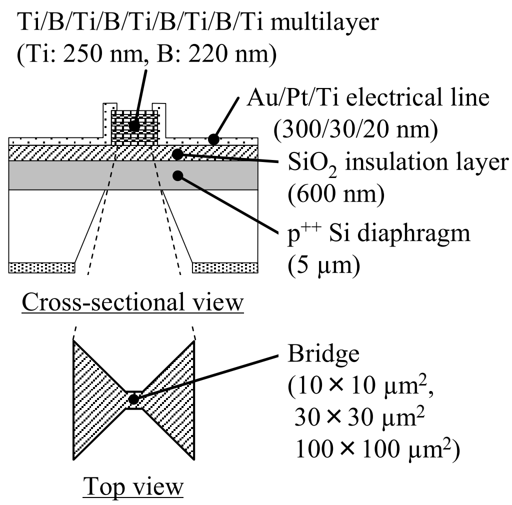

Fig. 1 Structure of the B/Ti multilayer reactive igniter

Thruster

Figure 2 illustrates the cross-sectional structure of the micro thruster. It consists of three layers. The first layer is silicon, and the second and the third one is glass. The first layer has nozzles and the igniters on the diaphragms. The nozzles are fabricated by etching the silicon substrate using ethylene diamine pyrocatechol water (EPW), and the p^{++} Si diaphragms remain by etch stop. The diaphragm, which bursts after ignition, thermally insulates the igniters, and also seals solid propellants.

The second layer contains the solid propellants, and the third one covers them. The holes of 1.2 mm diameter for the solid propellants are mechanically drilled, and then the first and second layers are bonded with epoxy adhesive. The pellets or powder of the solid propellant (boron/potassium nitrate, NAB) and the slurry of ignition charge (lead thiocyanate/potassium chlorate, RK) are inserted into the drilled holes. Finally, the third layer is bonded to the second layer with the epoxy adhesive. 32 micro solid rockets are arrayed in a 22 mm × 22 mm substrate.

We tested six configurations of the solid propellant shown in Fig. 3. The configuration (a) tests the B/Ti multilayer igniters without the solid propellant. In the configurations (b), (c) and (d), the solid propellant pellets are set above the igniters with gaps of 0.6, 0.3 and 0 mm, respectively. The density of the pellet is approximately 1.7 g/cm^3. The gaps are made by the small offsets of the propellant holes drilled from both sides of the second glass layer. In the configuration (e), the solid propellant powder fills the propellant holes. The density of the powder is approximately 0.6 g/cm^3. In the configuration (f), the ignition charge, which is slurry before dry, is used between the igniter and the solid propellant pellet.

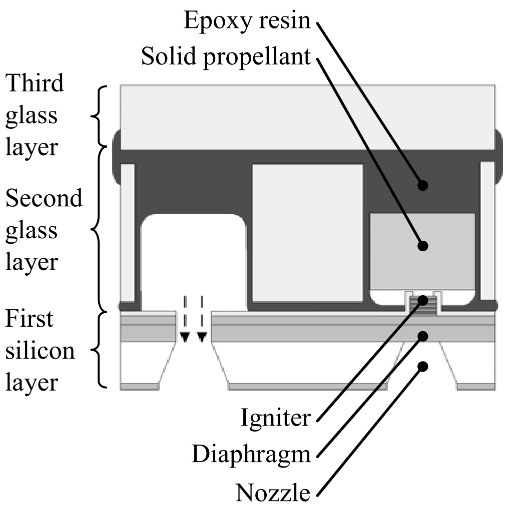

Fig. 2 Cross-sectional structure of the micro solid rocket array thruster

Measurement Setup

The microthrusters were tested in vacuum using a setup shown in Fig. 4. For ignition, 35 V is applied to each igniter. The microthruster is fixed on a printed circuit board for wiring, and set on the cantilever. Under the cantilever, a quartz force sensor is installed to measure thrust. A photodiode is used to measure

