MEMS Application of Quenching Effect to a Novel Micro Solid Rocket

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Abstract

Precise position and attitude control of pico-satellite requires huge number of impulses of the order of 10^{-6} Ns. MEMS solid rocket array is a promising propulsion system but the higher degree of miniaturization causes unreliable operation mainly due to quenching. In order to breakthrough this situation, a novel design of solid micro-rocket is proposed, which generates tiny impulses repetitively from a single rocket not from array. This unique micro-rocket is based on the utilization of quenching, which causes propellant reaction to sustain only in a small area. A test chip of a micro solid propellant tank and micro heater array is fabricated and ignition test is conducted. Obtained results show the feasibility of this concept and future direction of this quenching-based propulsion is discussed.

Introduction

Pico-satellite of weight less than 1kg is attracting a lot of interests for the future constellating mission with low launching cost. In order to accomplish the multipoint observation in the planetary explorer and earth observatory, position and attitude control is key issue. The MEMS technology has potential to accomplish a high degree of miniaturization of even the space propulsion system without functional degradation. So far many kinds of MEMS thruster have been fabricated and tested, such as cold gas thruster [1], monopropellant thruster [2], bi-propellant rocket thruster [3], and so on. Such MEMS-based system has another advantage of compatibility with the electric circuits. Among them, digital MEMS thruster [4-6], which is array of tiny rockets fabricated by MEMS technology and uses the solid propellants, is promising due to its simple structure of no movable part, low electric power, no propellant leakage and higher density of energy. However precise μN-order impulse is not accomplished yet while the successful micro rockets generate impulse of 10^{-3} Ns order. Electrical micro propulsion, represented by micro PPT and micro-Resistojet [7], fundamentally matches for such control application but micro chemical propulsion is still advantageous for low voltage and low power operation.

A challenging miniaturization of micro rocket array was tested by Youngner et al [8] but no successful result is reported. The major barrier for such micro chemical propulsion is quenching due to energy dissipation into substrates. Though the MEMS technology has successfully scaled-down many kinds of sensor and actuator systems but there still remain a lot of thermal and chemical problems.

We have ever experimentally studied on solid propellant reaction in a micro space and concluded that the quenching cannot be eliminated without external heating. In this paper, taking this aspect into consideration, an innovative design is desired for smaller MEMS solid rocket.

Multi-pulse MEMS solid rocket

The MEMS solid rocket array [4-6] was designed to use up each propellant in a single tank. As many impulses as tanks can be generated. However it is frequently occurs that the propellant in the tank does not burn up perfectly when its size is reduced to less than 100μm order. Such quenching results in large dispersion of impulse, which is a critical problem for spacecraft control. We hit upon an idea that this quenching is applicable for partial consumption of propellant and contrived the novel chemical propulsion proposed in this paper. Figure1 shows the schematic diagram of the multi-pulse MEMS solid rocket. Silicon wafer is etched through and sandwiched by two glass substrates to configure the micro solid tank. The size of this tank is 2mm length, 400μm width and 100 μm depth, which is about one

