IMPROVEMENT OF UNIFORMITY AND IGNITION CHARACTERISTICS OF MICRO IGNITER ON GLASS WAFER FOR MICRO SOLID PROPELLANT THRUSTER

Daeban Seo[1*], Jongkwang Lee[2], Sejin Kwon[1]
[1]Department of Aerospace Engineering, KAIST, Daejeon, KOREA
[2]Samsung Electronics LCD R&D Center, Yongin, KOREA
*Presenting Author: seodb@kaist.ac.kr

Abstract: The design, fabrication and performance evaluation of a novel micro-igniter for micro-solid propellant thrusters are presented. The micro-igniter consisted of the membrane and the heat coil, and it was fabricated using a glass wafer for its structural stability. To improve uniformity and ignition characteristics, the glass membrane was fabricated by a polishing process for making its thickness uniform. Also, the heat coil was placed at the bottom of the membrane to contact with a propellant directly. In this study, the micro-igniter was designed including the chamber and upper layers for carrying out firing tests. After the micro-igniter was fabricated, uniformity and ignition characteristics were evaluated successfully, and the minimum distance between unit-igniters in an array was decided by firing tests.

Keywords: Micro-igniter, uniformity, ignition characteristics, glass membrane

INTRODUCTION

A micro solid propellant thruster is a kind of micro-propulsion systems for attitude and orbit control of nano-satellites. It is considered as the most suitable micro-propulsion system through current MEMS technology because it has a simple structure and no moving parts. In general, a micro solid propellant thruster is fabricated in an array-type to compensate the disadvantage of solid propellants which can burn only once. So, a micro solid propellant thruster array should have not only reliable performance but also uniform performance between unit cells.

The most important part in a micro solid propellant thruster is a micro-igniter. It is a device which ignites a propellant using Joule's heat for starting combustion, so it can have a great effect on the overall thruster's performance. A micro-igniter generally consists of a heat coil and a membrane. A heat coil generates Joule's heat and applies the heat to a propellant filled in chamber, and a membrane protects a propellant from the outside. Therefore, a micro-igniter should have reliable ignition characteristics and good structural stability, and it should guarantee uniformity for successful development of a micro solid propellant thruster array. To satisfy these conditions, many micro-igniters for a micro solid propellant thruster were developed. Most research groups developed a micro-igniter on a silicon-substrate [1, 2], and our team developed it on a glass-substrate [3]. Micro-igniters based on a silicon-substrate had thin dielectric membrane, so they gave reliable ignition characteristics. However, they were not suitable for protecting a propellant from harsh space-environments and for filling a propellant because of their thin membrane. On the other hand, a micro-igniter based on a glass-substrate had a thick membrane with a thickness of tens of microns. So it represented good structural stability, but deterioration of ignition characteristics occurred due to the thick membrane. Although both silicon- and glass-based micro-igniters were developed successfully, studies on uniformity of micro-igniters has not yet been reported.

In this study, we developed a novel micro-igniter on a glass-substrate for carrying out a study on uniformity of a micro-igniter and improving ignition characteristics. The reason that a glass-substrate was used as a material was to guarantee good structural stability. By the firing test, performance evaluation of the micro-igniter and finding out the optimum distance between unit-igniters in an array-type were performed.

DESIGN AND FABRICATION

Concept of micro-igniter

The schematic of the micro-igniter is illustrated in figure 1. It is important for a micro-igniter to have uniform thickness of a membrane for its uniformity. In the previous glass-based micro-igniter, it could not have uniform thickness of a membrane because the membrane was fabricated using wet etching process of a glass-wafer. To solve this problem, fabrication process of the membrane was changed in this design. The membrane was fabricated by polishing process instead of wet etching process after the membrane layer bonded to the chamber layer.

