

Fabrication and Characterisation of Silicon Micromachined Nozzles for Continuous Ink Jet Printers

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Abstract

A silicon micromachined nozzle for continuous ink jet printing is developed at our department. The commonly used glass nozzles in high quality applications often show large variations in frequency behaviour from unit to unit which is mainly due to mechanical resonances. The manufacturing process is rather complicated and it is difficult to achieve high droplet formation stability at a given stimulation frequency. This must be overcome by either adjusting the operating frequency in the printer or by selecting nozzles that operate well at the wanted frequency.

The proposed silicon nozzle has a simple geometrical design and the fabrication process has high reproducibility which results in less variation in performance from unit to unit. The batch fabrication with several nozzles per silicon wafer will also reduce the cost per unit.

In the prototype nozzle a 13 mm x 2 mm x 30 μm channel is etched in a silicon die. The orifice is etched through the die at the centre of the channel. On the nozzle front side, the silicon around the 10 micrometer x 10 micrometer orifice is removed leaving a pyramid shaped nozzle extending from the surface. The backside of the nozzle die is bonded to a glass lid.

The channel is supplied with an inlet and an outlet drilled through the glass lid. The flow-through option facilitates cleaning at the end of the manufacturing process since the cleaning fluid does not have to pass the orifice. During operation the outlet is sealed.

A piezo-element is attached to the silicon die close to the orifice for stimulation of the droplet formation.

An 11 micrometer jet at a flow rate of 0.22 ml/min emerges at a pressure of 15 atm. compared to about 40 atm. for a typical glass nozzle. The droplet formation and flight stability is characterised with an in-house developed optical measurement system. The results show that the nozzle generates droplets with high droplet formation stability in a region around the wanted stimulation frequency of 1 MHz.

Introduction

A continuous ink jet printer based on the Hertz technique[1] produces high quality images by charging and deflecting unwanted droplets from a continuous train of droplets. The droplets are created from a jet that is ejected from a nozzle with a small orifice.

The jet naturally breaks up into droplets but the droplet formation rate is not constant[2]. However, the droplet formation rate can be stabilised by mounting a piezoelectric crystal on the nozzle. When the crystal is supplied with a stimulation signal at a frequency around the natural droplet formation rate it will cause periodic break-up of the jet. This allows the nozzle unit to generate equally sized droplets with highly constant distances in time between the droplets. The design of the nozzle also influences the droplet formation[3,4,5].

The Hertz continuous ink jet printer principle demands a highly stable droplet formation rate to be able to electrically charge and deflect unwanted droplets from the continuous stream of droplets. The principle is shown in figure 1.

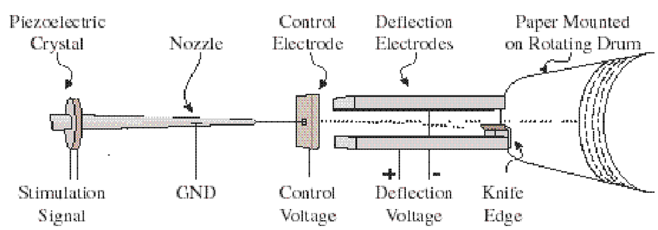

Figure 1. The Hertz continuous ink jet printer principle. A control electrode, positioned at the point of droplet formation, charges the unwanted droplets and these are later deflected and caught by a knife edge. The uncharged droplets are not affected by the deflection field and hence hit the paper in the desired pixels.

The nozzle is traditionally made from a glass tube that is heated and pulled. The orifice of the nozzle is hence often circular and has a diameter of approximately 10 μm.

The manufacturing of glass nozzles with orifices in the range of 10 μm is a craftsmanship which demands experienced personnel. The nozzles are however still individuals due to the complex mechanical resonances and the processing of large numbers of nozzles which should have identical performance in droplet generation is difficult.

A method to produce nozzles that have very little variation in performance is desired. One alternative to mass produce nozzles with repeatable performance is to use silicon micromaching. Silicon wafers processed in clean-room environment by the same processes that are used to manufacture semiconductor devices can be used for construction of micromechanical structures[6].

Micromaching of silicon has shown to be a feasible method to produce nozzles for continuous ink jet printers[7,8]. The repeatability of production is due to the quality of the manufacturing procedures. The size of the orifice for the nozzle is depending on the accuracy of the lithography process as well as the controlled depletion of silicon. Once these processes are tuned in is it possible to produce uniformly sized nozzles.

The prototype nozzle units manufactured at the department were aimed to have nozzles with well defined small orifice sizes (≈ 10*10µm), to keep the front area of the nozzle as little as possible and to facilitate flushing of the nozzle.

