

Novel Micro Piezo Technology for Ink Jet Printhead

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Abstract

Micro Piezo technology is offering superior features in ink ejection performance, compatibility with a wide variety of inks, and durability. As a result, this technology has already being utilized effectively in various commercial and industrial fields such as photo lab printing, digital printing, textile printing, and color filter manufacturing. However, new printheads that have a larger number of nozzles and higher performance are constantly required to improve printing speed or productivity, both for commercial products and industrial applications.

We have succeeded to develop a next-generation Micro Piezo printhead, which has 360 nozzles-per-inch and piezo elements of 1 micrometer of thickness. In spite of the nozzle density doubled, this printhead retains all the advantages of the current Micro Piezo printheads, including the ability to produce variable sized droplets and the capability to eject ink droplets at high frequency. The installation of next-generation Micro Piezo printheads in printers and other devices will make it possible to design speedier and more compact inkjet equipments than ever before.

In this paper, the key to improve the printhead performance and increasing nozzle density is studied. Then, the structure and characteristics of the next-generation Micro Piezo printhead are described.

Introduction

Today, ink jet technologies are currently attracting a great deal of attention as they are being put to use more and more frequently in printing and manufacturing processes. Ink jet systems have the advantages of being ideally suited to small print loads and of being gentler on the environment. Compared to other inkjet systems, Micro Piezo technology is offering superior features in ink ejection performance, compatibility with a wide variety of inks, and durability. As a result, this technology is already being utilized effectively in various commercial and industrial fields such as photo lab printing, digital printing, textile printing, and color filter manufacturing. The Micro Piezo printhead is not only suitable for functions ranging from consumer applications to commercial and industrial applications, but it also offers outstanding cost effectiveness due to its high degree of reliability and production volume efficiency. However, new printheads that have a larger number of nozzles and higher performance are constantly required to improve printing speed or productivity, both for commercial products and industrial applications.

Structures of current Micro Piezo printheads

Piezoelectric ink jet printheads have a mechanism that transfers piezo-striction to a volume change of the pressure chamber and this volume change induces oscillating ink flow that generates droplets from a nozzle opening. We had two types of the piezoelectric ink jet printheads in terms of the mechanism of the piezo transducer [1].

MLChips (Multi-Layer Ceramic with Hyper Integrated Piezo Segments) type MACH

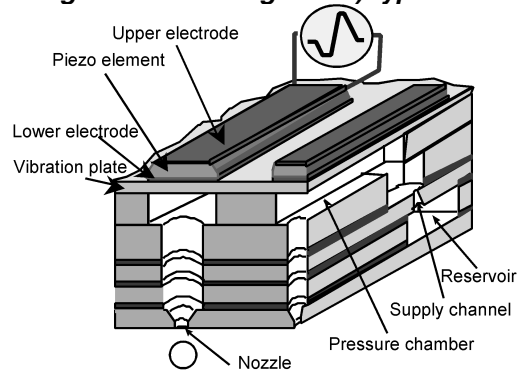


Figure 1. Structure of MLChips type MACH

To meet the market demand for low-cost and high performance ink jet printers, EPSON developed MLChips MACH in 1995 [2]. The principle of the transducer, shown in Figure 1, is similar to the conventional piezo printhead, the piezo strips are not independently manufactured but processed and sintered together with the flow channel substrate as a single layered ceramics structure. It is strongly required to make both of the vibrating plate and the piezo strip thinner to improve the ink jet printhead for jetting fine droplets. By taking the process that unifies the core parts of the printhead without machining and gluing, the MLChips could develop the high cost performance printers by reducing the printhead dimensions.

MLP (Multi-Layer Piezo) type MACH

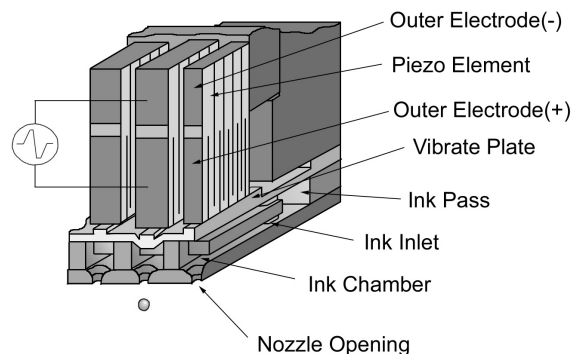


Figure 2. Structure of the MLP type MACH

Another current Micro Piezo ink jet printhead is called MLP type MACH (Multi-layer ACTuator Head) developed in 1992 [3]. The MLP type MACH, shown in Figure 2, has multi-layer piezo