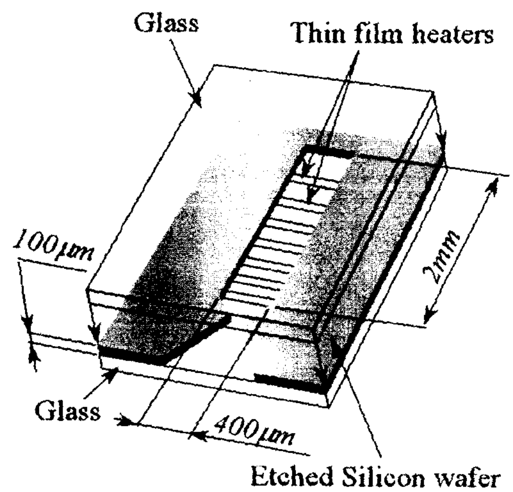

Fig.1. Schematic diagram of the test chip of the Multi-pulse MEMS Solid Rocket

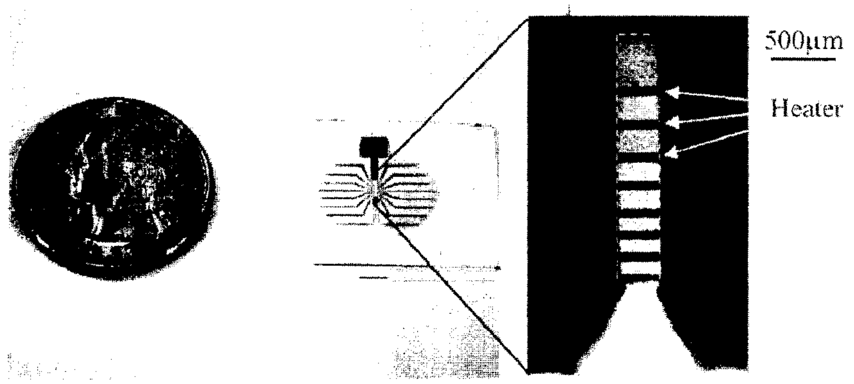

Fig.2. Fabricated test chip of the Multi-pulse MEMS solid rocket (left) and its enlarged view (right).

digit smaller than the past-researched micro solid rockets. Key issue of this propulsion is having the multi heater on a single micro tank. This structure is designed on the assumption that the quenching occurs just after propellant ignites. That is, combustion of a tiny portion of propellant on a heater is accomplished and one micro rocket generates as many pulses as the number of heaters.

Experiment

Fabricated test chip of this multi-pulse MEMS solid rocket is composed of silicon wafer and two glass substrates as shown in Fig.1. Silicon wafer of 100µm thickness is etched through for the form of micro tank, whose size is 100 x 400 x 2000µm. Pt/Ti thin film is deposited on the glass substrate with EB evaporation. By using the lift-off method, eight heaters of 100µm width are made up with different intervals as shown in Fig.2 for testing. Two glasses and etched silicon wafer is glued with adhesive.

In our study, HMX or RDX prepared by Asahi Kasei and nitrocellulose by Kishida Chemicals are used as propellant. Their thermal properties are shown in Table 1. HMX and RDX are crystallite as shown in Fig.3. Among the current explosive compounds, both HMX and RDX are the hardest explosives and possess the higher specific thrust. Average particle diameter of HMX and RDX is about 10µm and 100µm, respectively. Nitrocellulose has fibrous structure as shown in Fig.4 and it is difficult to charge it in the micro rocket tank. In order to improve the contact with heaters, nitrocellulose is charged after dissolving in the acetone.

In all ignition tests, constant joule heating is performed using DC power source. High speed CCD camera is used to observe the propellant in the micro tank through glass substrate.

Results

Figure 5 shows the video frames of ignition test of HMX propellant. After the heater is switched on, there is a time lag of 10ms order and HMX near heater started melting and vaporizing. The reacting region expands gradually and HMX finally disappears within the range of 100µm beneath the heater, as indicated in the last frame. The propellant combustion, which is confirmed by the illumination on the heater, continued longer than 100ms but stopped at the moment heating stops due to the rupture of thin film heater. This combustion shut-off was caused by nothing but the quenching. RDX also shows the same reaction although it has higher sensitivity than HMX.

Same ignition test is conducted after charging the

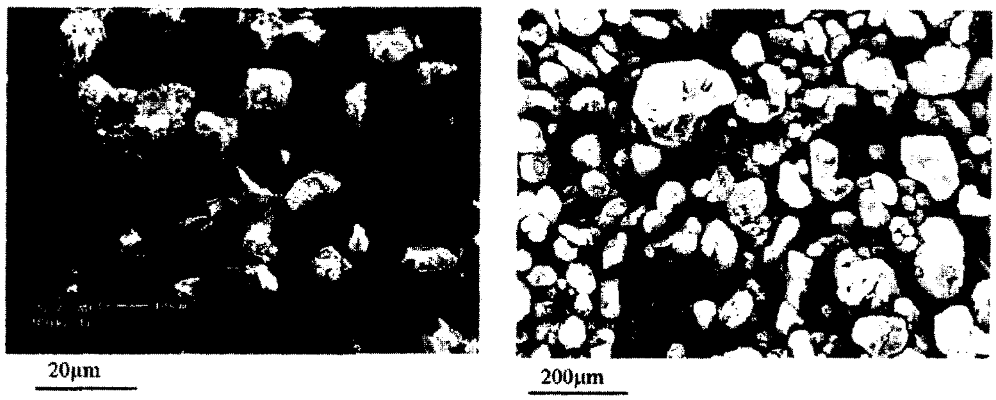

Fig.3. Microscopic images of HMX (left) and RDX (right)

Table 1 Physical properties of propellants

	HMX	RDX	Nitrocellulose
Melting temp(°C)	273	205	130~
Ignition temp(°C)	327	260	230
Specific thrust(s)	266	266	230

