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EXPLOSIVE POWDERS FOR FURTHER MINIATURIZATION OF MEMS ROCKET

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Several kinds of solid propellants were tested for MEMS rocket array application. In order to accomplish a reliable propellant combustion in a micro tank, it is concluded that explosive powders are advantageous owing to their higher ignition sensitivity than the usual aerospace propellants. This paper focuses on newly-developed spherical DDNP powder. Its diameter can be chosen from 80 to 500μm and size-uniformity is very high. This large ball is easy to handle though its sensitivity is almost same as the original DDNP. Two kinds of MEMS rockets are fabricated and its ignition and combustion characteristics are obtained.

1. INTRODUCTION

Micro thruster is a key issue for functional operation of pico-satellites and many researchers in space engineering are looking forward to their successful development. MEMS application for thruster is promising [1] and many projects are being carried out in many countries; cold gas thruster [2], colloid thruster [3], monopropellant thruster [4], MEMS rocket array [5] and so on.

The well-known MEMS rocket array, or Digital Propulsion, is an excellent idea for MEMS-based chemical propulsion because of its no movable part and no propellant leakage. The electric power is saved using chemical energy and the power supply system is expected very compact due to its low-voltage operation. Each rocket is used-up at a single shot but array structure gives multiple shots as many as the number of rockets, which is requisite for satellite control application. So far, several test devices were developed [6-8] and micro solid rocket is recognized feasible as far as its diameter is around 1mm or larger.

However, a high barrier still exists in front of its application to future constellating mission. The required impulse for pico-satellite control is less than 10^{-6}Ns though that of 1mm-order rocket yields about 10^{-3}Ns. In order to bridge this gap, we have to tackle a difficult topic of further miniaturization of solid rocket. The number density of rocket is also desired to be as many as possible. Such attempt was already treated by using the newest MEMS technology [9] but no good result has been reported yet. It was already pointed out [10] that quenching problem has to be taken into account for micro solid rocket even though the combustion duration is very short. The quenching causes incomplete combustion resulting in non-uniform impulses. In order to prevent such unreliable operation of MEMS rocket array and to make the rocket structure as simple as possible in place of the conventional multi-stage ignition system, the most importance issue is the choice of propellant.

Towards the accomplishment of MEMS solid rocket miniaturization to the order of 100μm or less, this paper focuses on a new solid propellant that is spherically-formed DDNP (diazodinitrophenol). The conventional solid rocket motor uses several kinds of propellants and the main part is compounds of explosive, fuel, oxidizer and binder. However, such commercially available compound is not appropriate for MEMS rocket array because the inhomogeneous structure of composite degrades reaction reliability and also too much sensitivity of explosives is seriously concerned for possible vibration and shocks in operation. Our spherical DDNP has several advantages for microsystem application, which are introduced here in comparison with the other highly-sensitive explosives and well-known propellants. Obtained results from its combustion tests using MEMS-based rocket devices, such as combustion velocity and initiation delay are reported and discussed.

2. EXPERIMENTS

2.1 Review of preliminary combustion tests

As mentioned above, choice of propellant is the key issue for the first step to develop solid rocket of the order of 100μm or less. Fig. 1 shows microscopic pictures of HMX, RDX, Nitrosellulose (NC) and DDNP. Average particle diameter of HMX and RDX, which are crystalline, is about 10μm and 100μm respectively. The large dispersion of their particle size is a bad news for the re-productivity and

