FABRICATION AND PERFORMANCE EVALUATION OF A MICRO IGNITER MEMBRANE ASSEMBLY FOR MEMS THRUSTER ARRAY

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Abstract: The fabrication and performance evaluation of a MEMS thruster array assembled with an improved micro igniter are described. We improved the stability of the igniter by using a glass membrane with a thickness of tens of microns. The membrane was fabricated by anisotropic wet etching of photosensitive glass and deposition of Pt for electric heat coil. The thermal and electrical, and mechanical characteristics were measured. Ignition tests with fully assembly thruster were performed successfully to estimate the ignition characteristics and the thrust performance.

Key words: MEMS thruster, micro igniter, glass membrane, ignition

1. INTRODUCTION

Micro propulsion is a key component of micro/nano satellite since satellite will need a very small and accurate force to attain orbit transfer, attitude control, and station keeping. MEMS solid propellant thruster is the most feasibility for development with current MEMS technology [1].

MEMS thruster generally consists of micro nozzle, micro igniter, micro combustion chamber, and propellant. The micro igniter which initiates thruster and determines the overall propulsion performance is a most important component to realize MEMS thruster. Various micro igniters have been widely investigated to decrease the electric power consumption. The conventional micro igniters consisted of a thin dielectric membrane from silicon substrate. However, they were not reliable in harsh environments and filling propellant was very difficult because of a few micron thick membrane [2-3].

In this study, we improved the stability of the micro igniter using a glass membrane with a thickness of tens of microns and developed 3 ×3 thruster array.

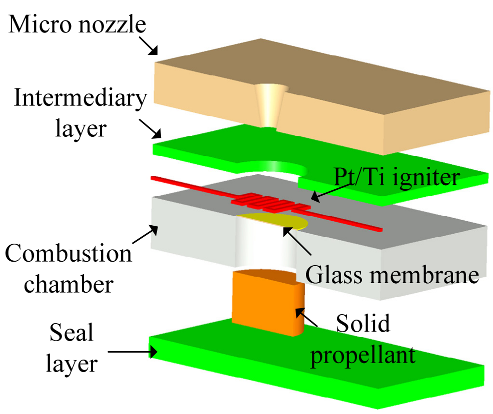

Fig. 1: Schematic of MEMS thruster.

This micro igniter ensured to easy fill propellant as maintaining low power consumption, to simplify the fabrication method with low fabrication cost. Performance evaluations of the micro igniter were carried out. After the development of the micro igniter, other components of MEMS thruster were fabricated from glass and integrated with the micro igniter. Ignition characteristics of MEMS thruster were performed.

2. DESIGN AND FABRICATION METHOD

2.1 Design

The schematic of MEMS thruster is illustrated in figure 1. MEMS thruster consists of four layers and solid propellant. Micro nozzle is located at the first layer. The third layer contains the micro igniter and solid propellant. The fourth layer seals the combustion chamber. An intermediary layer is added between the micro igniter and the micro nozzle. The operation principle is as follows: the micro igniter is supplied with the electric power. The temperature of the micro igniter is raised by the Joule heating. The solid propellant is ignited by the micro igniter when the ignition temperature of the propellant is achieved. The high temperature and high pressure combustion gases are generated and the membrane is broken. The thrust is generated through the micro nozzle.

Important design parameters of the micro igniter were the material of the resistance, and the membrane. Pt was adopted for the material of the resistance because it exhibits high at high temperature and resistance to oxidation and corrosion. Tens of microns thick glass membrane was selected for the micro igniter. The glass membrane had a lower thermal conductivity, cheaper fabrication cost than the dielectric membrane.