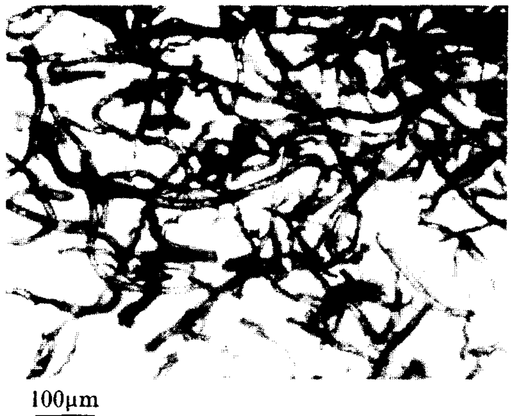

Fig.4. Microscopic image of nitrocellulose

nitrocellulose. Charged nitrocellulose starts melting and vaporizing almost as soon as thin film heater is on. This is because nitrocellulose contacts thin film heater better than HMX or RDX. At 250ms later from the heating starts, melting nitrocellulose near heater generates the reacting gas intensively. A series of this reaction is restricted in the 100-200μm away from the heater.

Figure 6 shows the micro rocket tank after ignition test using nitrocellulose propellant. Seven thin film heaters have been used for ignition. The white ellipse shows a reaction zone that is formed when one heater is switched on. This figure indicates that the heater allows only the nitrocellulose in the vicinity of each heater to react. The appropriate interval of thin film heater is found to be 200- 300μm in this configuration.

Conclusion

We designed and tested a novel micro rocket that is based on the active utilization of quenching. The combustion of HMX and RDX charged in a micro tank occurs only in the vicinity of heater. Nitrocellulose rocket showed stronger reaction because of the improved contact with microheater. The other part of tank than the reacted zone is found utilizable for gas jet generation. This means the feasibility of our idea that very tiny impulses can be generated repetitively from a single rocket. In addition, it should be noted that this planar configuration of our micro rocket can be gathered as many as necessary. This means that even propulsion of finger-top scale can generate more than one million impulses.

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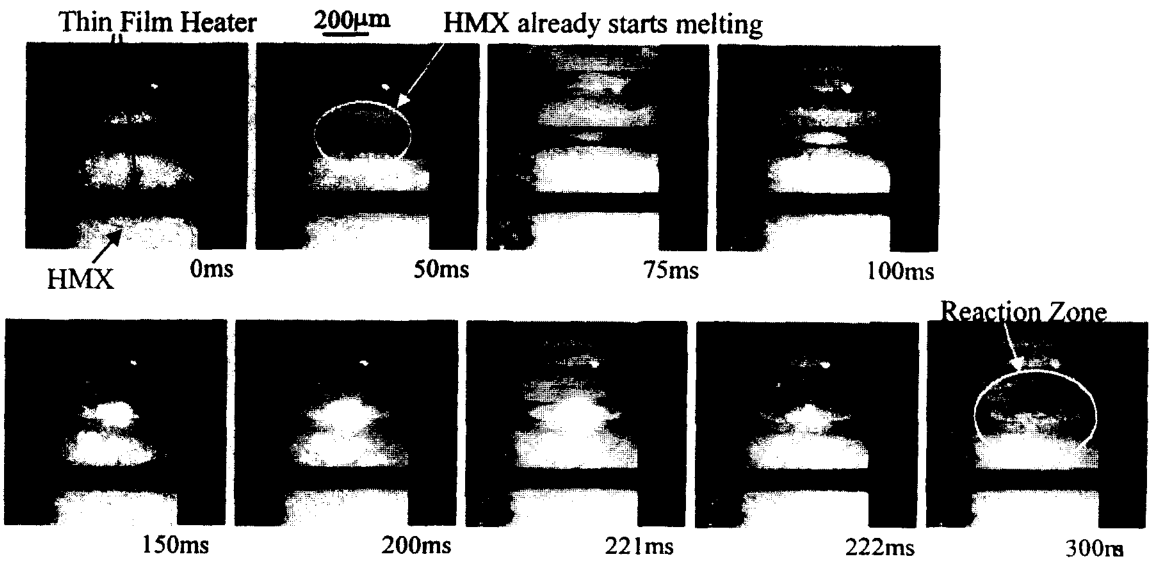

Fig.5. Video frames of heating test. Output energy is 5.0W. HMX is charged in the micro tank.

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Fig.6. Image of micro rocket tank after ignition test. The white ellipse indicates the dimension of reaction region generated when each one heater is switched on.