Design and Fabrication of Thermal Bubble Fuel Injector

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Abstract

This study uses the thermal bubble inkjet technology to design and fabrication a micro fuel injector. Due to the low surface tension of fuel property, this study applies the hydrophobic treatment on nozzle plate and the contact angle is improved from less than 10 to 49.5 degrees which avoiding the puddling condition on the nozzle plate surface. The inkjet technology trend approaches the droplet volume decreased and printing resolution increased. While the running speed of engine system needs increased ejection flow rate of thermal bubble fuel injector. Therefore, in this study, injection flow rate of the thermal bubble fuel injector approach to 8.2 c.c./min with frequency of 3 kHz compared to the commercial print head of 2 c.c./min with 8 kHz.

Introduction

The thermal bubble inkjet technology being used on the design of digital controlled fuel injector which applying on a fuel engine system. Each single pulse signal on the thermal bubble fuel injector controls the individual atomization quality of fuel droplet. The advantages of digital control on fuel droplet atomization are active control of fuel ejection volume and optimization of combustion efficiency.

In the internal combustion engine, the high atomize effects fuel injector could be provide small fuel droplets to mixes with surrounded hot air. At the mixing process, the uniform fuel-air mixing could be improved efficiency of combustion and air pollution. The conventional fuel injection system of motorcycle is use the carburetor to supply atomized fuel. The carburetor fuel atomization system is a passive control fuel atomization system, so that the fuel-air ratio is not accuracy.

In the printing technology, the ejection droplet can be controlled. In the print head, hundreds of nozzle are accuracy control simultaneously. Therefore, if apply the print head technology to fuel injection system, this system is a digital control system. On the other head, if we assemble number of micro fuel injectors to surround with the throttle body, the fuel distribution could be controllable.

Tseng et al.[1] using the thermal bubble method to ejection uniform fuel droplets for mixing enhancement. In this study, the thermal bubble technologies are use to developed the micro fuel injector.

Design of the Fuel Injector

The principle of micro fuel injector design is similar to commercial thermal bubble ink jet print head. The thermal bubble technology uses thermal energy to grow a bubble in the firing chamber, then the bubble pump working fluid to eject droplet out of the nozzle. Therefore the heater size, diameter of nozzle and the geometry of firing chamber are important factors in micro fuel injector design.

In this study, there are 100 heaters in a micro fuel injector and with two series heaters in one loop circuit. So that apply a pulse signal on the loop circuit, two nozzles are ejecting fuel droplet simultaneously.

As shown in Fig. 1, the heater size is 105×105 μm^2 and the geometry of firing chamber also shown in this figure. By assuming that bubble growing maximum volume is about the same with the firing chamber. It could be easy to estimate the volume of bubble is one half of sphere, and the diameter of bubble approximate to the size of firing chamber edge. Therefore, the ejected fuel droplet volume is approximate to bubble volume is 303 pl in this design. Inside the chip structure of micro-fuel injector, the geometry of chamber is 300, 120, and 60 μm in length, width and fluid channel thickness, respectively. The heater size within the chip is 105×105 μm^2. The diameter of nozzle is 80 μm and thickness of the nozzle plate is 50 μm.

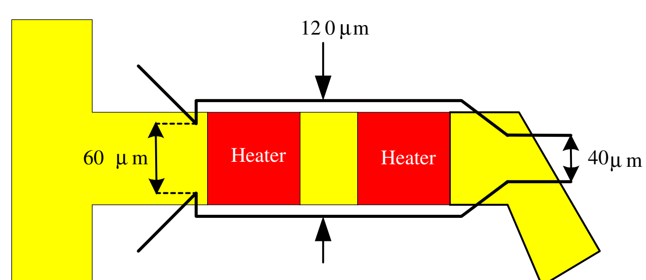

Figure 1. Design of the heater element

Fabrication of the Fuel Injector

The fabricating process starts with a N-type <100> silicon wafer and growing the silicon dioxide as a thermal barrier layer by thermal oxidation. After oxidation process, the heater metal and conduction line metal was deposited by sputter, respectively, and was defined by photolithography. Following the deposition and definition of heater and conduction line, the passivation layers (silicon nitride and silicon carbide) were deposited by PECVD.

Another of the anti-shocked passivation layer of tantalum (Ta) metal was deposited by sputter and defined by photolithography. Finally, the contact holes were etched by RIE, and the contact pad metal TiW/Au was also be deposited and defined.

The micro fluid channel was shown in Fig. 2. In this study, the micro fluid channel was defined by thick photoresist and the nozzle plate was fabricated by electroforming. Due to the low surface tension of fuel property, this study applies the hydrophobic treatment on nozzle plate to avoiding the puddling effects on the nozzle plate surface. In the hydrophobic treatment, we used the Teflon hydrophobic solution numbered as Teflon AF-601 of DuPont with the hydrophobic solution diluted to 1 % by FC-40 of 3M. Then, the diluted hydrophobic solution was spin coated on nozzle plate. Finally, the soft bake in 160°C/10 min and post bake in 230°C /10 min by hot plate.