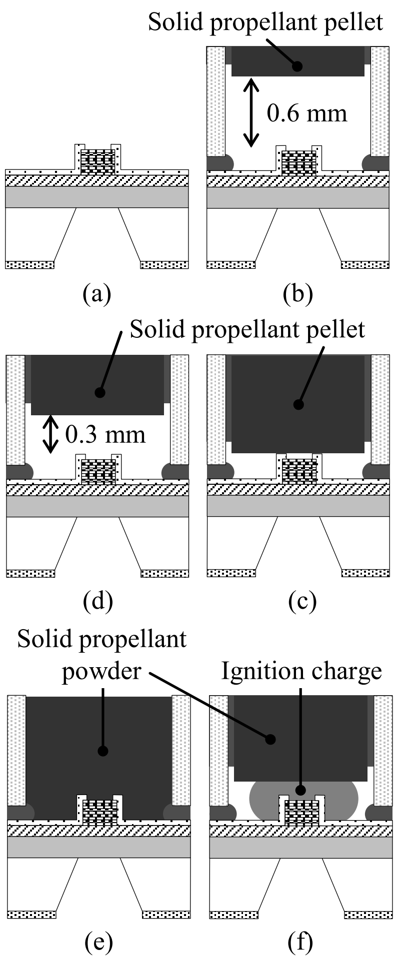

Fig. 3 Configurations of the solid propellant

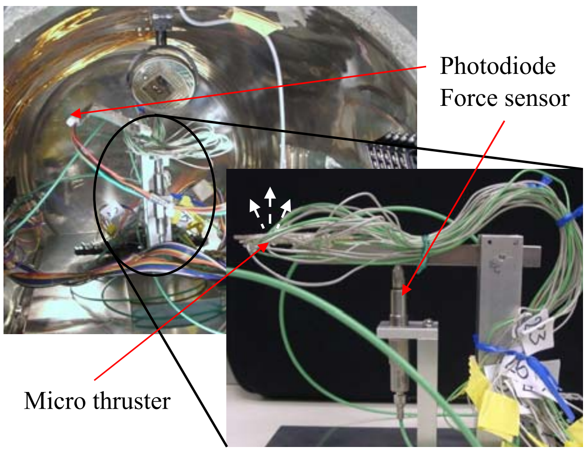

Fig. 4 Measurement setup

ignition delay and combustion time by detecting light from the ignition and combustion. All of them are set in a vacuum chamber, which is evacuated by a rotary pump.

RESULT

Table 1 summarizes the experimental results. For the configuration (a), 9 in 12 igniters successfully reacted. The yield is 75 %, suggesting the uncontrolled quality of B/Ti deposition. Figure 5 and 6 show the maximum thrust and light emission time as functions of the bridge size. Large dispersion are found in both thrust and light emission time. For the attitude control of microsatellites, the impulse is important and to be controlled. The B/Ti multilayer igniter itself could be used for the precise attitude control of microsatellites, if the impulse can be controlled. The impulse is approximately proportional to the product of the thrust and light emission time, which is shown in Fig. 7. It has also large dispersion, and shows no particular trend against the bridge size. The method to control the impulse is not clear from this result.

For the configurations (b), (c), (d) and (e) without the ignition charge, we obtained no result which confirmed the successful ignition of the solid propellant regardless of the forms of the solid propellant or the gaps between the igniter and the solid propellant. Although some of the diaphragms were partly damaged, none of them ruptured.

For the configuration (f) with the ignition charge, 7 in 9 rockets ignited, but only one rocket started and maintained the combustion of the solid propellant. In this case, the light emission time is approximately 150 ms, which is much longer than those in the other case, as shown in Fig. 8. Figure 9 shows the measured thrust and detected light intensity for the successful ignition. The initial impulse generated by the chemical reaction of B/Ti and the ignition charge reached 150 mN, while thrust generated by combustion of the solid propellant is several mN and lasts for 120 ms. The total impulse is approximately 5 $\times$ 19^{-4} Ns, most of which is generated by the solid propellant. It is approximately one tenth of the theoretical value.