Materials and Methods

The nozzle unit consists of a silicon microstructured die and a glass lid. The structure of the nozzle unit is presented in figure 2. The die houses the pyramid shaped nozzle and the ink flow channel. The glass lid serves as a backing for the flow channel and provides the flow channel with ink inlet and outlet through two water-jet drilled holes (ϕ=1 mm). The nozzle is mounted in a nozzle holder which houses a 1 µm PTFE filter.

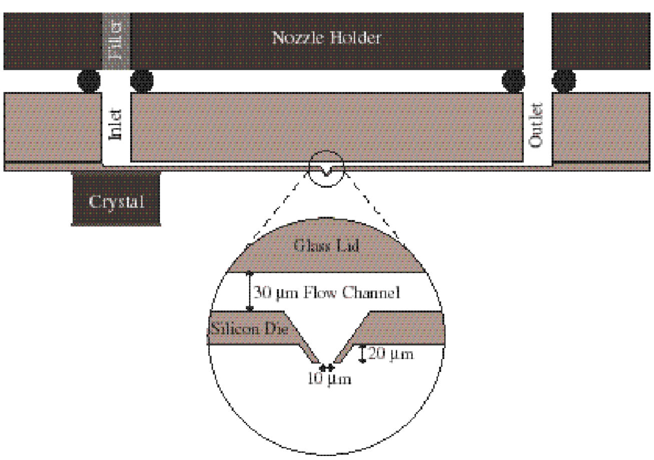

Figure 2. A cross-section of the nozzle structure. The dimensions for the flow channel in the nozzle prototype are (l) 13mm, (w) 2mm and (d) 30µm. The water-jet drilled holes in the glass lid have a diameter of 1 mm.

The flow channels and the inverted pyramids are anisotropically etched in the back side of the silicon wafer <100>. A pyramid is etched in order to define the structure of the nozzle extending from the front side of the wafer. The back side of the wafer is thereafter n-doped to protect the nozzle structure in the following pn-etch. The process steps can be studied in figure 3.

The die is anodically bonded to the glass lid after etching and sawing. The glass lid is mounted on the die so that the through holes are positioned at each end of the flow channel. By doing this the system can be flushed with a cleaning fluid to remove any particles that are left from the manufacturing process without forcing them through the nozzle. After flushing the system the outlet hole in the glass lid is sealed with a removable seal.

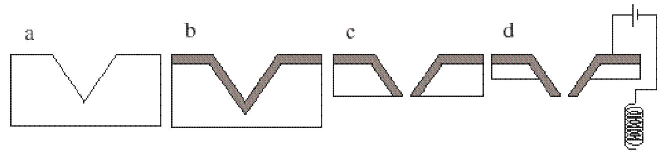

Figure 3 a: The flow channel and inverted pyramid is anisotropically etched. b: The backside of the wafer is n-doped(grey). c: The front side is anisotropically etched to attain the desired orifice size. d: The passivisation voltage is turned on to protect the doped section and the pyramid shaped nozzle is uncovered when the etching is continued.

The piezoelectric crystal is mounted on the surface of the die and kept in place by one of the clips holding the nozzle in the nozzle holder.

To assess the droplet formation stability for the suggested nozzle unit we utilised a measurement setup developed at the department[9]. The principle of the system can be studied in figure 4. The droplets passing through the laser beam cause a shadow image on the detector whose output is sampled by a fast digitising oscilloscope. The standard deviation for distance in time between a large number of consecutive pairs of droplets is used as a measure of droplet formation stability.

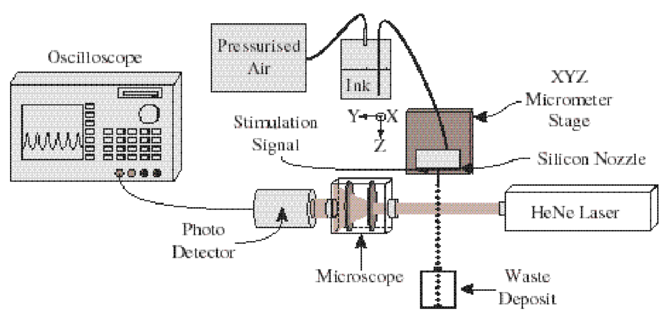

Figure 4. The optical measurement system setup.

The measurement system is used to study how different stimulation signals influence the droplet formation stability. Experiments were conducted with a constant amplitude of the stimulation signal while the frequency of the signal was varied in 10 kHz steps.