After the hydrophobic treatment, the contact angle is improved from less than 10 to 49.5 degrees, which shown in Fig. 3.

During the fuel injector assembling process, the nozzle plate was bonded with the chip of fuel injector by accurate alignment and bonded with the bonding pad of chip and the leads of TAB (Tape Automated Bonding) tape. Finally, attach the TAB tape to the cartridge by glue, which is show in Fig. 4.

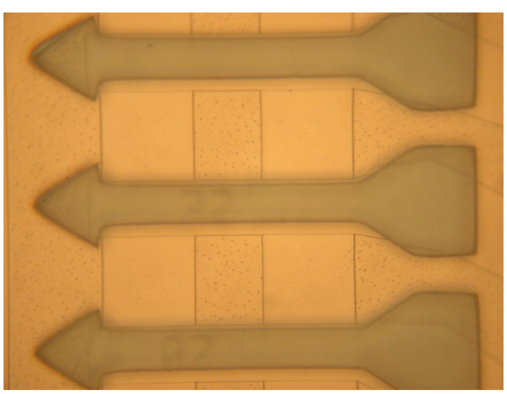

Figure 2. Top view of the micro fluid channel

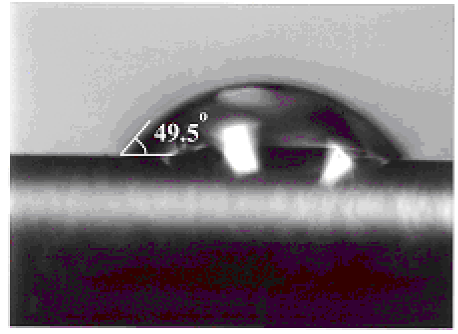

Figure 3. After the hydrophobic treatment, the contact angle is improved from less than 10 to 49.5 degrees.

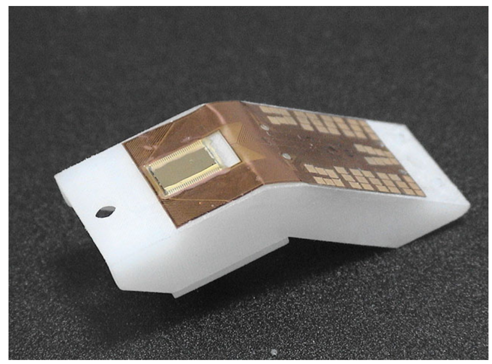

Figure 4. Thermal bubble fuel injector

Fuel Injector Testing

In the fuel droplet ejection testing, addition the different pulse signal into the electrode. Recording the ejection flow rate of the fuel injector from the flow meter. In this study, the flow meter was located between the fuel tank and the fuel injector.

Figure 5 shows that the ejection flow rate is increasing with the pulse width increasing with the same voltage and firing frequency. Furthermore, the frequency response is decreasing with the pulse width increasing. Within the pulse width range between 5 to 7 μSec, maximum of the ejection floe rate is 7 c.c./min.

In Fig. 6, experimental result shows that ejection flow rate is increasing with the apply voltage increasing with the different firing frequency. At the firing frequency with 3 kHz, the maximum ejection flow rate is 8.2 c.c./min and ejected volume of fuel droplet is about 455 pl. Comparing with the commercial inkjet print head model type of HP51629, the fuel ejection flow rate of the this study is four times and the volume of fuel droplet is five times of HP51629 inkjet print head.

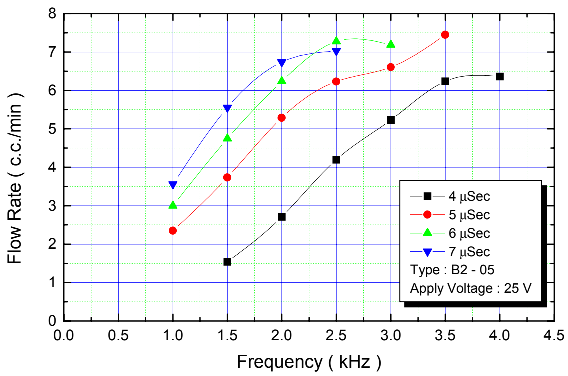

Figure 5. Characteristic curve of the ejection flow rate versus the firing frequency in different pulse width.

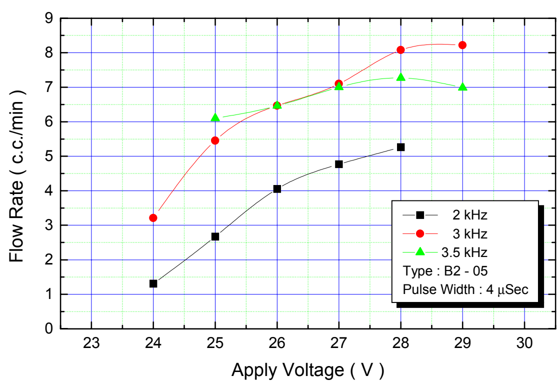

Figure 6. Characteristic curve of the ejection flow rate versus the apply voltage in different firing frequency.

