Development Study of Mono-Propellant Micro Propulsion Using MEMS Technology

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Abstract

Fabrication technique and performance test of catalytic micro propulsion are treated based on MEMS technology. This propulsion is designed to use hydrogen peroxide as liquid mono-propellant for attitude control of pico-satellite. The propellant is fed into the micro reactor channel and decomposed into hot gas yielding controllable thrust by catalyst. In order to increase the efficiency of the reaction that depends on the contact area of propellant and catalyst, porous surface formation on the channel accompanied by platinum particle deposition has been performed using H_2PtCl_6 solution as a precursor. Several thrusters were fabricated in different concentration of H_2PtCl_6 solution to determine the best quantity of Pt particles. For the comparison of the performance of each thruster, the volume of oxygen generated by the decomposition of hydrogen peroxide and the thrust were measured.

1. Introduction

In the past decades, rockets and satellites have been getting bigger in order to launch heavier payload and to explore deeper space. On the other hand, however, the challenges of minimizing them by applying MEMS technology are proceeded recently aiming for low-cost constellation mission. It is said that the final target of miniaturization is the pico satellite whose weight is less than one kilogram without any functional degradation.

One of the most critical components for such miniaturization is thruster that is used to control the position and attitude of satellites precisely with very tiny thrust. So far several kinds of micro-thruster have been developed [1,2] and the cold gas thruster based on MEMS technology looks close to the last stage [3,4]. Compared with the cold gas system, chemical propulsion is advantageous for tank size and required power. Both solid propellant type and liquid type micro-thrusters had been fabricated and tested. The micro solid rocket array is promising for leak-free compact structure but liquid mono-propellant thruster has more flexibility for structural design and mission control if micro-valve and micro-combustor are improved.

Here micro-combustor/reactor of liquid propellant is treated experimentally because different attentions from the gas combustors have to be paid to liquid reaction in a tiny space. Hitt, et al. [5] tested catalytic reaction of hydrogen peroxide in their MEMS-based micro-channel but did not obtain any practical thrust. Osaki and Takahashi [6] discussed the mono-propellant micro-thruster using heater-assisted system from the viewpoint of micro-fluidics. In this paper, a new type of micro-thruster with porous silicon micro-channel and catalyst of platinum particles is fabricated, which use the hydrogen peroxide monopropellant. This micro-channel and Pt particles are expected to increase the contact area of catalyst and propellant. The schematic of this thruster is shown in Fig.1. Changing the quantity and quality of Pt catalyst, several types of micro-thruster were fabricated and their performances were compared. Fabrication process and performance test of these liquid micro-thrusters are described and discussed.

2. Fabrication

The way for activation of propellant reaction is to increase the contact area of the catalyst and the propellant. DRIE structure can increase but we cannot expect much improvement by its scale of only 10μm. On the other hand, porous structure can increase the surface area extremely and crystal silicon is known to be electrochemically etched into porous

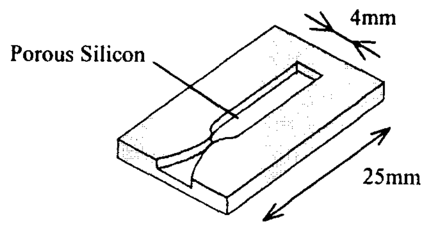


Fig.1 Schematic of chemical micro-thruster with porous silicon

surface. Some of the authors have already developed macroporous formation of a few micrometers order in micro-channel system [7], which is applied in the current study. Nano porous is not treated here because Pt film deposition erases the pores. Here we tested the channel of 20μm in depth for electro chemical etching. LPCVD silicon nitride was used as the resist for both channel formation and electro chemical etching. Fig.2 shows the fabrication process of porous micro-channel for the thruster reactor. First, the N-type (100) silicon substrate of 3Ωcm resistivity is thermally oxidized and LPCVD silicon nitride film is deposited. Silicon nitride and silicon dioxide are etched by CF_4 plasma and BHF solution respectively. Silicon substrate is etched by KOH solution and the channel is formed. The channel is electrochemically etched in the solution of HF/water/ethanol (16.5:16.5:67.0) with illumination as to keep the current density 15mA/cm^2 for ten minutes. Finally, silicon nitride and silicon dioxide are etched away for the next bonding step. Figure.3 shows the hand-made equipment for porous silicon formation and Fig.4 is

