Fabrication of ethanol blended hydrogen peroxide 50 mN class MEMS thruster

Jeongmoo Huh, Jeongsub Lee, Daeban Seo, Shinjae Kang and Sejin Kwon
Department of Aerospace Engineering, Korea Advanced Institute of Science and Technology, 373-1 Guseong-dong, Yuseong-gu, Daejeon, 305-701, Republic of Korea

E-mail: trumpet@kaist.ac.kr

Abstract. MEMS thruster with blended propellant was fabricated and experimentally tested in order to improve specific impulse of micro scale monopropellant thruster and to improve stability of thrust to be better. 90 wt. % H₂O₂ blended with 25 O/F ratio ethanol was used as propellant of thruster and platinum on alumina support was used as catalyst for decomposition of propellant. Thruster was made by five layers of photosensitive glasses. Four layers were integrated by thermal bonding method and catalyst was directly inserted into chamber before UV bonding process for the last layer bonding. Results of experimental tests showed ethanol blended hydrogen peroxide had higher specific impulse than unblended hydrogen peroxide. Expected improvement of thrust stability due to the blended propellant was found only in the transient state of thrust. Also, unlike the thrust instability of vertical type thruster of previous research, improvement of thrust stability was found owe to horizontal type thruster pattern on glass, despite aspect ratio limitation of glass fabrication with wet etching process. During the experimental test, combustion phenomena of ethanol with decomposed hydrogen peroxide were observed through glass layer and it made fracture on structure of thruster.

1. Introduction
Microelectromechanical Systems technology has made conventional machining technology be in a completely different way suggesting revolutionary fabrication technology for micro scale product with low cost and mass product. MEMS technology has been applied to space technology and it is desirable because cheaper, lighter and faster are significant in space technology. One example of applications of MEMS for space technology is micro and nano satellite. Micro and nano satellites, which has mass of 10~100 kg and 1~10 kg respectively, has great advantages at cost of launch vehicle owe to its low mass. Moreover, group operation of distributed small satellites flying can make diverse operation possible, improve revisit time, and make high system reliability than that of classical satellites. For attitude control and orbit maneuver of miniaturized spacecraft, small size novel propulsion system is needed. MEMS thruster fabricated by MEMS technology has dimensions of micro scale and can make mili-newton class thrust. Many research groups have developed miniaturized thruster.

In early 2000, research of Hitt[1] suggested the possibility of micro scale hydrogen peroxide monopropellant thruster. Result of the research showed it was not enough to decompose propellant with coated silver catalyst on diamond shape pillar within the chamber, because of the low durability of silicon pillar in high pressure and high temperature of chamber. Takahashi[2] deposited platinum catalyst on surface of porous silicon within chamber, and he found porous structure was robust against fluidic motion but catalyst particles were went away. Lee[3] made platinum catalyst coated on alumina
support to ensure large surface area for catalyst reaction and inserted it directly into chamber made by photosensitive glass. Because glass has lower thermal conductivity than that of silicon, it is desirable to make thruster with glass to reduce heat loss. But there is limitation of aspect ratio of patterning and thickness of glass. As a result, He found thrust instability with his vertical type thruster. Result of the research said instability occurred because of not enough injector thickness and pressure drop within injector.

For improvements of previous research, ethanol blending hydrogen peroxide MEMS thruster is suggested in this article. Blending propellant is one way to improve specific impulse of thruster[4]. If blending propellant is used in monopropellant micro scale thruster, the thruster would have not only system simplicity as monopropellant type but also improved specific impulse. It is also expected that higher chamber pressure occurred by blending propellant can improve the instability problem of previous work. With these advantages, to cope with difficulties of small patterning on relatively thick glass, the new thruster in planar type was fabricated and tested.

2. Catalyst Fabrication

Most case of monopropellant micro scale thruster use micro fabrication technology to maximize surface of structure for catalyst coating. However, structural coating catalyst showed not enough decomposition efficiency for propellant. But, previous research[3] showed use of porous support of catalyst and direct insertion into structure of thruster had high decomposition efficiency. Generally, for experimental test in which blended propellant is used, catalyst should be chosen to be durable in high temperature and high pressure of chamber environment. And it is recommended that ideal support material should be physically, thermally, and chemically robust with high surface to volume ratio[5]. Therefore, in previous research[4], barium hexaaluminate was used which had approximately six times higher than that of alumina at temperature of 1200 °C, because alumina turned its phase and lost high surface to mass ratio at the temperature. However, in this micro scale research, high surface to volume ratio of micro scale thruster has high thermal energy loss, so that the support which has highly porous but phase turnable in high temperature could be chosen in this research.

