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Test of B/Ti multilayer reactive igniters for a 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: $2B + Ti \rightarrow TiB_2 + 1320$ cal/g occurs, and sparkles are spread to a distance of several millimeters or more. The B/Ti multilayer igniters with three sizes were fabricated, and tested in six configurations of solid propellant. Although one rocket with ignition charge was ignited successfully, the noncontact ignition of the solid propellant was not achieved. However, the B/Ti multilayer igniters themselves generated small impulses of 10^{-6} N s order, suggesting the possibility of self-propulsion.

1. Introduction

Miniaturization of spacecrafts is advantageous in reducing the cost and time of development, increasing the lunching chances of new spacecrafts and opening new space applications. 10 kg class or smaller manmade satellites are referred as microsatellite, and used for scientific, technological and sometimes educational 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 have developed a 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 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.

2. Experimental setup

2.1. 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:

$$2B + Ti \rightarrow TiB_2 + 1320\ \mathrm{cal/g} \qquad (1)$$

This reaction is exothermic, and produces sparkles, which spread to a distance of several millimeters or more as shown in Fig. 1. It is successfully used for the ignition of air bag inflators, although the total released energy from the reaction is considerably small. The reported advantages of the B/Ti multilayer reactive igniter in comparison with resistive heating igniters are fast response, low firing energy, small size and reliable ignition across an air gap. The purpose of this study is to investigate whether this igniter is also applicable to the ignition of a solid propellant, even if the igniter makes no or little physical contact to the solid propellant in vacuum.

Fig. 2 shows the structure of B/Ti multilayer igniters fabricated on diaphragms in the first layer of the microthruster. The diaphragms are fabricated by p^{++} Si etch stop technique using ethy-

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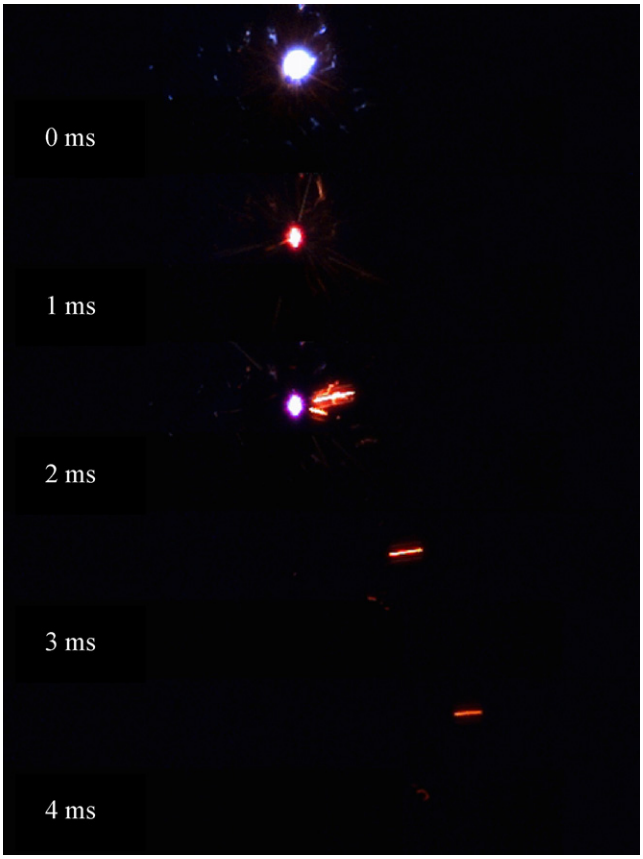

Fig. 1. Sparkles from the B/Ti multilayer reactive igniter, spreading to a distance of several millimeters or more.

lene diamine pyrocatechol water (EPW) following B diffusion to a depth of ca. 5 μm. 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 μm × 10 μm, 30 μm × 30 μm and 100 μm × 100 μm, and the resistances range from 5 Ω to 10 Ω. The electron beam evaporation of B must be carefully done using a carbon hearth liner by slowly