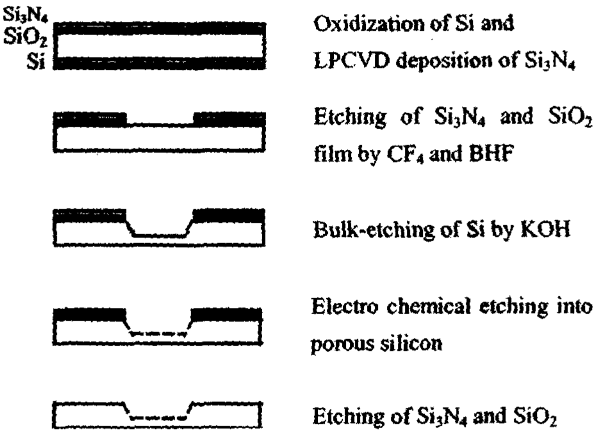


Fig.2 Fabrication process of micro porous channel

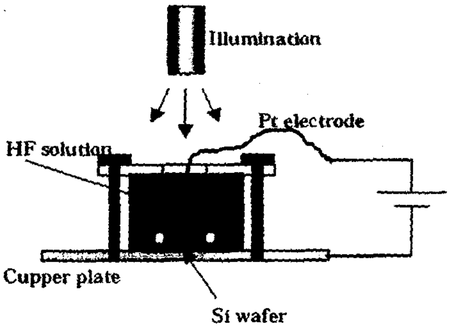


Fig.3 Schematic of hand-made equipment for macroporous silicon formation

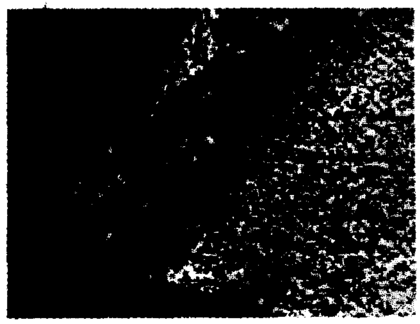


Fig.4 SEM image of the boundary of the channel

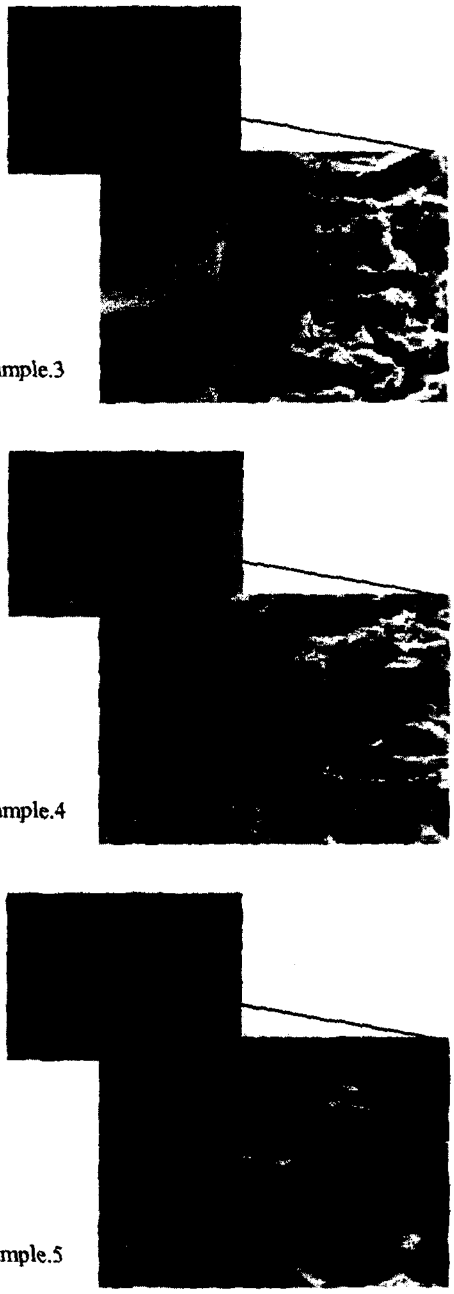
Fig.5 SEM image of the Pt particles on porous silicon