As catalyst, platinum was chosen because it has good performance for propellant decomposition, high temperature melting point as 2041 K, and durability in high temperature and high pressure[6,7]. As support, γ-alumina was chosen because γ-alumina has high surface to mass ratio as 255 m²/g, strong adhesion with metal, and thermally physically robust[7-9]. Pellet type γ-alumina was grinded and was strained through sieve.

For fabrication of catalyst, alumina granules were washed with water before heated in oven at 300 °C, 24 hours. After eliminate the water from alumina, alumina was in H₂PtCl₆ solution for wetness impregnation, followed by 90 °C, 12 hours process in oven. After the solution were completely evaporated, alumina was heated in furnace with 500 °C, 3 hours for calcination process. Finally, reduction process was completed in condition of 500 °C, 3 hours with hydrogen gas 200cc/min volume flow. Fabricated catalyst is in figure 1 and EDS result show element of catalyst in figure 2 and table 1.

### Table 1. Element weight percent and atomic percent of catalyst.

| Element | Wt %  | At %  |
|---------|-------|-------|
| O       | 26.22 | 47.07 |
| Al      | 45.2  | 48.12 |
| Pt      | 27.67 | 4.07  |
| Cl      | 0.91  | 0.74  |
| Total   | 100   | 100   |

![Figure 1. Pt/Al₂O₃ catalyst with size of 40-45mesh, 355-425μm.](image1)

![Figure 2. Composition of catalyst.](image2)
3. Design and fabrication of thruster

To get objective thrust, 50 mN, specific impulse of blended propellant was calculated theoretically. With objective thrust, Isp, and gravitational acceleration, propellant mass flow rate was calculated. From designed chamber pressure 5 bar and ambient pressure 1 bar, Mach number was calculated. And after c* was calculated with chamber temperature, throat area was determined and lastly expansion ratio was designed. Designed expansion ratio was 1.67 and expansion angle of conical nozzle was 12°.

| Thruster specification               |
|-------------------------------------|
| Thrust                              | 50 mN |
| Specific impulse                    | 117 s  |
| Chamber pressure                    | 5 bar |
| Propellant mass flow                | 0.034 g/s |
| Catalyst capacity                   | 2 g/s/cm³ |
| Catalyst volume                     | 0.0196 cm³ |
| Catalyst/support                    | Pt/Al₂O₃ |
| Support size                        | 40-45 mesh |
| Chamber aspect ratio                | 1.5 |

Table 3. Specification of designed thruster.

Figure 3. Drawing of designed thruster(left), micro nozzle and injector magnified by optical microscope(right).

Figure 4. Drawing of five layers of thruster component.

Figure 5. After 4 layers thermally bonded (left), integrated micro thruster(right).

4. Experimental test and discussion

4.1 Experimental setup

In order to measure the thrust, micro force sensor with sensor plate, thrust stand and feeding line were setup. Solenoid valve and syringe pump were used to feed propellant. After propellant was fed to thruster, thrust acted to downward direction and the sensor measured magnitude of thrust.
Figure 6 shows drawing and picture of experimental setup.

![Experimental setup for performance test.](image)

**Figure 6.** Experimental setup for performance test.

### 4.2 Result of experiment and discussion

The experimental results said that thruster worked by ethanol blended hydrogen peroxide propellant got higher thrust than thruster without blending under same mass flow. Figure 7 shows result of performance tests, left and middle figures are about transient thrust performance and right about steady state thrust. It took about 10 second to get target thrust. In experiment, two phase gas and liquid flow was observed at former part of transient section and only gas phase flow was observed latter part of transient section. It is estimated that because micro fluid flow of propellant was handled, even small quantity of water which was product of decomposed hydrogen peroxide, would made catalyst wetted in cold start and reduced catalyst decomposition efficiency. As more propellant was decomposed, temperature of chamber rose and it made water of decomposed hydrogen peroxide turn to vapor, catalyst dried, and catalyst have higher decomposition efficiency at high temperature. This phenomenon would be much effective in case of blended propellant thruster because of more enthalpy fed. It is observed in the left two plot of figure 7. Standard deviation of error between thrust acquired and curve fitting data was 2.8 for blended propellant and 3.2 for unblended, so expected small perturbation was identified. However, no small perturbation was found in case of steady state.