elements sliced to thin pillar shape, one end of them is fixed to the base and the other end is connected to the vibrating plates of the pressure chambers. This piezo element gets shorter to extend the pressure chamber by the transverse piezoelectric effect when voltage is supplied. The MLP actuator can transfer the piezoelectricity directly to the displacement of the vibrating plate. Because of the displacement of the piezo element is proportional to the supplied voltage, the volume changing of the pressure chamber is also proportional to the supplied voltage. Therefore, ink droplet's property can be controlled easily using waveform control method [4]. Nozzle density of MLP type MACH is 180 nozzles-per-inch or npi.

The key to improve printhead performance

Basically there are 2 ways to improve printhead performance, one is increasing nozzle number and the other is improving the performance of each nozzle. Nozzle number can be increased relatively easily by making printheads bigger, or putting multiple printheads in a row. But these methods make a production cost higher and application products bigger. The way around the problem is putting more nozzles into a printhead by increasing nozzle density in each row. However, increasing nozzle density of MLP type MACH was difficult, because machine tools are used to slice piezo elements. On the other hand, MLChips had problems to increase nozzle density in terms of a complicated cavity structure and ceramics materials.

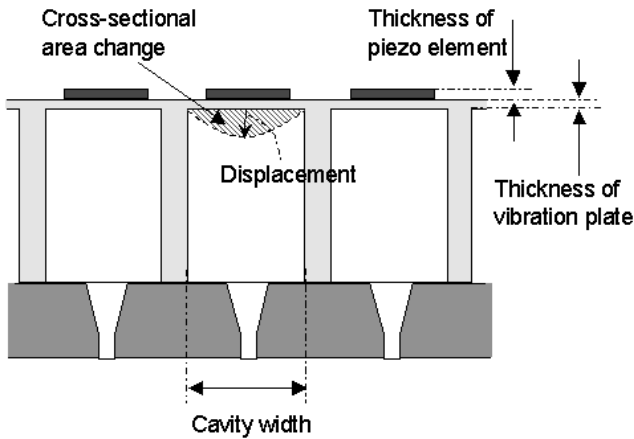


Figure 3. Cross sectional diagram of an ink jet printhead. Cross-sectional area change is important parameter to measure nozzle performance.

The piezoelectric ink jet printhead uses a mechanism that transforms piezoelectricity into a volumetric change in the pressure chamber. This volume change generates droplets from a nozzle orifice, and the volume change is determined from a cross-sectional area change (shown in Figure 3) and an actuator length. In the case of increasing nozzle density simply, the displacement and the cross-sectional area change reduces certainly, because the cavity width gets narrow. Reducing the cross-sectional area change means reducing the performance of each nozzle, therefore the total performance of the printhead doesn't improve.

The key to improve the printhead performance is increasing nozzle density without reducing the performance of each nozzle.

Actuator characteristic change by dimensions

To estimate the effect of actuator dimension change, FEM model calculation was done. At first, the actuator performance by a cavity width change was estimated. The main condition used to this calculation is shown in Table1 and results are shown in Figure 4. When the cavity width becomes half, the displacement becomes approximately 1/4 and the cross sectional area change becomes approximately 1/8. It means the performance of each nozzle becomes about 1/8. Therefore, for the purpose of making nozzle density higher, there is no point to just making the narrower cavity or the actuator, without any other changes.

Table1: Condition to simulate the cavity width property.

Piezo elements thickness	4.0 micron
Vibrating plate thickness	4.0 micron
Electrode thickness	0.1 micron
Cavity width	Parameter
Applied voltage	30 V

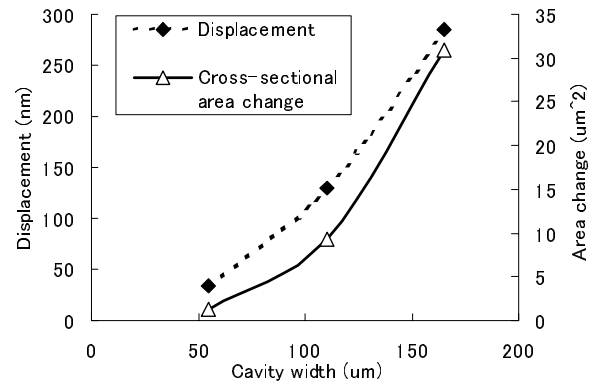


Figure 4. Actuator characteristics vs. cavity width: When the cavity width becomes half, the displacement becomes approx. 1/4 and the cross sectional area change becomes approx. 1/8.

