Ink Jet Head with Multi-Layer Piezoelectric Actuator

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Introduction

Ink jet heads with piezoelectric actuators have been able to gain market recognition and secure a slice of the market primarily by virtue of their excellent print quality. To obtain good quality output, it is necessary to ensure the accurate ejection of precisely shaped ink droplets. By speeding up the ink ejection cycle, it is also possible to improve print speed A key factor influencing ink jet performance is the ability to control ink ejection. With piezoelectric actuators, the ejection process can be controlled with extreme precision in proportion to applied voltage. In the past it was not possible to reduce the thickness of piezoelectric layer, which meant that the technology could only be used in large, expensive printers. Epson conceived the multilayer actuator (MLA) as a means of utilizing thin piezoelectric. One type of MLA is the multilayer piezo (MLP), which consists of piezoelectric elements and electrodes arranged in alternate layers. By using MLAs containing piezoelectric elements that are 20μm thick, we have been able to create a compact, low-price printer with superb ink jet control is year Epson released ahead in which the new MLP is used as the actuator. In this paper, I will describe the features and basic structure of this head.

Features of Multilayer Actuator Head

MLA ink jet heads offer a number of advantages ~m the viewpoint of meeting future demand for ink jet printers with improved print quality and printing speeds. Most of the features described below have been realized through the use of MLA technology to control the resonance frequencies of the head.

Characteristics that Ensure High Print Quality

- Ejection of ultrafine ink droplets
- Reduction of satellite droplets
- Rectilinear propagation of droplets
- Reduction of variation in ink ejection speed
- Ink responsivity

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Consistent Ejection of Ultrafine Ink Droplets

The volume of ink droplets ejected by the MLA-based ink jet head is determined by cavity distortion volume, which depends on the displacement of the MLA, by the resonance frequency (Tc) of the cavity, and by the drive wave form. Assuming that flight speed is constant, the best way to reduce ink droplet volume is to reduce the resonance frequency (Tc). Since the resonance frequency (Tc) is determined by the inertance of the nozzle and the supply aperture and the rigidity of the cavity, the most effective approach is to increase cavity rigidity by reducing cavity size. Because of the high force generated by the MLA, it is possible to express actuator displacement effectively as changes in cavity volume, despite the increased rigidity of the cavity. This means that it is possible to combine high cavity rigidity with high actuator displacement capacity. The resonance frequency (Ta) of the MLA itself is extremely small compared with the resonance frequency (Tc) of the cavity. As a result, the MLA can more easily conform to subtle control signals contained in the drive waveform, and it thus is possible to achieve subtle control over cavity contraction and expansion. The contraction of the cavity when the meniscus has been drawn slightly inside the nozzle is an especially effective way to eject ultrafine ink droplets.

Reduction of Satellite Droplets

It is possible to prevent satellite droplets by controlling meniscus oscillation immediately after ejection, and by configuring the drive waveform applied to the MLA so that the meniscus does not project immediately prior to the ejection of the ink droplet. Another characteristic of MLA-based ink jet heads is the fact that the droplet ejection process is implemented according to oscillation under the resonance frequency (Tc) of the cavity. Since this results in smooth variation of ink speed at the nozzle exit according a sine wave pattern, it is possible to create large main droplets.

Rectilinear Propagation of Droplets

This factor is significantly influenced by the flight speed of the ink droplets and the degree of wetting around the nozzle exit. The large force and displacement of the MLA create an ideal environment for increasing cavity pressure and raising the speed of the ink droplets. In addition, it is easy to operate the MLA so that the meniscus is drawn slightly inside the nozzle, which prevents surplus ink from wetting the area around the nozzle exit. It is also possible to prevent flight path distortion, which is a cause of uneven wetting around the nozzle exit. This is achieved by aggressively damping pressure oscillation immediately after droplet ejection through the activation of the MLA, which prevents surplus ink mist from wetting the surface of the nozzle plate.

Reduction of Variation in Ink Ejection Speed

When ink ejection speed varies widely across the same head, the positioning of ink droplets on the print media will be uneven, leading to a decline in image quality. The speed of the ink droplets is determined by cavity distortion volume, which depends on the displacement of the MLA, by nozzle size, by resonance frequency (Tc), and by the drive wave form. The voltage displacement characteristics of the MLA are extremely linear within the range of actual utilization. The individual actuator elements of the MLA are formed through separate processing of the whole MLA, with the result that the voltage-displacement characteristics are extremely uniform. This means it is possible to achieve total uniformity in the amount of distortion of each cavity at the time of droplet ejection. Variation of ink ejection speed within the same head can therefore be kept to an extremely low level, enabling ink droplets to be deposited precisely on the print media.

Ink Responsivity

Good ink responsivity increases the range of inks that can be used. MLA-based inkjet heads feature a basic structure in which the drive section is isolated from the ink. This reduces limitations on the choice of ink. However, it is necessary to satisfy reliability criteria, including eject ion characteristics and clogging performance, and further improvement will be needed in this area.

