

Development of the New MACH (MACH with MLChips)

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Abstract

We have successfully developed the new MACH (Multi-layer ACtuator Head). This is composed of MLChips (Multi-Layer Ceramic with Hyper-Integrated Piezo Segments) instead of MLP (Multi-Layer Piezo). MLChips is a ceramic MLA (Multi-Layer Actuator), in addition it has the ink chambers to reduce the production process. The features of MACH with MLChips through the comparison with MLP type MACH are described in this paper.

Introduction

Seiko Epson has successfully developed a new type of MACH (Multi-Layer Actuator Head) composed of ML-Chips (Multi-Layer Ceramic with Hyper-Integrated Piezo Segments) instead of MLP (Multi-Layer Piezo). MLChips is also a ceramic MLA (Multi-Layer Actuator) and in addition contains ink chambers to streamline the production process. In this paper I will describe the features of the MACH with MLChips through a comparison with the MLP type MACH.

We have been pursuing higher image quality by developing ink jet heads with Piezo devices that excel in ink droplet control and offer high ink selectivity. However, since Piezo devices are ceramic, they are fragile and extremely difficult to process. For some reason their thickness is limited to 0.1 mm and this is a direct factor contributing to the high cost of printer heads.

To solve this problem, we devised a Piezo device that is heat-treated simultaneously as an integrated ceramic multi-layer structure. That is, the Piezo device is made from a completely ceramic MLA (Multi-Layer Actuator). This allows the Piezo device to be made extremely thin while fully realizing its advantages in an ink jet head.

MACH with MLChips

We have already commercialized an ink jet head called MACH (multi-layer actuator head) using MLA, and its high image quality has been widely recognized. The first MACH used an MLP (multi-layer Piezo) for the MLA. In subsequent improvements, this MLP type achieved a nozzle density of 180 DPI and response of 14.4 kHz, making it twice as compact as the original version and higher in performance.

We have also developed a MACH using another type of MLA called MLChips (multi-layer ceramic with hyper-integrated Piezo segments). In this paper, we discuss the MLChips type while drawing comparisons with the MLP type.

Structure of MACH with MLChips

The structures of MLChips and MLP are compared in Figures 1 and 2.

The MLP is a ceramic MLA with a multi-layer structure consisting of Piezo green sheets of approximately 20 microns alternately placed with electrodes. The actuator unit is machine processed at a 140-micron pitch to achieve a head nozzle density of 180 DPI.

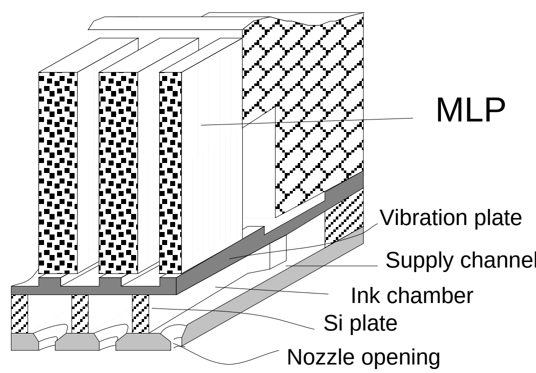

Figure 1. Structure of MLP type

On the other hand, the MLChips structure integrates in its multi-layer structure several ink chambers, vibration plates, and Piezo devices. Unlike the MLP, it requires no further machine processing whatsoever. The ink chamber is formed using only a multi-layer structure of zirconium ceramic, which is chemically stable and highly tenacious. On top of this are stacked the electrodes and Piezo device, and this ceramic MLA is heat treated as a unit. The ink chamber requires no adhesives and is formed using only chemically stable ceramic. In addition the Piezo device is stable due to the unitized heat treatment of mechanical and electrical junctions. The reliability of the ink jet head can thus be assured extremely easily (electrical reliability including open shorts, mechanical reliability such as peeling and cracking, and chemical reliability such as ink resistance).

However, the multi-layer structure allows less freedom in terms of shape, making it difficult to design a smooth flow channel. In initial designs, a whirlpool developed near the supply hole, where the flow speed sharply slowed down, and the flow necessary for air bubble ejection could not be obtained. Thus the supply hole side of the connecting plate was changed to a track shape, as shown in Figure 3, which eliminated the whirlpool and assured a smooth flow.