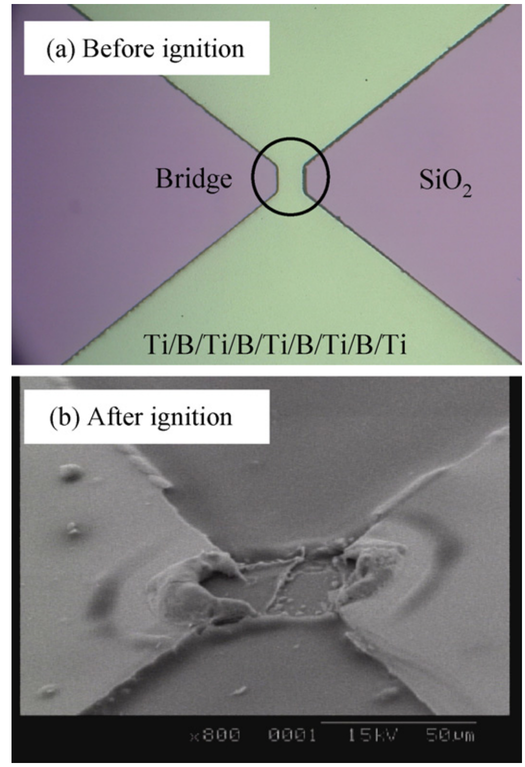

Fig. 3. B/Ti multilayer reactive igniter (a) before and (b) after ignition.

increasing and decreasing beam current to avoid explosion. After that, Au/Pt/Ti electrical lines are formed by lift-off. Fig. 3 shows the B/Ti multilayer igniter before and after ignition.

2.2. Thruster

Fig. 4 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

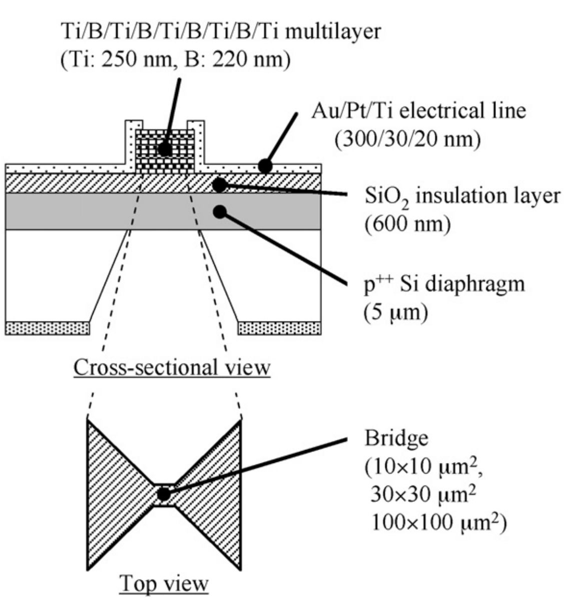

Fig. 2. Structure of the B/Ti multilayer reactive igniter.

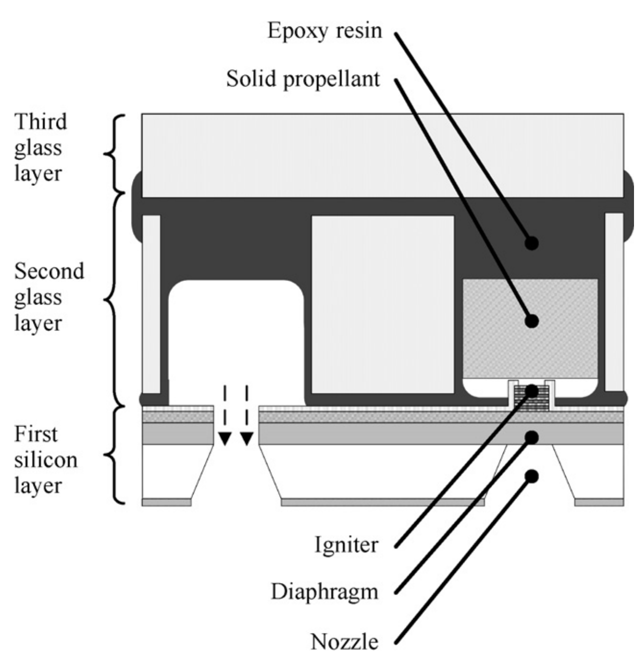

Fig. 4. Cross-sectional structure of the micro solid rocket array thruster.