Next, actuator performance by the thickness change was estimated. The main condition used to the calculation is shown in Table2 and results are shown in Figure 5. When thickness becomes a quarter the displacement and the area change become approx. 12 times. Accordingly, performance of each nozzle can be kept while making the cavity width narrower, by making the thickness thinner.

Table2: Condition to simulate the thickness property.

Piezo elements thickness	Parameter
Vibrating plate thickness	Parameter, same as above
Electrode thickness	0.1 micron
Cavity dimension	W55*D70*L840 micron
Applied voltage	30 V

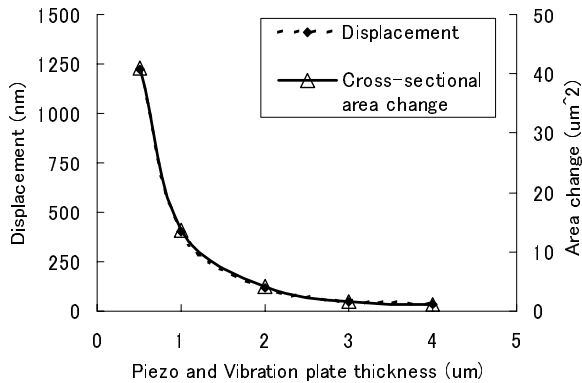


Figure 5. Actuator characteristics vs. piezo and vibrating plate thickness: When thickness becomes a quarter the displacement and the area change become approx. 12 times.

On the other hand, by making piezo elements too thin other problems occur, such as the electric field strength becomes too high or the vibrating plate becomes too soft, besides manufacturing technology matters. The main condition used to the calculation is shown in Table 2 and results are shown in Figure 6. A responsivity of ink in a cavity is influenced by the compliance of vibrating plate that means softness of the plate. The responsivity can be estimated by a natural period of ink pressure vibration in the cavity. As the natural period became longer, a maximum ejecting frequency of ink droplets goes down. When the thickness became less than 1 micrometer, the natural period and the electric field strength go high rapidly. Accordingly, to make nozzle density higher, the thickness of piezo elements and vibrating plates must be decided appropriately considering both cross-sectional area change and the problems described above.

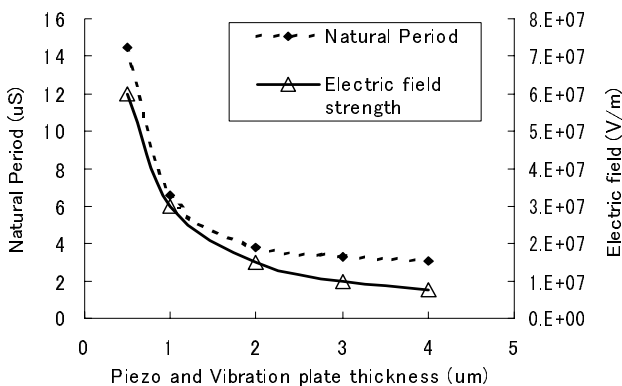


Figure 6. Natural period of ink and electric field strength vs. piezo and vibrating plate thickness

Novel Micro Piezo technology

Basic structure of next-generation Micro Piezo printhead is simple as shown in Figure 7, an actuator structure is similar to MLChips and a cavity structure is similar to MLP type MACH. On the other hand, dimensions are different largely, the thickness of piezo elements and the thickness of vibrating plate are merely

approximately 1 micrometer and nozzle density is 360dpi. Measured displacement at 30V was approximately 400nm. Then, a very large plane strain value that is 0.3% was obtained from FEM deformation calculation.

Piezo elements are formed and aligned using thin-film processing technology and photolithographic technology and ink cavities are also formed using innovative MEMS technology. By putting these technologies into practical use, ultra-fine and accurate elements were able to form as shown in Figure 8 and Figure 9.