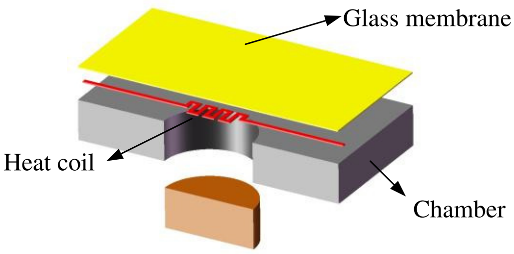

Figure 1. Schematic of micro-igniter

The position of a heat coil was also changed in this design. Micro-igniters developed until now had a heat coil placed at the upper side of a membrane. In the case of glass-based micro-igniter, it was a critical problem because heat-loss much occurred and delay time was needed for ignition due to the thick membrane. Therefore, we changed the position of the heat coil in order to contact with propellant directly.

Design of micro igniter

In general, a membrane and a heat coil are regarded as components of a micro-igniter. So a chamber layer with a propellant should be added for a firing test. We designed the micro-igniter to evaluate its performance adding a chamber layer as shown in figure 2. In this design, 7 unit-igniters were arranged in different distances between them for finding out the minimum distance that could prevent propagation of combustion. Also, the upper layer was added for the structural problem. After the propellant was filled in chamber layer, it was sealed by the bottom layer.

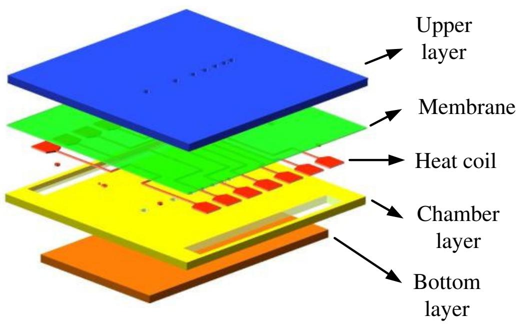

Figure 2. Designed micro-igniter for firing test

Fabrication process

All parts of the micro-igniter were fabricated from a photosensitive glass because it was useful for fabricating micro-systems with high aspect ratio. A low heat conductivity of a glass was another advantage for the micro-igniter in that combustion propagation between unit-cells could be minimized.

The fabrication process of the micro-igniter was divided into 4 parts: fabrication of the bottom, upper and chamber layer, fabrication of the membrane layer with heat coil, integration of the membrane layer and the chamber layer, and final integration process. First, bottom layer was fabricated through a dicing process of a glass-wafer. To fabricate the upper and chamber layer, the glass wafer was selectively exposed to UV light at an approximate wavelength of 310 nm. Then the exposed glass-wafer was inserted to a furnace for heat treatment. After heat treatment was completed, exposed area was etched by HF solution for completing the fabrication process.

Second, the membrane layer with the heat coil was fabricated by lift-off process as shown in figure 3. Photoresist was spin-coated onto the glass wafer and patterned using photolithography (figure 3 (a) and (d)). Then, Cr/Ni layers were deposited onto the wafer usi-

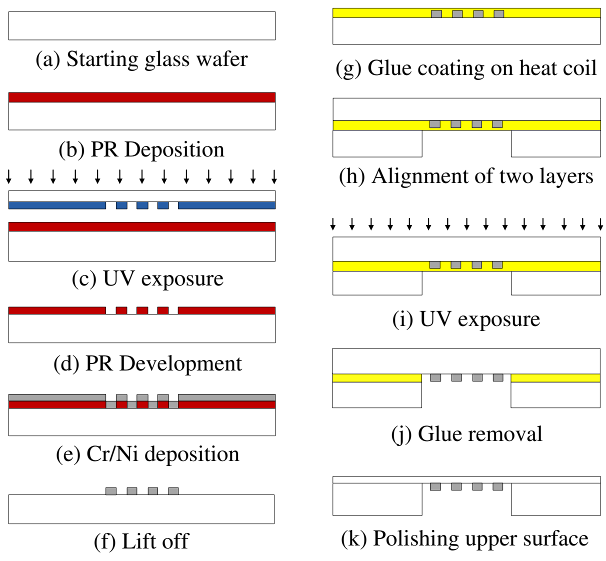

Figure 3. Fabrication process of membrane layer and integration process of membrane and chamber layers

ng a sputter (figure 3 (e)). Photoresist above the glass and the Cr/Ni layers were removed by acetone. After this process, the heat coil and contact pads were remained onto the wafer (figure 3 (f)).