Generally, it is considered that high chamber pressure makes low perturbations of thrust[10], but this was not prominent in this micro scale thruster.

Steady state thrust of figure 7 shows ethanol blended hydrogen peroxide propellant got higher thrust than that of hydrogen peroxide without blending. Experimented propellant flow was 3ml/min, which was larger than designed flow rate 1.7ml/min. Average magnitude of thrust is 51 mN for blended propellant and 36 mN for unblended propellant. Assuming mass flow rate was accurate as 3ml/min, specific impulse is approximately 74 sec and 52 sec for blended and unblended respectively.

Thrust magnitude fluctuation was approximately ± 9.1% and ± 8.8% for ethanol blended hydrogen peroxide and unblended hydrogen peroxide respectively. Standard deviation was 2.8 for blended propellant and 3.2 for unblended.

Despite no stability improvement in steady state of two second, the improvement found in case of transient state during about ten seconds shows stabilization ability of blended propellant. Considering
possibility of thrust stabilization and increase of specific impulse of this experiment, blended propellant have advantages for micro scale monopropellant thruster.

Figure 9 shows combustion phenomenon of blended ethanol with decomposed hydrogen peroxide.

Figure 9. Auto-ignition of blended ethanol by decomposed hydrogen peroxide.

### 5. Conclusion

To improve performance of stability of micro thruster, planar type catalyst direct insertion MEMS monopropellant thruster with blending propellant was fabricated and evaluated.

Under the limitation of aspect ratio of glass pattern with wet etching, horizontal type thruster had more chances to improve stability of thrust than vertical type thruster.

The effectiveness of high enthalpy with blended propellant for thruster performance was prominent in the transient state rather in steady state, so that the expected improvement of stability of blended propellant thruster was valid only in the case of transient section not in steady section. Blended propellant suggests the possibility of thrust stabilization.

By blended propellant, micro scale monopropellant thruster can have not only system simplicity as monopropellant thruster, but also improved specific impulse and also possibility of stability improvement.

### Acknowledgment

This work was supported by the National Research Foundation of Korea(NRF) grant funded by the Korea government(MEST) (No. 2012R1A2A1A05026398).

### References

[1] Hitt D L, Zakrzewski C M and Thomas M K 2001 J. Smart Mater. Struct. 10 1163-75.
[2] K Takahashi, T Ikuta, Y Dan, K Nagayama and M Kishida 2006 Proc. Sens. Symp. 513-6
[3] J Lee, S Kim, S Kwon and M Yu 2012 J. Propul. Power. 28 396-404.
[4] J Lee and S Kwon 2013 Evaluation of ethanol-blended hydrogen peroxide monopropellant on a 10 N class thruster J. Propul. Power. AIAA Early Edition
[5] Satterfield C N 1993 Heterogeneous catalysis in industrial practice 2nd edition McGraw-Hill Singapore
[6] Lim H, An S, Kwon S, and Rang S 2007 J. Propul. Power. 23 1147-59
[7] Sungyong An and Sejin Kwon 2009 Scaling and Evaluation of Pt/Al2O3 Catalytic Reactor for Hydrogen Peroxide Monopropellant Thruster J. Propul. Power. 25 1041-5
[8] Tian H, Zhang T, Sun X, Liang D and Lin L 2001 Performance and deactivation of Ir/γ-Al2O3 catalyst in the hydrogen peroxide monopropellant thruster Applied Catalysis A 210 55-62
[9] Sungyong An, Jeongsu Lee, Rachid Brahmi, Charles Kappenstein, Sejin Kwon 2010 Comparison of catalyst support between monolith and pellet in hydrogen peroxide thrusters J. Propul. Power 26 439-45
[10] Sungyong An, Jungkun Jin, Jeongsu Lee, Sungkwno Jo, Daejong Park and Sejin Kwon 2011 Chugging instability of H2O2 monopropellant thrusters with reactor aspect ratio and Pressures J. Propul. Power 27 422-7