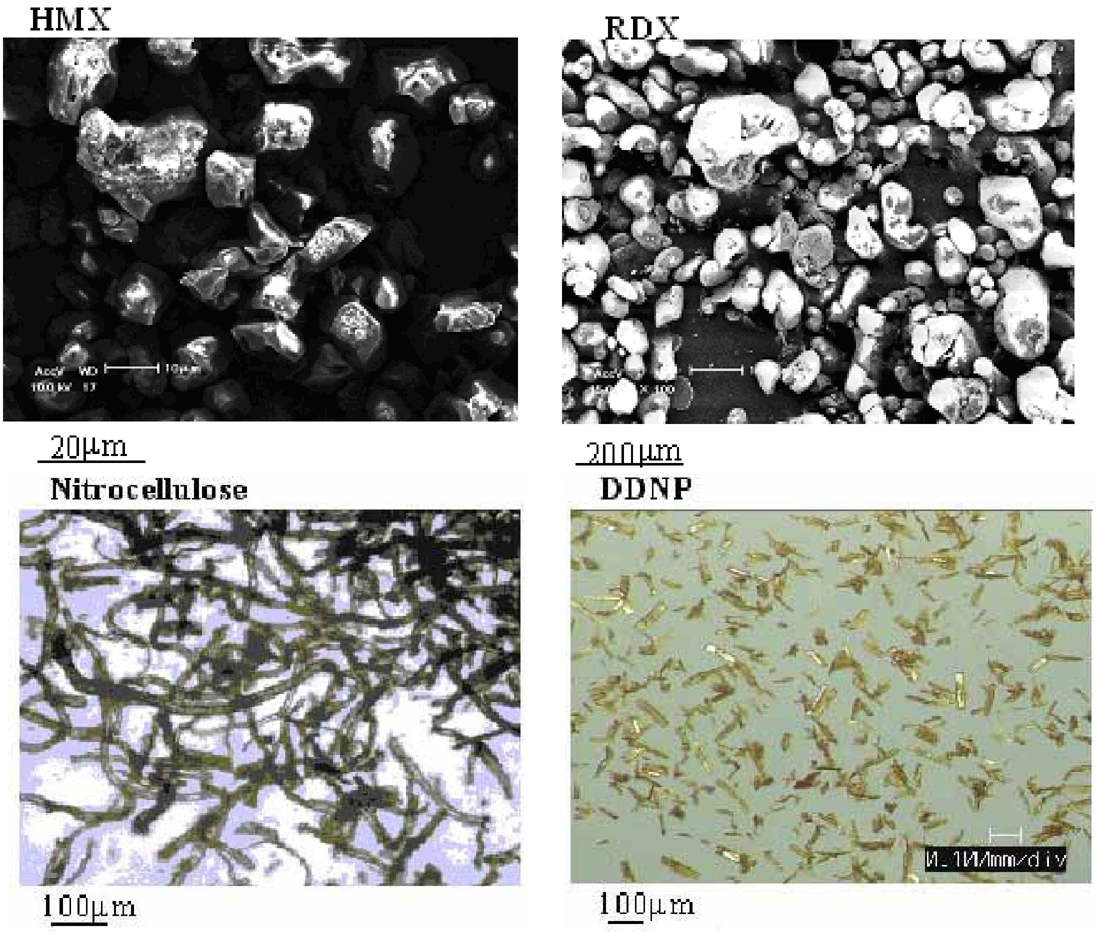

Fig.1 Examples of past-examined explosive powders

Table 1 Sensitivities of initiating explosives

	Impact Sensitivity	Friction Sensitivity	Ignition Point (4s)
lead rhodanate+KClO3	2kgm	50g	194 °C
lead trinitroresorcinate	0.3kgm	150g	275 °C
PETN	0.3kgm	5000kg	202 °C
DDNP	0.04kgm	1000g	180°C

Data depends on references but tendency is same.

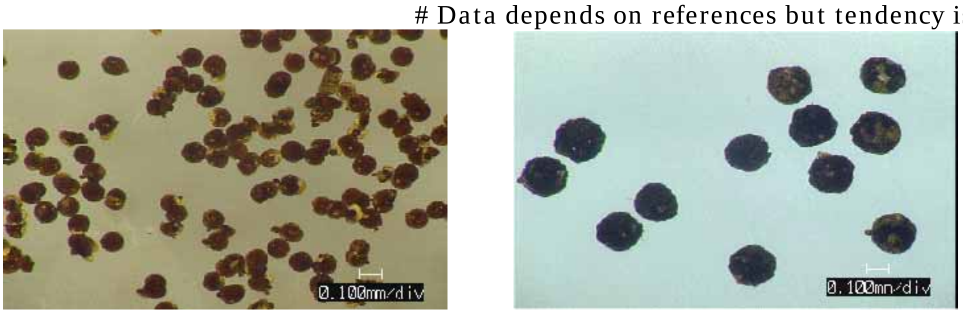

Fig.2 Spherically-formed DDNP

understanding of experiments. We had used micro rocket of depth of 100μm to 500μm for preliminary combustion tests and found that all of HMX, RDX, NC keeps reaction no longer than a few hundreds micrometers from ignition heater. This combustion stability is critically dependent on pressure, particle size, ingredient, and so on. However, we concluded to use more sensitive propellant against this quenching, even which can be used for multiple gas generator as described in Ref.. [11].

There are several initiating explosives, or primary explosives. Table 1 shows their sensitivities but we have to choose one of them by performing experiments because unfortunately their initiation mechanism has not yet been clarified. At our preliminary experiments, lead rhodanate, lead trinitroresorcinate and DDNP worked well in 100μm order rocket but simultaneously we realized that it is so difficult to handle all of them especially when charging into the micro tanks. From this experience, we chose spherical DDNP (Fig. 2) as the propellant of micro rocket, whose sensitivity is expected almost same as the original DDNP. This paper reports microscale combustion test of three kinds of DDNP, two types of DDNP diameters are about 180μm, 100μm, and the other type of DDNP is original spicular shape. These explosive powders were prepared by Asahi kasei Corporation. Spherical formed DDNP grows on every nuclers which are made of the aromatic compound for the crystals of DDNP. This large size powder makes its handling easy and also is expected to decrease its impact sensitivity for safety at the launch of spacecrafts.