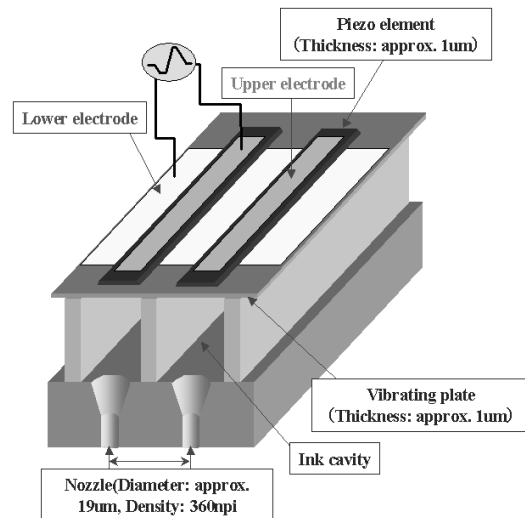


Figure 7. Basic structure of next-generation Micro Piezo printhead

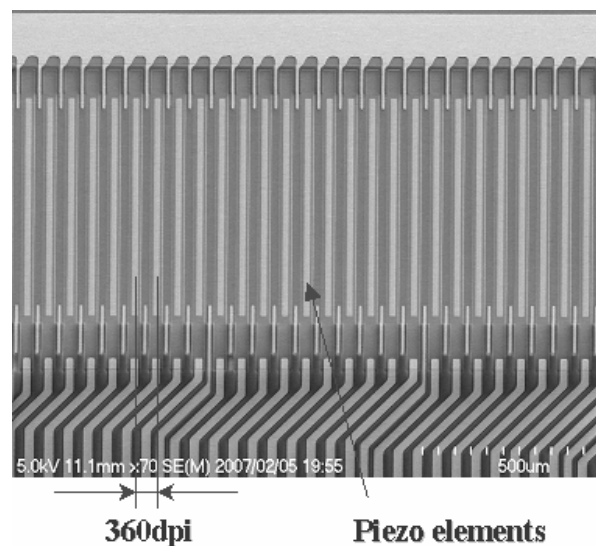


Figure 8. SEM image of next-generation Micro Piezo elements

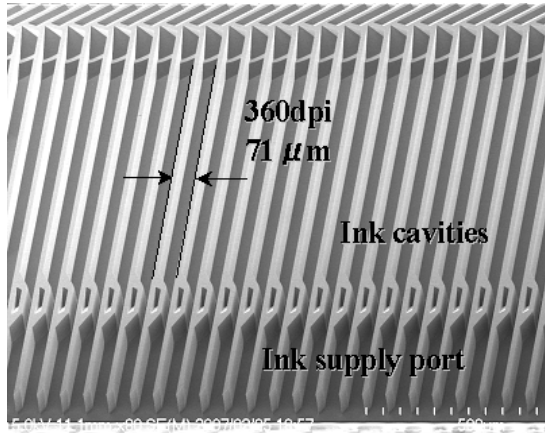


Figure 9. SEM image of ink cavities

Ink ejecting characteristics of a next-generation Micro Piezo printhead

In spite of the nozzle density doubled, the next-generation Micro Piezo printhead retains all the advantages of the current printheads, including the ability to produce variable sized droplets and the capability to eject ink droplets at high frequency.

Driving voltage characteristic

It was described above that the thickness of piezo must be thinner to keep the performance while making the cavity width narrower. But the result of the above calculation is done under the assumption that the piezo property didn't depend on the thickness or driving voltage. Therefore driving voltage characteristic was studied and results are shown in Figure 10 and Figure 11. Figure 11 is indicated with relative values based on the characteristic at 20V. Both droplets size and droplets velocity change in proportion to driving voltage, so it is understood that this next-generation Micro Piezo element is keeping its linear property even in thickness of 1 micrometer.

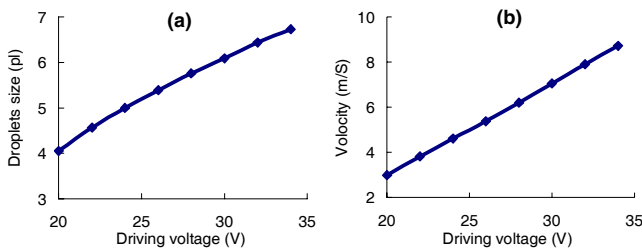


Figure 10. Droplets characteristics vs. driving voltage

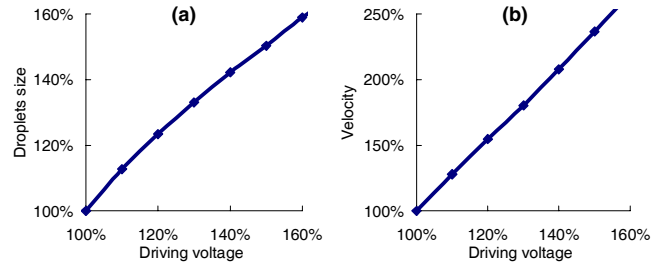


Figure 13. Droplets characteristics vs. driving voltage: indicated with relative values based on the characteristic at 20V