Characteristics that Enhance Print Speed

- Improved frequency response
- Dot gradation
- Increased number of nozzles

Improved Frequency Response

Frequency response is determined by meniscus refill time, and by the attenuation of the resonance frequency cycles (Tc, Tm). The resonance frequency (Tm) is an oscillation pattern determined by the surface tension of the meniscus and the inertance of the nozzle and supply aperture. The resonance frequency (Tc) can be attenuated rapidly by applying an antiphase pulse signal to the MLA after ink droplet ejection. This means that the next droplet can be ejected as soon as the meniscus refill has been completed and resonance frequency (Tm) has been attenuated to some extent.

Dot Gradation

This feature enables the head to combine high-quality output with high throughput. In general, dot gradation is achieved by controlling either dot volumes or dot numbers. As stated earlier, it is possible with an MLA-based head to make the MLA conform precisely to the drive waveform, which means that the volume of ink droplets can be varied simply by optimizing the wave-form. As shown in Figure 2, it is possible to modulate the dot volume simply by raising or lowering intermediate potential (Vc). Furthermore, since the high frequency responsivity of the device enables microscopic ink droplets to be produced, it is possible smooth gradation can be achieved without reducing throughput.

Increased Number of Nozzles

Printing speed can easily be improved by increasing the number of nozzles. For many years we have been told that piezoelectric actuator system cannot compete with thermal ink jet heads in terms of cost, compactness or density. However, advances in precision processing and photolithography have enabled us to create a 180 dpi nozzle array through the use of piezoelectric element measuring just 20μm per layer.

Clearly, these characteristics of the MLA-based ink jet head meet a wide range of market needs, including the demand for better output quality and speed.

Outline of New MLP Ink Jet Printer Head

The New Longitudinal Oscillation Actuator Head Offers the Following Characteristics

- Cavity array with 180dpi nozzle pitch
- Cavity formation through Si etching
- Maximum responsivity of 14.4kHz
- Dot gradation capable of supporting 360dpi and 720dpi output.

180dpi Nozzle Pitch

The achievement of 180dpi nozzle pitch has enabled us to achieve high performance while realizing major reductions in size and cost compared with conventional 90dpi arrays. The **use of Si** as the cavity material is reflected in improved rigidity and performance.

Maximum Responsivity of 14.4kHz

As is apparent from the wave form shown in Figure 2, this feature allows the meniscus to be drawn into nozzle through slight expansion of the cavity prior to ink droplet ejection. It also enables cavity resonance frequency (Tc) to be controlled through the slight expansion of the cavity after droplet ejection.

Dot Gradation

This is achieved by controlling the number of dots. Ink droplets measuring approximately 50ng are used to achieve minimum resolution at 720dpi. Minimum resolution at 360dpi is achieved by ejecting two droplets measuring approximately 55ng.

The Basic Components of the Longitudinal Oscillation Type are as Follows:

- Nozzle plate
- Si cavities
- Polymer elastic sheet
- Longitudinal oscillation MLP

The Nozzle Plate consists of two nozzle arrays. The nozzles are formed through the use of precision pressing to perforate a stainless steel plate. The nozzle profile combines cylindrical and tapered sections. The application of a water-repellent treatment to the surfaces of the nozzle plate and cylindrical sections helps to improve rectilinear ink droplet propagation. The nozzle profile also prevents ink misting, since the meniscus is drawn into the tapered section, which oscillates immediately after droplet ejection.

Etching technology is used to create **the Si cavities**. Each space consists of a reservoir, supply aperture and cavity. To prevent cross-talk, neighboring cavities are separated by 10µm slits. Since the cavities are formed of silicon, there is no flexing or deformation due to MLP displacement. In addition, the supply aperture can be formed to a tolerance of +lµm, which ensures the uniformity of ejected droplets.

The Elastic Sheet consists of PPS film and stainless steel foil. The stainless steel is etched to create an island with a pitch of 180dpi and a flexible section in the PPS film . The island and the flexible section of the PPS film enable MLP displacement to be converted efficiently into changes in cavity volume. They also function as a rigidity compliance section in order to determine the resonance frequency (Tc) of the cavity.

The MLP consists of piezoelectric element measuring just over 20µm per layer, with alternate electrode layers. piezoelectric elements are cemented to a ceramic plate in bulk and then machine-sliced at a 180dpi pitch . The force generated by one MLP during ink droplet ejection is in excess of 1N.