Results and Discussion

The use of silicon nozzles for continuous ink jet printers is possible since the droplet formation performance of the silicon nozzle is comparable or superior to that of a glass nozzle. The main advantage with the silicon nozzle is the ease of manufacturing and the possibility to put nozzles in close proximity of each other. Small distances between nozzles are interesting if nozzle systems with multiple nozzles per colour are to be developed.

The design of the nozzle with its pyramid shape has shown to be robust and reliable. A top view of a silicon nozzle can be studied in figure 5. The droplet formation does not seem to be affected by the square shape of the orifice. See figure 6.

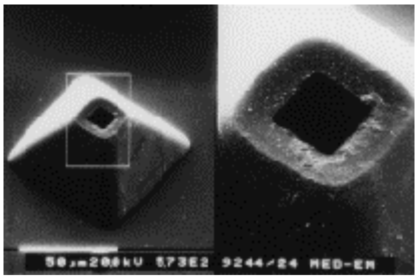

*Figure 5. A top view of the nozzle captured with an SEM. The orifice size is approximately 10*10 µm. The small front area in combination with the pyramid-shaped nozzle reduces the risk of misalignment of the jet due to deposition of ink close to the orifice.*

Figure 6. A jet ejected from a square orifice changes to cylindrical shape after a few droplet diameters. This can be seen as the waves on the jet close to the nozzle. The waves that cause break-up of the jet grow as the jet travels and are not visible until close to the droplet formation point.

Glass nozzles have previously been found to have good stimulation frequencies where the droplet formation stability is high. However, in close proximity to these frequencies have bad stimulation frequencies, where the droplet formation stability is low, been detected. A small increase or decrease of the stimulation signal could change the stability from high to low or from low to high.

Measurements conducted with the optical measurement setup showed that the droplet formation stability for a wide range of frequencies was comparable to that of a glass nozzle working at high droplet formation stability. The measurements were conducted at a flow of 17 ml/min driven by a pressure of 9.5 atm The ejected jet travelled with a velocity of approximately 30 m/s. The nozzle was however operational at 0.22 ml/min which demanded a driving pressure of 15 atm.

The natural droplet formation frequency for the nozzle was calculated to be around 600 kHz and the maximum droplet formation frequency was calculated to be around 850 kHz

The result of measurements conducted at 7 mm distance from the orifice with two different stimulation amplitudes can be studied in figure 7. The droplet formation stability was found to be influenced both by the stimulation frequency and the amplitude of the stimulation signal. The higher amplitude generates droplets with high droplet formation stability in a slightly wider range of frequencies then the lower amplitude.

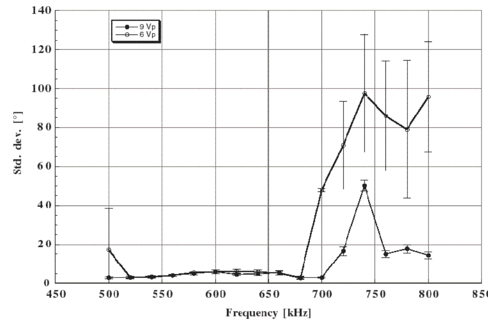

*Figure 7. Standard deviation for time between droplets for a 10*10 µm nozzle measured at 7 mm from the orifice. The nozzle was operated at a flow of 0.17 ml/min which was achieved when a 9.5 atm. pressure was applied. The stimulation frequency was varied from 500 to 800 kHz.*

The droplets were observed in stroboscopic light in order to capture images to relate to the measurement data. In figure 8 are images captured at different distances from the nozzle shown. The droplets are created with a stimulation frequency of 590 kHz and the ink flow is 0.17 ml/min. The distance to the point of droplet formation is approximately 0.5 mm.

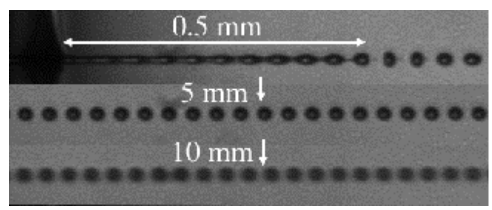

Figure 8. Images of droplets captured in stroboscopic light. At the point of droplet formation (top), 5 mm from the nozzle (middle) and at 10 mm from the nozzle. The stimulation frequency was 590 kHz.

Experiments have shown that it is possible to clean clogged nozzles by applying suction to the opened outlet while the inlet is closed. The inlet is thereafter opened, allowing ink to flow into the nozzle unit, while the suction is still applied to the outlet. After flushing the system for some minutes the system is operational again.

We have not experimented with the positioning of the piezoelectric crystal though we realise this is an important factor in the strive for high stability droplet formation.

References

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