2.2 Experimental set-up

Test chips of MEMS solid rocket are composed of silicon wafer of 100μm thickness and two glass substrates as shown in Fig.3. Silicon wafer is etched through for micro tanks which have depth of 100μm, width 400μm and length 2000μm or 6000μm. Pt/Ti thin film heater is deposited on the glass substrate as seen in Fig. 3, some of which are used as igniter and others for sensors. Nozzle with throat was not set there. Powders were charged in tank by hand. After measurement of sample's mass, combustion test was started. Heater power consumption was set 5W. Combustion velocity and ignition delay are measured by using high speed camera.

3. RESULTS and DISCUSSION

Table 2 lists conditions and results of combustion tests. Compared tests No. 5 to 6, No. 7 to 8, the combustion speed of 6mm tank is faster than that of 2mm tank. Combustion velocity is not constant but it is trend that the longer tank length is, the faster the combustion speed is. But, test No. 3 showed lower combustion speed than No.6 and No. 8. When the heater switched on at No. 3, propellant was ignited but combustion was not propagated. After a period of time, the combustion was accelerated suddenly and all propellant in tank was burned out. This kind of unpredictable phenomena usually occurs in every particle system. But accelerated speed was same as No.6 and No.8. The speed turned out lower one after averaging. From these observations, it is concluded that combustion speed is independent of explosive powder shape.

Ignition delay was found smallest when we use spicular shape of DDNP. When spherical DDNP (about 90 μm diameter) used, the ignition delay was

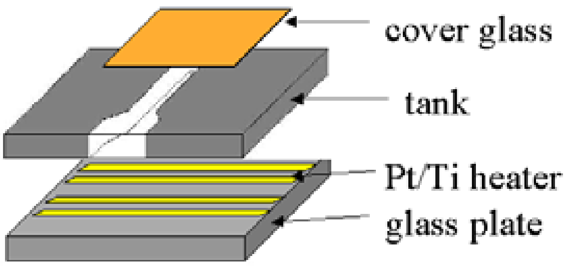

Fig. 3 Schematic diagram of sample of the homemade MEMS solid rocket

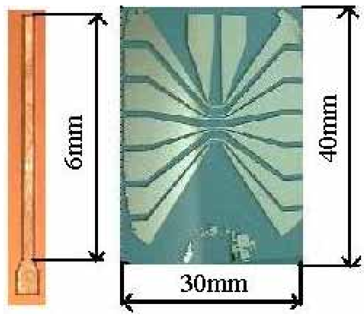

Fig. 4 Picture of MEMS tank [left] Pt/Ti heater on glass plate [right]

Table 2 Conditions and results of combustion tests

Powder shape	Tank length [mm]	Propellant mass [mg]	Charged density [g/cc]	Charged ratio [%]	Ignition delay [ms]	Averaged combusti-on speed [cm/s]
34×85μm spicular	2	0.0151	0.19	12	4	28.57
34×85μm spicular	2	0.1594	1.99	122	4	33.33
34×85μm spicular	6	0.2907	1.21	74	7	23.08
φ180μm spherical	2	0.1249	1.56	96	10	25.00
φ180μm spherical	6	0.2953	1.23	75	36	46.15
φ100μm shperical	2	0.0847	1.06	65	5	28.57
φ100μm shperical	6	0.1169	0.49	30	5	35.29

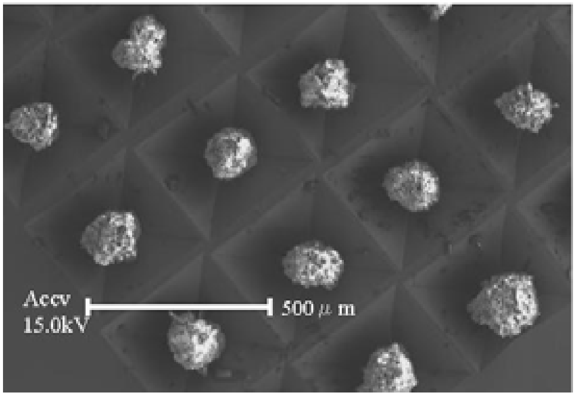

Fig. 5 SEM image of micro-tank array for spherical DDNP

as small as spicular powder. This results is consistent with our past prediction [10] that the propellant particle size and contact area with ignition heater decide the ignition delay. If we want short delay time, small explosive powder is preferred as far as the handling skill allows its charging process. The spherical DDNP of about 180μm diameter showed no disadvantages except of the ignition delay. So, we conclude that the best explosive powder for this kind of micro rocket is as large spherical DDNP as applicable in the micro tank.

Based on these results, we are developing smallest micro rocket of 200μm order. As the combustion reliability test, micro tank array for 180μm DDNP was fabricated as shown in Fig. 5. There are many merits but detail will be described in the next paper.

4. CONCLUSION

Many explosive powders are reviewed for micro rocket application. Consequently, initiating explosives are chosen for reliable combustion of further-miniaturized MEMS rocket array. In order to solve their difficult handling and too much sensitivity problems, a newly-developed spherical DDNP is introduced and tested. Obtained data of combustion velocity and ignition delay suggest that even the DDNP of 180μm shows the same performance as the spicular crystalline powder. We believe that there are many other promising applications of this new explosive for various micro power systems.

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