It is important to monitor the temperature of nozzle plate surface during all nozzles firing operation at the same time for thermal heat generated by the thermal bubble fuel injector to pumping fluid ejection out the nozzle. As shown in Fig. 7, temperature on the surface of nozzle plate is about 70°C with the heating pulse width of 4 μSec. The temperatures on nozzle plate surface are around 60°C for the heating pulse width at 5, 6, and 7 μSec. As the results of Fig. 5 show that ejected flow rate is about 2.75 c.c./min at the heating pulse width of 4 μSec, which is much less than that for pulse width at 5, 6, and 7 μSec at 2 kHz and 25 volts for firing frequency and applied voltage, respectively. Therefore, the cooling effect by ejected fluid with pulse width 4 μSec is poorer than other cases. Therefore, with increasing the ejected flow rate of fuel droplet taking away heat generated by the heater of thermal bubble generator, temperature on the nozzle plate surface will decrease.

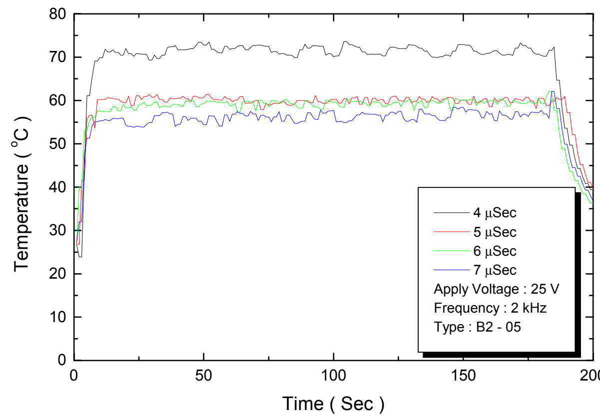

Figure 7. Operating temperature of nozzle plate surface in different pulse width

In Fig. 8, a bob of fuel was ejected by the 100 nozzles are firing simultaneously. The microcosmic view of fuel ejection is shown in Fig. 9 for four columns of nozzles were ejected fuel droplets at the same time. It shows good performance of atomization into small fuel droplets by the thermal bubble fuel injector.

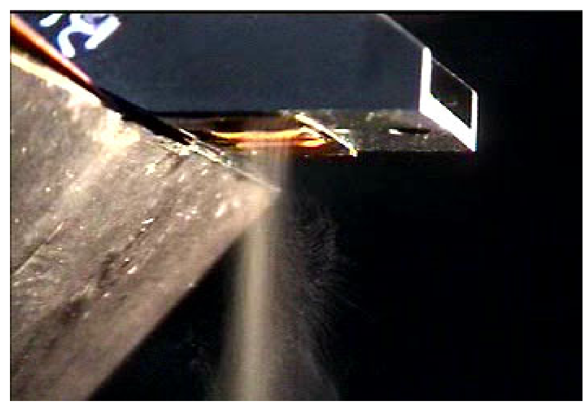

Figure 8. Fuel ejection of the thermal fuel injector

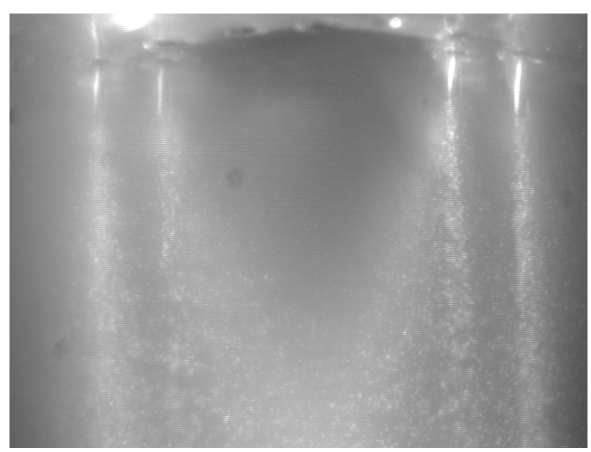

Figure 9. Visualized the droplets ejection

Summary and Conclusion

With the application of thermal bubble, the fuel injector has a large impact and market potential in this field. The thermal accumulated effect and puddling condition were important and serious issues in the design of micro fuel injectors. In this study, it reveals that thermal bubble technology applied to the fuel injector is successfully controllable and operating. The hydrophobic treatments were used in this study to avoid the puddling effects on the nozzle plate surface. The maximum ejection flow rate of the fuel injector is 8.2 c.c./min, this ejection flow rate could be applied the 125 c.c. motorcycle engine to operate on different loading and speed ranges.

Reference

1. Tseng, F. G., Kim, C. J., and C. M. Ho, "Control of Mixing with Micro Injectors for Combustion Application", *Proceeding of MEMS (DSC-Vol.59), ASME IMECE*, Atlanta, Nov. 1996. pp. 183-187.

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Biographies

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