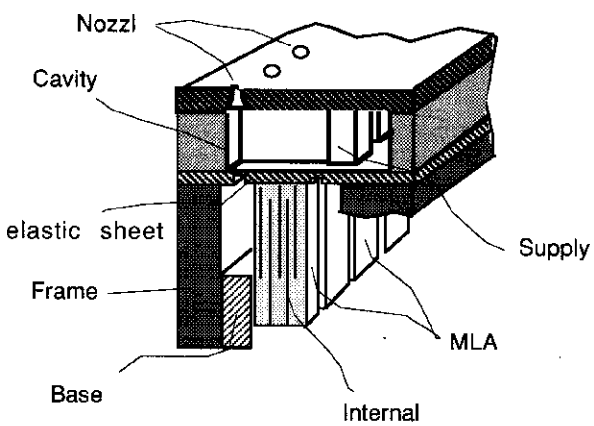

Figure 1. The composition of a longitudinal oscillation head

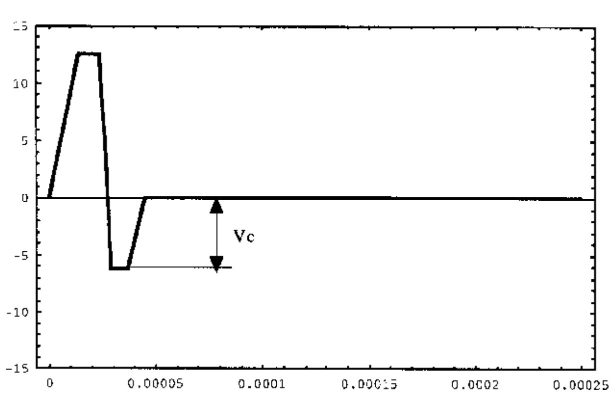

Figure 2. The drive waveform of the longitudinal oscillation head

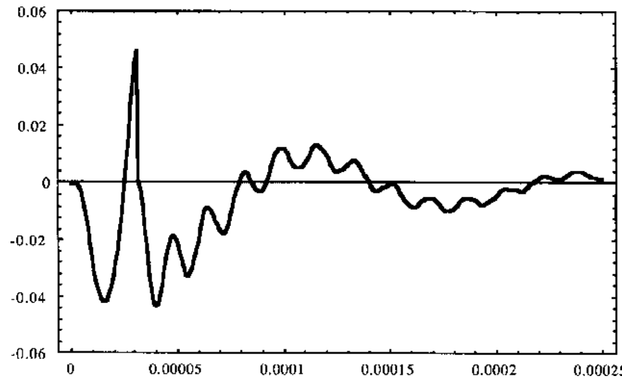

Figure 3. The changes in meniscus displacement with the elapse of time

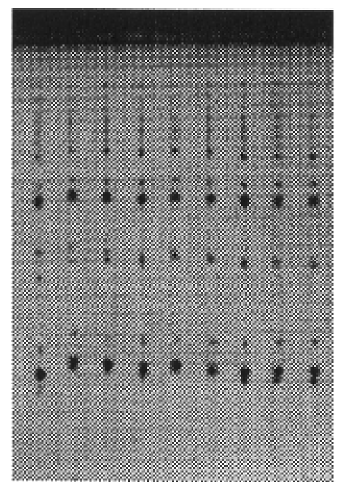

Figure 4. The flight pattern of ink droplets. (velocity 11m/s, frequency 14.4kHz)

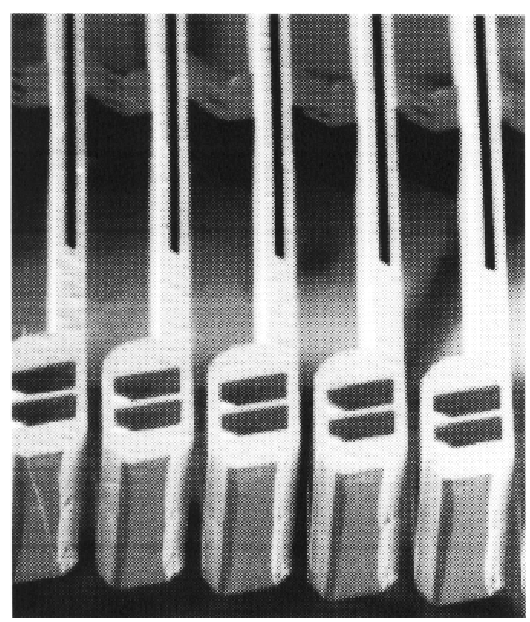

Figure 5. The structure of Si Cavity (Supply part)

Summary

Demand for high-quality color recording is likely to expand still further in the future, and there are certain to be rapid advances in color ink jet technology, including improvements in print quality and speed. In particular, we need to achieve dramatic improvements in print quality through the achievement of higher resolutions and better gradation. Dot gradation is achieved by controlling either the volume or number of ink droplets. Regardless of the method used, however, it will be necessary to develop recording technology that is capable of ejecting microscopic droplets at high frequency and in precise quantities, and of positioning them precisely. In this sense, a print head equipped with an MLA actuator is capable of meeting a wide range of high-quality color recording needs, thanks to characteristics that include the ability to control meniscus oscillation precisely through optimization of the waveform applied to the piezoelectric actuator, and the ability to combine high cavity rigidity with high actuator displacement capacity.

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