Figure 10 shows the ignition delay. The ignition delay is roughly several μs to several tens μs for the configuration from (a) to (e) without the ignition charge, while it is as long as a few hundreds μs or longer for the configuration (f) with the ignition charge. This is because the heat dissipates from the igniter to the ignition charge, which was put on the igniter in the form of slurry.

From the above results, it is concluded that the noncontact ignition of the solid propellant using the B/Ti multilayer igniters is difficult. It is thought that the solid propellant or the ignition charge need to be preheated for ignition by the physical contact with the igniters. In this study, we found no positive reason to select the B/Ti multilayer igniter rather than the resistive heating igniter.

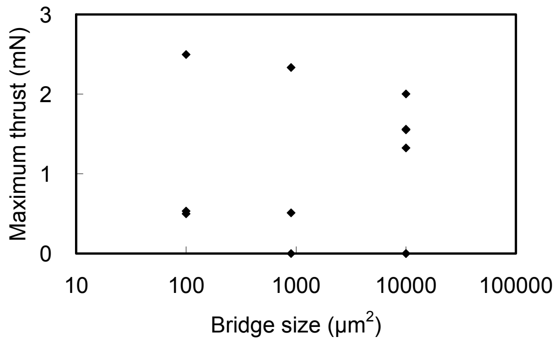

Fig. 5 Relationship between the bridge size and the maximum thrust

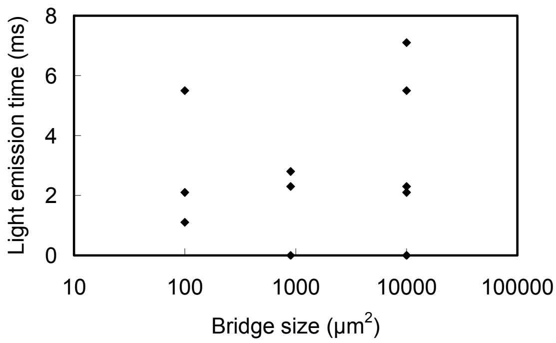

Fig. 6 Relationship between the bridge size and the light emission time

Table 1 Summary of experimental results

Config.	Propellant	Gap	Number of tested rockets	Number of reacted igniters	Number of ignited rocket
(a)	None	N/A	12	9	N/A
(b)	Pellet	0.6 mm	14	13	0
(c)	Pellet	0.3 mm	12	12	0
(d)	Pellet	0 mm	8	8	0
(e)	Powder	0 mm	24	16	0
(f)	Pellet + Ignition charge	0 mm	9	9	Solid propellant: 1 Only ignition charge: 6

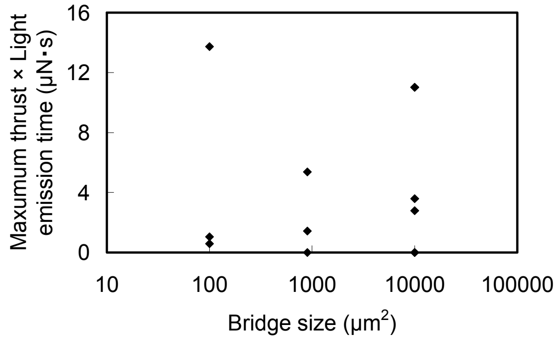

Fig. 7 Product of the thrust and light emission time

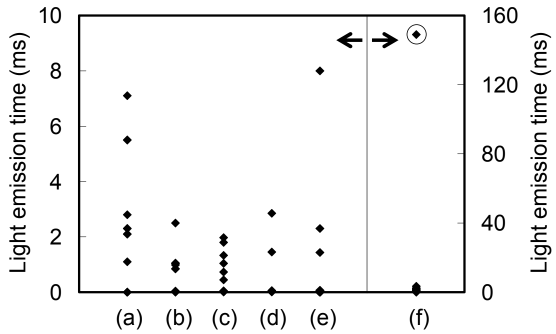

Fig. 8 Light emission time for each configuration
The circle indicates the successful ignition.