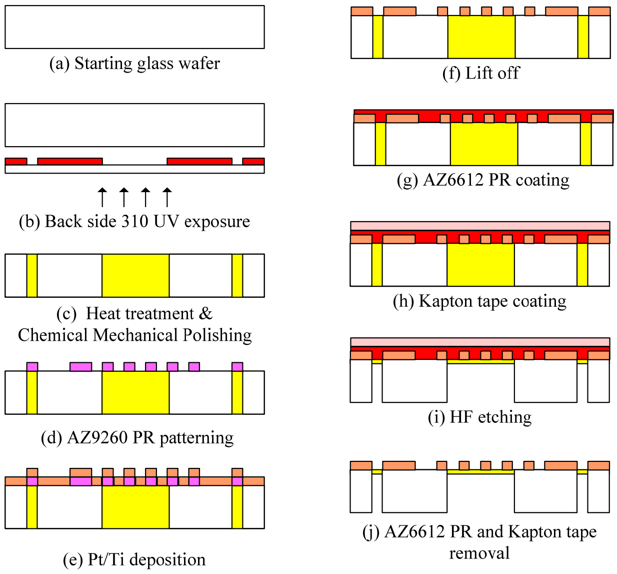

Fig. 2: Fabrication method of micro igniter on the glass membrane.

2.2 Fabrication method

The micro igniter on the glass membrane was fabricated from photosensitive glass. Photosensitive glass was a useful material in the production of components for a variety of micro systems. High aspect ratio etching was relatively easy [4]. Additional advantage was a lower heat conductivity which ensured a good thermal insulation between the chambers.

The fabrication process of the micro igniter on the glass membrane is shown in figure 2. A quartz wafer with a chromium absorber pattern was prepared to transmit at the required wavelength of 310 nm. The substrate was exposed to UV light at an approximate wavelength of 310 nm (figure 2(b)). The photosensitive glass was illuminated by UV light with an energy density of approximately 2.5 J/cm^2. During the UV exposure step, silver atoms were formed by a photochemical process in the illuminated section. Heat treatment (figure 2(c)) was achieved using a programmable furnace. During the heat treatment, the photosensitive glass crystallized around the silver atoms. The crystallized sections (glass-ceramic) had different physical properties than the glass itself. After the heat treatment, the surface was polished for photolithography process. Photoresist was spin-coated onto the glass and patterned using photolithography (figure 2(d)). Pt/Ti lift off process was carried out to form the electric heater (figure 2(e) and (f)). The surface on which Pt/Ti layer was patterned was protected from HF solution. Photoresist was spin-coated onto the surface and then the surface was taped by Kapton tape (figure 2(g) and (h)). The final step in the fabrication was to etch the glass-ceramic (figure 2(i)). The etching was performed in a diluted 10 % HF. The etching time was monitored to control the thickness of glass membrane. After etching process, Kapton tape and photoresist were carefully removed in acetone.

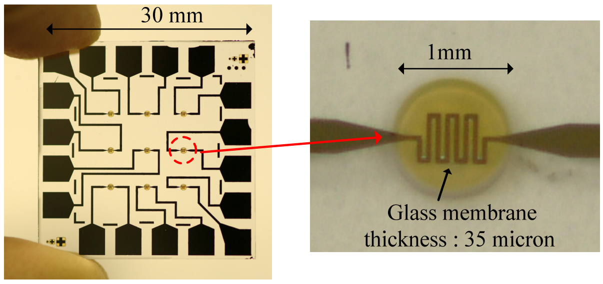

Fig. 3: Fabricated micro igniter.

The fabricated micro igniter on the glass membrane is shown in fig.3. The yellow part was the glass membrane. The thickness and diameter of the membrane were 35 μm and 1 mm, respectively. The width of Pt/Ti pattern was 40 μm. The heating area was 520 μm × 440 μm.

3. CHARACTERISTICS

3.1 Thermal and electrical characteristics

The relation of the temperature to the given power was induced from the relation of the resistance variation to the temperature and the given electric power. The relation is shown in equation 1 – 3, respectively:

$$R = R_0(1 + TCR \times T) \quad (1)$$

$$R = R_0(1 + PCR \times P) \quad (2)$$

$$T = T_0 + {PCR}/{TCR} \times P \quad (3)$$

where R is the resistance of the micro igniter, T and TCR is the temperature and the temperature coefficient of the resistance, and P and PCR is the electric power and the power coefficient of the resistance. The change of temperature was given by furnace with the measurement of the change of the resistance without electric power. The change of the resistance was measured as the electric power loaded to the micro igniter varied. TCR and PCR were obtained from the linear fitting results of the experimental results. The temperature response to given electric power was estimated from Eq. (3).