Variable Sized Droplets Technology (VSDT)

One of the most sophisticated characters of current Micro Piezo printhead is VSDT, variable sized droplets can be also ejected from next-generation Micro Piezo printhead. Images shown in Figure 12 are ink droplets appearances of various droplets size, each droplets velocity are controlled around at 7m/S using waveform control method [4].

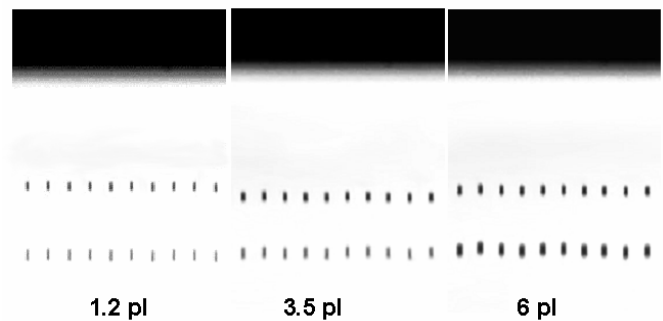


Figure 12. Droplets appearances of various droplets size: Each droplet velocity is controlled approx. 7m/S. Images and droplets sizes are taken at 10kHz.

Furthermore, the ink droplets appearance and maximum driving frequency can be changed largely, by combining the driving waveform and voltage. Figure 13(a) shows sphere droplets, droplets size is 5pl and velocity is approx. 5m/S ejected at 10kHz. The droplets in Figure 13(b) were ejected at 58kHz, and droplets size is 5pl, velocity is approx. 7.5m/S. The droplets in Figure 13(c) were ejected at 100kHz, droplets size is also 5pl and velocity is approx. 7m/S. Even in a very fast frequency next-generation Micro Piezo printhead can eject stabilized and well-controlled ink droplets like Figure 13(c).

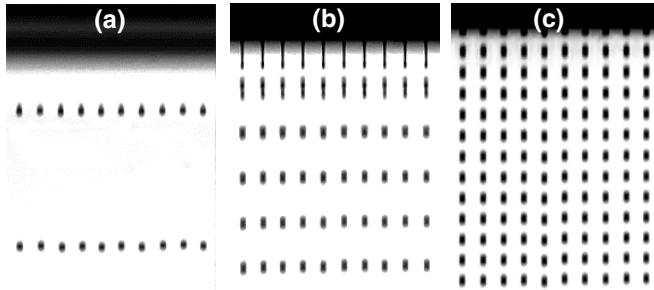


Figure 13. Droplets appearances at various ejecting condition

Conclusion

To improve printhead performance by increasing nozzle density, thickness of piezo and vibrating plate has to be thinner. We have succeeded to develop a next-generation Micro Piezo printhead, which has 360npi nozzle density and piezo elements of 1 micrometer of thickness. In spite of the nozzle density doubled, this printhead retains all the advantages of the current Micro Piezo printheads, including the ability to produce variable sized droplets and the capability to eject ink droplets at high frequency. The installation of these next-generation Micro Piezo print heads in printers and other devices will make it possible to design speedier and more compact inkjet equipment than ever before.

References

- [1] S. Sakai, Proc. IS&T's 16th International Conference on Digital Printing Technologies, (2000).
- [2] M. Usui, Proc. IS&T's 12th International Conference on Digital Printing Technologies, (1996).
- [3] T. Kitahara, Proc. IS&T's 11th International Congress on Advances in Non-Impact Printing Technologies, pp. 346-349 (1995).
- [4] T. Takahashi, Proc. IS&T's 17th International Conference on Digital Printing Technologies, (2001).

Author Biography

Tomoaki Takahashi received his B.Sc. in physics from Tohoku University, dept. of physics in 1985. He had researched TFT display, electro-photographic printing process, and ink jet printing system at another company. In 1996, he joined in SEIKO EPSON Corporation and has worked on the development of piezo ink jet printheads. His primary responsibilities are putting novel Micro Piezo technologies to practical use and improving the performance of ink jet printheads.