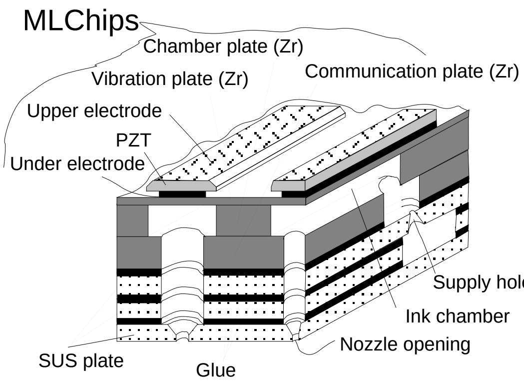

Figure 2. Structure of MLChips type

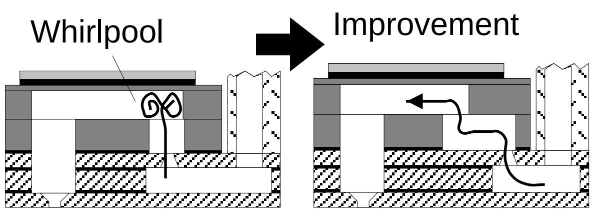

Figure 3. Improvement of Flow

Unlike the MLP, the operating principle is a flexible deformation based on a bi-metal effect between the Piezo device and vibration plate. The thickness of the Piezo device is approximately 20 µm, and that of the vibration plate approximately 10 µm.

The electrostatic capacity of each ink chamber is approximately 500 pF, approximately one tenth that of MLP. Energy consumption per dot is therefore extremely low at approximately 0.5 µ-J.

The ink chambers have a width of 340 µm and a pitch of 420 µm (60 DPI). Each chip has two columns of eleven chambers for a total of 22 chambers per chip (Figure 4). The ink jet head consists of SUS plates forming the supply holes, common ink chambers, and nozzles, which are connected to the MLChips with adhesive. Since the pressure for ink ejection is almost completely contained within the MLChips, the adhesive needs only enough mechanical strength to assure a seal. For the Stylus series, each head uses three MLChips.

Characteristics of the MLChips Structure

The characteristics of MLChips as an actuator vary greatly depending on two factors: the thickness of the vibration plate relative to the Piezo device, and the width of the Piezo device relative to the ink chamber. Figures 5 and 6 show these two relationships. In both cases, the width of the ink chamber is 340 µm, the thicknesses of the Piezo device and bottom electrode 20 µm and 5 µm, respectively.

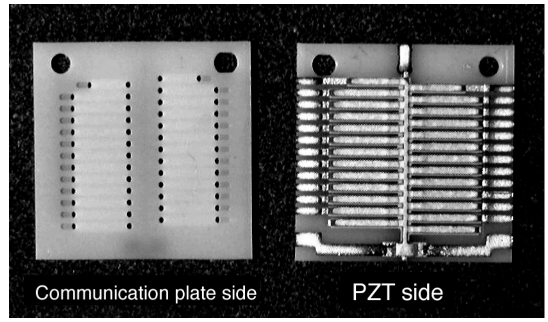

Figure 4. Photo of MLChips

Figure 5 shows the first relationship. Upon considering the displacement and displacement × pressure (disp. * pressure), which determine the volume and speed of ink droplet ejection, we adopted a 12-µm vibration plate for the 20-µm Piezo device. The second relationship is shown in Figure 6. To be able to determine the actual width of the Piezo device with the bottom electrode, we adopted a structure in which the Piezo device covers the bottom electrode, but does not constrict the part of the vibration plate left uncovered by the bottom electrode (see Figure 2). Furthermore, after considering variances, we set the width of the bottom electrode (which is the actual width of the Piezo device) at approximately 70% the width of the ink chamber. This structure reduces variances in ink chamber characteristics to below 10% on a chip.

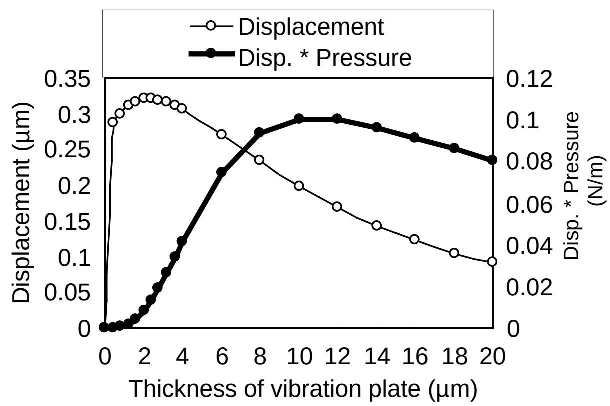

Figure 5. Relation between Thickness of vibration plate and Displacement, Disp. Pressure at 24 volt*

Similarly, Figure 7 shows the required width and length of the ink chamber to achieve equivalent actuator characteristics (ink ejection volume and displacement pressure) when the thicknesses of the vibration plate and Piezo device are changed. Compared to when the PZT is 100 µm thick, at a 20-µm thickness the ink chamber's width can be halved and its length reduced to one-fourth.