Performance of the micro igniter was estimated on the different membranes to figure out the effects of the membrane. The proposed glass membrane, the 2 μm

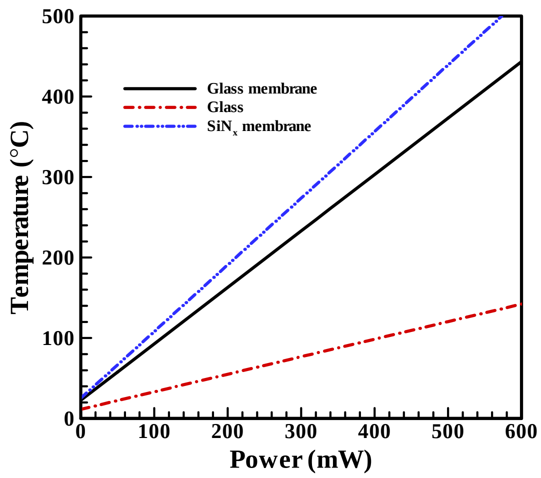

Fig. 4: Temperature as a function of power.

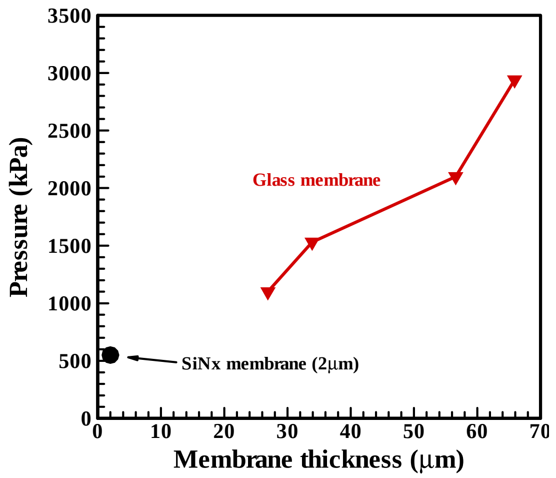

Fig. 5: Fracture pressure of membrane

thick SiN_x dielectric membrane, and the 500 μm thick photosensitive glass substrate with the same heating area were used. The temperature responses to given electric power of all cases are presented in figure 4. The electric power necessary to obtain a temperature of 300 °C at the micro igniter on the glass membrane was approximately 16 % higher than the dielectric membrane and three times lower than the glass substrate.

3.2 Fracture pressure

The fracture pressure of the micro igniter is also an important characteristic because the fracture pressure is closely related with filling propellant. Micro igniter on the membrane is robust to withstand the pressure of filling up but also sufficiently thin to be able to break when the pressure increases. Micro igniter on the dielectric membrane needed an additional technique due to the low fracture pressure.

In the present study, the fracture pressure of the membranes was measured using the pressure chamber.

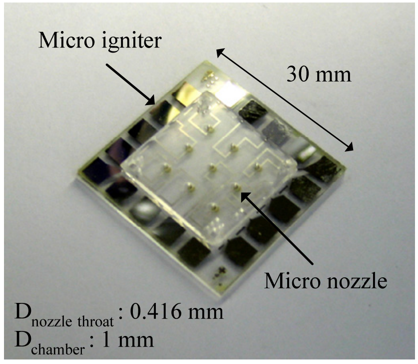

Fig. 6: Fabricated MEMS thruster.

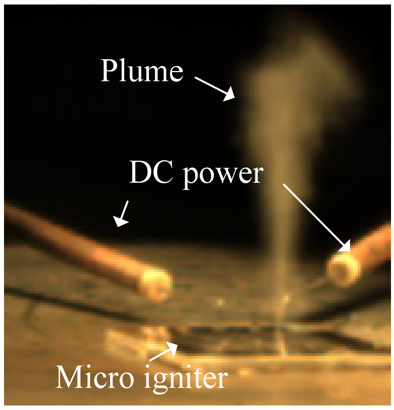

Fig. 7: Combustion test of MEMS thruster.

The glass membranes with diverse thickness and the 2 μm thick SiN_x membrane were prepared for the experiments. The fracture pressure is presented in figure 5. The 35 μm thick glass membrane could withstand 1531 kPa that was four times as high as the pressure that the 2 μm thick SiN_x membrane yielded.