Third, the membrane layer with heat coil and the chamber layer were bonded by UV curable glue in order to fabricate the membrane. In this study, the integration process of these two layers was very important. The reason was that if gaps existed between two layers, the propellant could leak into the gaps because the propellant used in this study was liquid when it was filled in the chamber. Therefore, we developed the new UV-bonding process as shown in the right-hand side of the figure 3 for preventing leaks of the propellant. UV curable glue was spin-coated onto the membrane layer (figure 3 (g)). The membrane layer was aligned with the chamber layer for integrating two layers, and these layers were exposed to UV light (figure 3 (h) and (i)). These layers were soaked in acetone to remove UV curable glue on the membrane area (figure 3 (j)). However, the UV curable

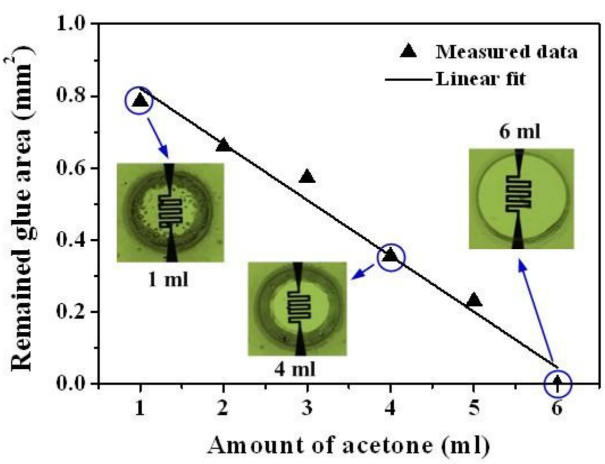

Figure 4. Remained glue area as a function of acetone's amount

glue was not removed cleanly after this removing process. To solve this problem, we repeated UV curable coating, UV exposure and glue-removing process varying viscosity of the glue by mixing it with acetone. Coating speed and time was fixed during coating process. When 6 ml acetone was mixed in 10 ml UV curable glue, the glue on the membrane was removed cleanly after glue-removing process as shown in figure 4. After the glue on the membrane was removed, the membrane layer was adjusted to 40 µm by polishing process (figure 3 (k)).

Finally, all layers of the micro-igniter were integrated through final integration process as shown in figure 5. In the first step, the propellant was filled in the chamber (figure 5 (a)). Lead styphnate was used as the propellant in this study, and this propellant was dissolved in a solution when it was filled. After the filling process, holes in the upper layer were protected by the Kapton tape to prevent the membrane being covered by the UV curable glue (figure 5 (b)). The glue was spin-coated onto the layer, and the Kapton tape was removed (figure 5 (c) and (d)). The upper layer was aligned with the chamber layer integrated with the membrane layer. These two layers were integrated after they were exposed to UV light (figure 5 (e)). The bottom layer was bonded to the bottom side of the chamber layer to seal the propellant. The Kapton tape was also used in order to prevent the propellant being wetted by the glue (figure 5 (f)). The glue was spin-coated, and the Kapton tape was removed (figure 5 (g) and (h)). Then, the bottom side of the chamber layer and the bottom layer were aligned and exposed to UV light (figure 5(i)). Through these processes, the fabrication of the micro-igniter was completed. Figure 6 shows the fabricated 4 layers of the micro-igniter, and Figure 7 shows the fabricated micro-igniter.