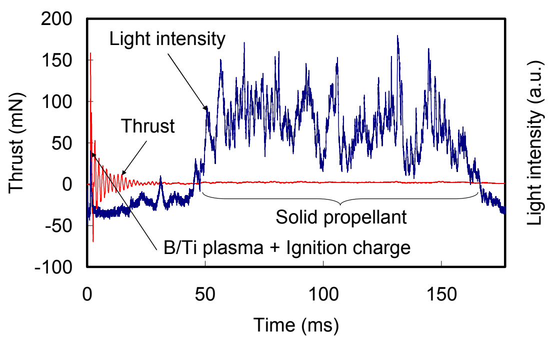

Fig. 9 Measured thrust and detected light intensity for the successful ignition in the configuration (f)

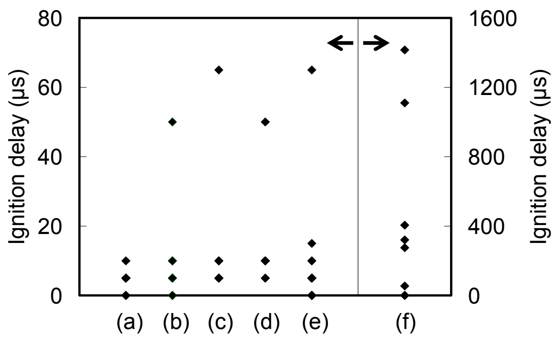

Fig. 10 Ignition delay for each configuration

CONCLUSION

In the development of the micro solid rocket array thruster, how to achieve the reliable ignition in vacuum is the most critical issue at present. For the resistively-heating ignition, good adhesion between the solid propellant and the igniter is necessary. Despite much effort to ensure the adhesion, the success rate of the ignition still remains approximately 90 % at the maximum. Thus, we tried to apply the reactive B/Ti multilayer igniter, which produces high temperature plasma, to the noncontact ignition of the solid propellant.
The B/Ti multilayer igniters with 3 sizes were fabricated, and tested in 6 configurations of the solid propellant. Although one rocket with the ignition charge was ignited successfully, we could not confirm the noncontact ignition of the solid propellant. It is thought that preheating by the physical contact with the igniter is need to exceed the activation energy of the solid propellant.

REFERENCES

[1] Johan Köhler *et al.*, A hybrid cold gas microthruster system for spacecraft, *Sensors and Actuators A*, 97-98 (2002) 587–598

[2] E. V. Mulerjee *et al.*, Vaporizing liquid microthruster, *Sensors and Actuators A*, 83 (2000) 231–236

[3] Tae Goo Kang *et al.*, High-impulse, Low-power, digital microthrusters using low boiling temperature liquid propellant with high viscosity fluid plug, *Sensors and Actuators A*, 97–98 (2002) 659–664

[4] A. P. London *et al.*, High-Pressure Bipropellant Microrocket Engine, *J. Propulsion and Power*, 17 (2001) 780–787

[5] Shuji Tanaka *et al.*, MEMS-based Solid Propellant Rocket Array Thruster with Electrical Feedthroughs, *Transactions of The Japan Society for Aeronautical and Space Science*, 46 (2003) 47–51

[6] Kazuyuki Kondo *et al.*, Vacuum test of a micro-solid propellant rocket array thruster, *IEICE Electronics Express*, 1 (2004) 222–227

[7] David H. Lewis Jr. *et al.*, Digital Micropropulsion, *Sensors and Actuators A*, 80 (2000) 143–154

[8] C. Rossi *et al.*, Design, fabrication and modeling of solid propellant microrocket-application to micropropulsion, *Sensors and Actuators A*, 99 (2002) 125–133

[9] K. L. Zhang *et al.*, A MEMS-based solid propellant microthruster with Au/Ti igniter, *Sensors and Actuators A*, 122 (2005) 113–123

[10] Thomas A. Baginski *et al.*, Electro-Explosive Device with Laminate Bridge, U.S. Patent, US2003/0192445