MLChips Ink Ejection Performance

The potential ink droplet ejection performance of ink jet actuators can be compared using displacement and dis-

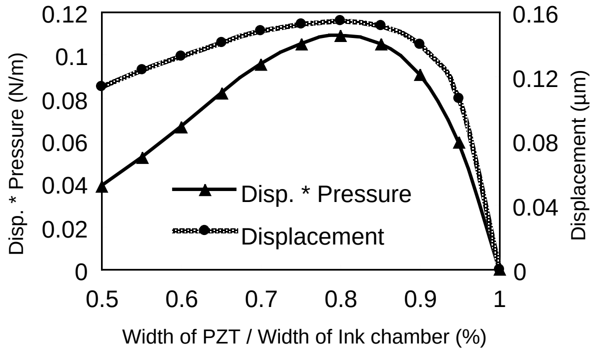

*Figure 6. Relation between Width % of PZT and Displacement, Disp. * Pressure at 24 volt*

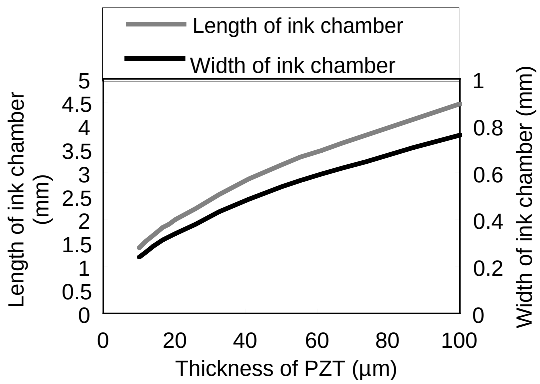

Figure 7. Relation between Thickness of PZT and Length, Width of ink chamber in the equivalent performance at the same voltage.

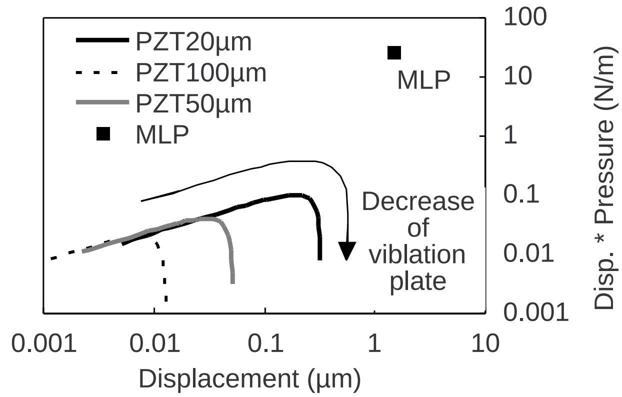

*Figure 8. Relation between Displacement and Disp.*Pressure: The parameter is PZT thickness.*

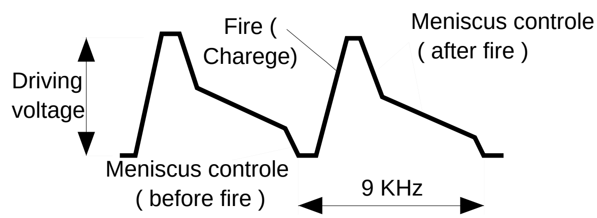

Figure 9. The drive waveform of MACH with MLChip

placement × pressure. Displacement regulates the volume of the ejection of ink droplets, while displacement × pressure estimates meniscus control. Figure 8 shows these relationships for MLChips and MLP. For MLChips, the ink chamber is 340 μm wide, and the vibration plate thickness is used as a parameter for three Piezo device thicknesses. The MLP is for a resolution of 180 DPI (MLP width is 80 μm, length is 5 mm, and ink chamber width is 100 μm), and the displacement × pressure has been standardized to the ink chamber (× 100/340).

By making the Piezo device thinner, we greatly improved the ink ejection performance potential. At the same time, the high potential of the MLP was reconfirmed.

Ink Droplet Ejection Performance of MACH with MLChips

Figure 9 shows the driving voltage waveform. Meniscus control is achieved both immediately prior to and after ink ejection. As Figure 8 shows, while the potential is not as high as MLP, ink droplet control is adequate for practical use. Having achieved the following characteristics, the MACH with MLChips has been incorporated in the Stylus color IIs and other machines.

- Ink volume: 55 ng
- Maximum responsivity: 9 kHz

Features of MACH with MLChips

Below the features of MLChips are compared with those of MLP.

1) Characteristics in common with MLP
   - -Adequate meniscus control
   - -High selectivity of inks
   - -Durable permanent head
2) Advantages compared to MLP
   - -Low cost due to simpler assembly process
   - -Very low energy consumption
3) Disadvantages compared to MLP
   - -Low nozzle density
   - -Variances in actuator characteristics that cannot be ignored
   - -Inferior meniscus control in terms of potential

Future Development of MACH

In this paper, we discussed the characteristics of MACH with MLChips in comparison with the MLP type. Both have technical advantages. We are confident that they will find uses in all areas including industry, offices, and homes, and that we have built a body of technology that will take the lead in creating a trend toward higher performance and lower cost.

The thinner Piezo device and vibration plate of the MLChips type overcomes many problems and offers significant advantages. Based on this, we hope to make further improvements in the image quality, speed, and cost of printers.

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