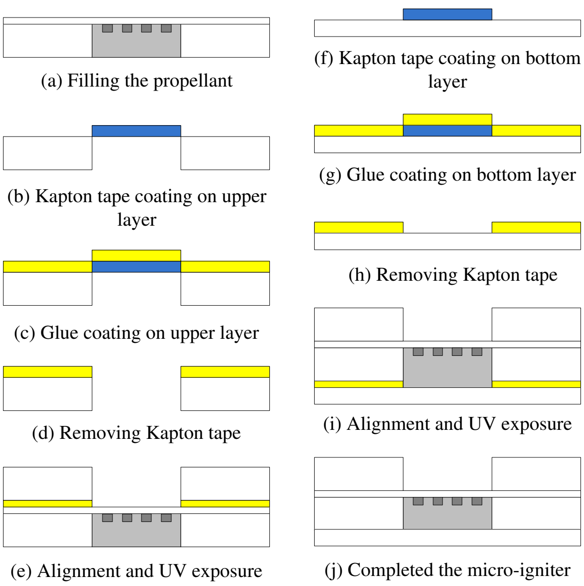

Figure 5. Final integration process of micro-igniter

IGNITION TEST

Experimental setup

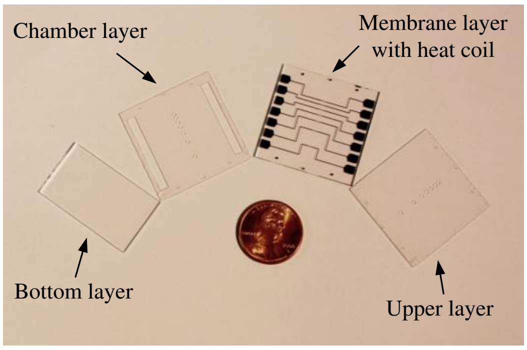

Figure 6. Fabricated layers of micro-igniter

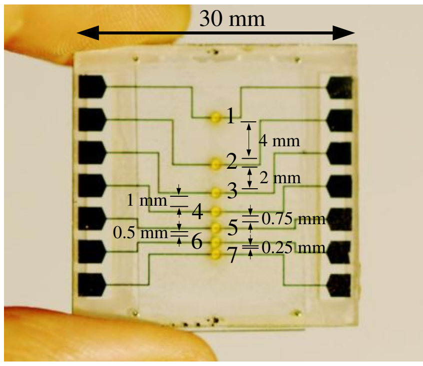

Figure 7. Fabricated micro-igniter

Experimental setup for an ignition test is illustrated in figure 8. An input voltage was applied to the micro-igniter using a power supply, and this voltage was measured using an oscilloscope. To apply a voltage to the micro-igniter accurately, we used a micro-positioner. A high-speed camera was used for acquiring images of the ignition process. All measured data by oscilloscope and acquired images were process using a computer.

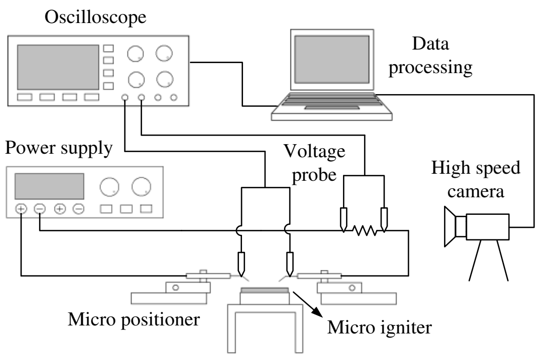

Figure 8. Experimental setup

Ignition characteristics

Firing test was performed in order to measure the ignition characteristics at room temperature. Figure 9 shows the combustion of the micro-igniter. A plume was observed during the combustion because the propellant completely burned in the chamber. The measured ignition delay and ignition energy are presented in figure 10. The ignition delay and the ignition energy decreased as voltage increased, and the measured minimum ignition delay was 11.04 ms with the ignition energy of 17.7 mJ. The ignition delay and ignition energy decreased by 60 percent and by 9.3 percent respectively compared to the previous glass-based micro-igniter developed by our team.