4. IGNITION TEST

4.1 Assembly of MEMS thruster

MEMS thruster was fabricated for the ignition test of the micro igniter. The micro nozzle layer, intermediary layer and seal layer were also fabricated with anisotropic etching of photosensitive glass. The diameter of nozzle throat was 416 μm. Area ratio of the micro nozzle was 1.85. Thermal and UV bonding techniques were used in the assembly procedure.

Lead styphnate was used as the propellant. Figure 6 shows the fabricated MEMS thruster.

4.2 Ignition characteristics

Firing test was performed in order to estimate the ignition characteristics and thrust performance. Figure 7 shows the combustion of lead styphnate. The ignition delay and the ignition energy are presented in figure 8.

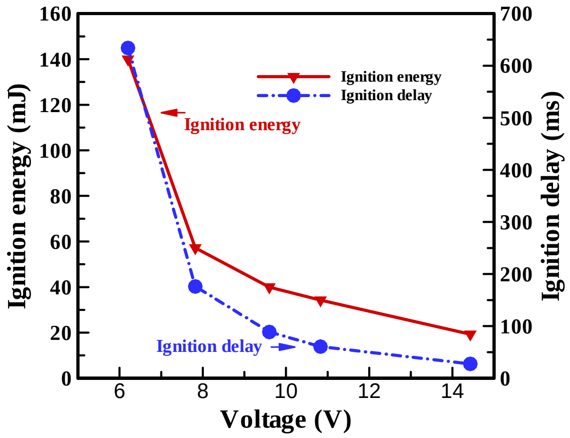

Fig. 8: Ignition energy and delay as a function of voltage.

The ignition delay and the ignition energy decreased as voltage increased because the high voltage caused the high temperature in the micro igniter. The minimum ignition delay was 27.5 ms with the ignition energy of 19.3 mJ. The measured maximum thrust and total impulse at the case of lead styphnate were 182 mN and 0.3 mNs, respectively.

5. IGNITION CONTROL SYSTEM

MEMS thruster array contains 9 thrusters on a single glass chip. Ignition system is needed because each thruster could be fired independently. MEMS thruster was assembled into PCB by wire bonding. Ignition control system was developed by using MOSFET, micro controller, and DC regulator. Figure 9 shows the MEMS thruster array with ignition control system.

6. CONCLUSION

The fabrication and performance evaluation of a MEMS thruster assembled with an improved micro igniter were described. We improved the stability of the micro igniter by using a glass membrane. We established the fabrication process of the micro igniter on photosensitive glass wafer. The membrane was fabricated by anisotropic etching of photosensitive glass and Pt/Ti lift off process. The temperature response to electric power and the fracture pressure of the membrane were estimated. Electric power to get the temperature up to 300 °C was about 400 mW. The power consumption of the glass membrane was about 16 % higher than the dielectric membrane. The glass membrane withstood 1531 kPa that is about 4 times higher than the dielectric membrane. The solid propellant could be filled with the micro chamber without an especial technique due to high structural stability of the glass membrane. MEMS thruster was fabricated for the ignition test of the micro igniter. Lead styphnate were used as the propellant. The micro igniter achieved a successful ignition. The minimum ignition energy was 19.3 mJ with the ignition delay of 27.5 ms. Maximum thrust and total impulse were 182mN and 0.3 mNs, respectively. Finally MEMS thruster array were integrated with ignition control systems. The present study demonstrated that simpler, robust, and low cost fabrication process of the igniter on glass wafer is possible and the fabricated igniter performed well when assemble into the thruster array.

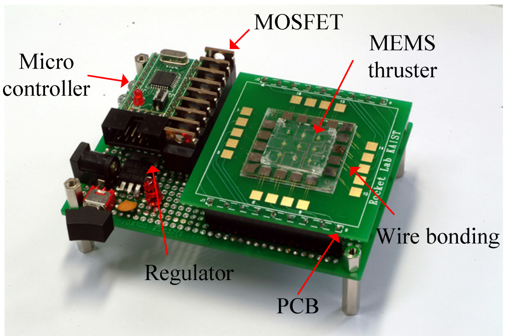

Fig. 9: MEMS thruster with ignition control system.

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