the SEM image of the boundary of the channel. Uniform pores are successfully formed on not only the channel bottom but the channel side wall, which is important and advantageous compared with DRIE method. Moreover, it has to be noted that the outside of the channel is not damaged and ready for bonding with the other substrate.

This porous surface is also desirable as a catalyst bed. We deposited Pt particle by using the popular wet process in the catalyst engineering. H_2PtCl_6 solution is used for Pt nano particle deposition. After a constant quantity of H_2PtCl_6 solution is spread on the surface of the porous silicon, the silicon substrate is put into the vacuum dryer for 30 minutes and burned in a furnace for 4 hours at 350°C. Fig.5 is the SEM image of the Pt particle on the porous silicon. It is confirmed that many Pt particles of 20~30nm of diameter are on the surface of the porous silicon. In order to find the optimum condition of this wet process for our macroporous surface, several attempts are performed as listed in Table.1. Changing the concentration of H_2PtCl_6 solution, five types of the catalytic channel were fabricated. The same quantity (5μl) of H_2PtCl_6 solution of different concentration was spread on the porous channel of each thruster. After the same process, there were many Pt particles enough to be recognized in naked eye for sample.1 and sample.2 because their channels

Table.1 The sample list

	Concentration [mol/l]
Sample.1	1.0
Sample.2	0.5
Sample.3	0.1
Sample.4	0.05
Sample.5	0.01



(a) Sample.3

(b) Sample.4

(c) Sample.5

Fig.6 SEM images of Pt catalytic channel surfaces

are buried by Pt completely. SEM images of sample.3 ~ sample.5 are shown in Fig.6. Pt particles much larger than the diameter of the pore are seen in Fig.5 (a). The large aggregation of Pt particles is also seen in (b). These large particles has poorer performance with higher-cost than nano ones. The porous surface is covered by them and its larger surface becomes meaningless. On the other hand, Pt particles of 20~30nm in diameter are seen in (c). As these particles are also seen in the inside of the pore, much increase of the surface area of catalyst can be expected in this sample.

3. Performance Test

(a) Volume of Oxygen

For one of the parameters of the performance of micro-thruster, the volume of oxygen that is generated by the decomposition of hydrogen peroxide was measured in each micro-thrusters. In order to examine the effect of porous micro-channel and Pt particles, another two kinds of thrusters were fabricated and tested in addition to the Sample.3 ~ Sample.5. One of that has a porous micro-channel and Pt film on it (Sample.6). The other has a flat micro-channel and Pt film on it (Sample.7). The thickness of Pt film here is 40nm. Experimental set up is shown in Fig.7. The volume of generated oxygen during five minutes operation in constant flow rate of the propellant was measured in water substitution method. Hydrogen peroxide of 60% concentration was supplied by syringe pump. Flow rate was fixed in 4ml/h and water temperature was 20℃. Experimental result is shown in Table.2. About 33.5ml of oxygen gas in average is detected from sample.6 and about 14.6ml is from sample.7. This comparison means that porous micro-channel is effective for improving the performance. Every thruster that has a porous micro-channel and Pt particle (Sample.3 ~ Sample.5) showed higher performance than those of Pt film. This result indicates that Pt particles are also effective for improving the performance.