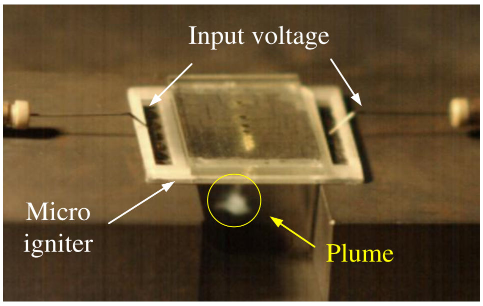

Figure 9. Firing test of micro-igniter

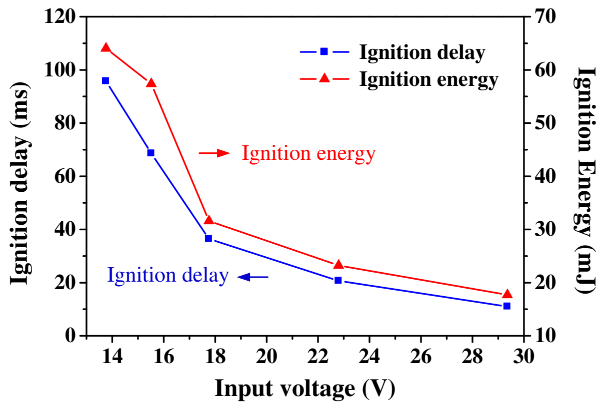

Figure 10. Ignition delay and energy as a function of voltage

Uniformity of micro-igniter

To evaluate uniformity of ignition characteristics of this igniter, all unit-igniters were ignited applying same voltage. The test results are presented in Table 1. The cell #7 was ignited simultaneously when the cell #6 was ignited as shown in figure 11. From this result, the minimum distance between unit-cells was decided as 0.5 mm. The calculated standard variations of the ignition delay and ignition energy were 1.35 ms and 3.11 mJ, respectively. The measured ignition success rate was 100%.

Igniter number	Ignition delay (ms)	Ignition Energy (mJ)
1	13.00	23.23
2	14.10	24.68
3	14.12	25.28
4	13.22	23.39
5	11.28	19.06
6	11.04	17.70
Standard variation	1.35 ms	3.11 mJ

* same input voltage

Table 1. Test results of micro-igniter

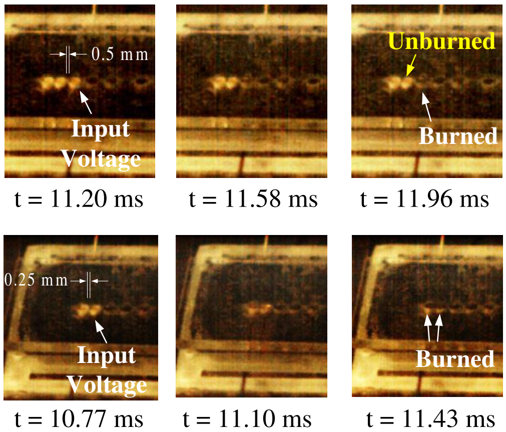

Figure 11. Ignition of cell #5 and #6

CONCLUSION

The design, fabrication and performance evaluation of a novel micro-igniter on a glass wafer for micro solid propellant thruster were described. This igniter was designed for improving uniformity and ignition characteristics of a micro-igniter. And fabrication process and firing tests of the igniter were performed in this study. The measured minimum ignition delay and energy were 11.04 ms and 17.7 mJ respectively, and standard variations of ignition delay and ignition energy were 1.35 ms and 3.11 mJ, respectively. The observed minimum distance between unit-cells in an array was 0.5 mm. We were the first to carry out the studies on uniformity of micro-igniters in the literature, and we successfully developed the micro-igniter which gives uniformity, reliable ignition characteristics and good structural stability. These features make the micro-igniter very suitable for being applied to micro solid propellant thrusters for control of nano-satellites.

ACKNOWLEDGMENTS

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