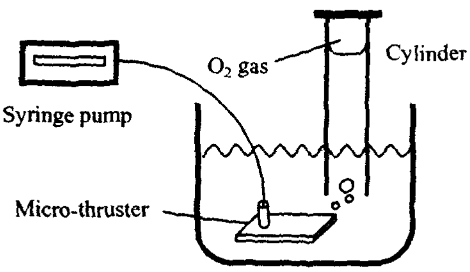


Fig.7 Experimental set up

(b) Thrust

Thrust was measured in each thruster under the atmospheric condition. Experimental set up is shown in Fig.8. The thruster is suspended by metal pendulum and heated by ceramic heater to support the reaction. The displacement caused by the thrust is measured by laser displacement meter. The flow rate and the current are constant at 4ml/h and 0.14A respectively and the voltage is set at 65V where the temperature of the thruster is 110℃. After the thruster motion becomes stable, the displacement is recorded by digital oscilloscope for 10 seconds. We calculated the mean displacement from the data of oscillating displacement. Precise calibration of the metal pendulum determined the relation of the displacement d[μm] and thrust F[μN]. Table.3 shows the result of the experiment. Those who have a porous micro-channel and Pt particles on it (Sample.3 ~ Sample.5) produced bigger thrust than that of Pt film (Sample.6). Though there weren't much differences in the thrust, these results indicated that porous micro-channel and Pt particles are also effective for improving the performance of micro-thruster.

Table.2 Results of the measurement

	Volume[ml]			Av.
Sample.3	55.9	56.2	56.3	56.1
Sample.4	73.8	75.0	75.5	74.8
Sample.5	44.6	41.8	40.5	42.3
Smaple.6	31.2	34.8	34.5	33.5
Sample.7	14.6	14.2	15.1	14.6

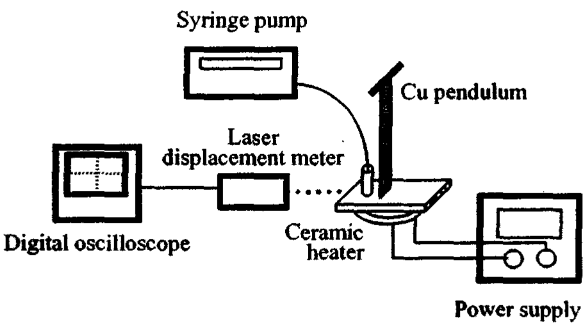


Fig.8 Thrust power measurement system

Table.3 Results of the measurement

	Mean displasement [μm]	Mean thrust [μN]
Sample.3	29.90	121.5
Sample.4	39.25	159.5
Sample.5	39.15	159.1
Smaple.6	29.70	120.7
Sample.7	28.97	117.7

4. Conclusion

A new type of catalytic micro-thruster was fabricated and tested. In order to increase the contact area of catalyst and propellant and obtain high performance, the channel of the micro-thruster was changed into porous and Pt particles were deposited on it. Obtained results indicated that the performance of micro-thruster with catalytic micro-channel was improved. However, the best quantity of Pt particles is not decided yet. Further improvement is expected by choosing the best Pt particle profile.

Acknowledgements

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Reference

[1] H. Helvajian, ed., "Microengineering Aerospace Systems", The Aerospace Press, (1999)
[2] M. M. Micci & A. D. Ketsdever, "Micropropulsion for Small Spacecraft," Progress in Astronautics and Aeronautics, Vol. 187,, AIAA, (2000).
[3] L. Stenmark and A. B. Eriksson, "Cold Gas Microthrusters – Final Edition", AIAA Paper-2002-5765, 2002
[4] J. Mueller, "JPL Micro-Thruster Propulsion Activities", AIAA Paper-2002-5714, 2002
[5]D. Hitt, et al., "MEMS-based satellite micropropulsion via catalyzed hydrogen peroxide decomposition", Smart Mater. Struct. 10 (2001) 1163-1175
[6] Y. Osaki and K. Takahashi, "Microfluidics of Liquid Propellant Microthruster for Pico-Satellites" (in Japanese), IEEJ Trans. Sensors and Micromachines, Vol.123, No.10, pp.436-441, 2003
[7] K. Takahashi, et al., "Simple Fabrication of Hydrophobic Surface for High-Temperature Microsystems ", Micro Total Analysis Systems 2003, Vol.1, pp.503-506, 2003