Jetting and Imaging Performance of the M-300/10 Jet Module

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Abstract

The design of Dimatix, Inc.'s M300/10 silicon MEMS based ink jet printhead is presented. The monolithic silicon structure allows compatibility with a wide range of ink types and precision manufacturing techniques produce ink jets with high uniformity. Detailed performance data is given on voltage, uniformity and straightness for a population of jet modules. This performance, along with fast dynamic response, enables a wide range of drop sizes in adjustable binary mode. Imaging work is described which correlates final image quality with system error sources and demonstrates the M300/10's ability to create high quality UV images.

Introduction

Expanding market demands in the graphics arts printing industry are calling for higher resolution and higher productivity digital printing capabilities using a widening range of ink types. Digital printing solutions provide the cost effectiveness for small runs by minimizing set-up cost. As digital printing proficiency continues to be demonstrated, demand shifts toward enhanced image quality at equal or even faster speeds. This impacts ink jet design by requiring smaller drop sizes deposited with greater accuracy and uniformity at higher productivity. New inks designed to better meet imaging requirements can pose challenges to ink jets with chemistries that can degrade the materials in the ink jet printhead structure. Also, ink properties that help an ink's imaging qualities can adversely affect their jettability. Increased productivity can be addressed by faster jetting and higher jet packing density.

Dimatix Inc. has developed MicroElectroMechanical Systems (MEMS) based ink jets to address these increasing demands on ink jet design. MEMS is a platform technology used to build devices ranging in size from a few microns to millimeters across. These devices are typically made from silicon wafers using processes originally developed in the semiconductor industry that machine the silicon into specific shapes. Shaped Piezo Silicon™ is a proprietary fabrication technology that applies well-established semiconductor manufacturing processes to the fabrication of piezo-electrically driven ink jets. The photolithography processing techniques used in MEMS have the capability to create features with <0.5 micron tolerances. This capability allows for the manufacturing of features that can provide the uniformity necessary to meet jet-to-jet performance consistency requirements in drop size, speed, and straightness. Silicon's coefficient of thermal expansion is also a close match to that of PZT, allowing the two materials to be coupled and operate over a wide range of temperatures. The Spectra Printing Division of Dimatix Inc. has demonstrated silicon's superior resistance to chemical attack over a wide range of ink types, jetting with solvent, UV, and aqueous inks. Through the use of silicon fusion bonding, structures can be built which are made completely of silicon, which solves the problem of adhesive bond lines being part of an ink jet's fluid path and the consequential capability issues with those adhesives and different ink chemistries.

The M-Class M300/10 is Dimatix Inc.'s first ink jet device designed to take advantage of silicon MEMS capabilities. The jetting structure is built entirely of silicon. Figure 1a shows the first step of the manufacturing process where a silicon wafer has pumping chambers and ink channel features etched into it. Figure 1b shows the next step where the silicon pumping chamber wafer is enclosed by silicon membranes on the top and bottom. The top silicon membrane is the diaphragm separating the fluid path and the Piezo-electric actuator. The bottom silicon membrane has the nozzles etched through it. Figure 1c shows the final step in the die manufacturing process where the PZT material is bonded onto the pumping chamber. The completed M-Class M300/10 device is 46mm long and 6.4mm wide containing 304 individually addressable channels divided into opposing rows of 152 as shown in Figure 2. Nozzles in a single row are spaced at a 141µm pitch creating a native resolution of 180dpi for the M300/10 jetting module.

***Figure 1a**. Si Wafer with Pumping Chamber Fluid Path Etch*

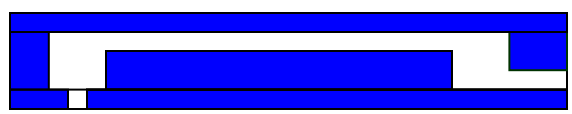

***Figure 1b**. Pumping Chamber Enclosed by Si Membranes*

***Figure 1c**. Completed M300/10 Jet*

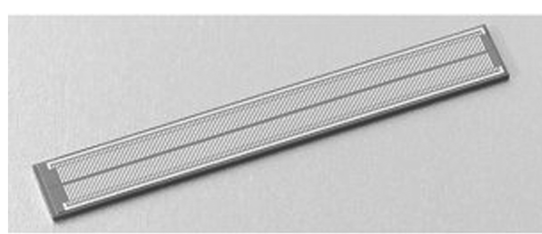

***Figure 2**. Layout of complete die (304 jets)*

The M300/10 MEMS device is then enclosed into a module that provides the mechanical, fluidic, and electrical interface to the silicon die jetting structure. Figure 3 shows an exploded view of the M300/10 jetting module and illustrates the module's features.

The Shaped Piezo Silicon die and electronics assembly is the core of the jetting structure. The internal heater mates to the top of this assembly, which is then enclosed by the die housing. The die housing provides three functions; supply the dual ink fill ports to the jet's refill chamber, seal the fluid path from the piezoelectric actuator and electronics, and furnish the module's precision mounting features. The filter housing provides built-in filtration and completes the electronics chamber enclosure by sealing it off inside and out when mated with the die housing. This completed module, as shown in Figure 4, is a unit that can then be packed into larger printhead array assemblies to provide application appropriate native resolutions.

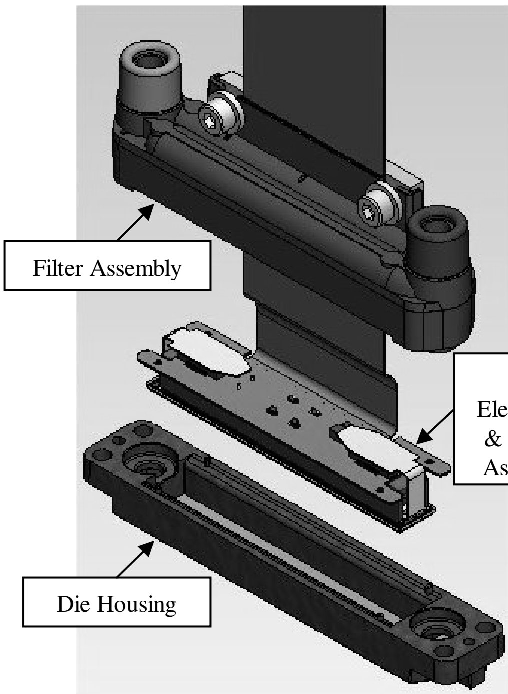

***Figure 3**. M300/10 Jet Module Components*

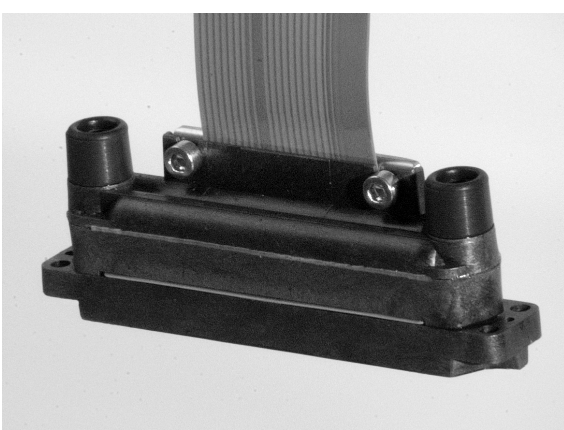

***Figure 4**. M300/10 Jet Module*

M-300/10 Jet Module Performance

The following section demonstrates the superior capability of the Shaped Piezo Silicon manufacturing process by presenting performance for several critical jetting parameters across a population of M300/10 jet modules.

Operating Voltage

One performance benefit of the M300/10 module is very low operating voltage. While the maximum operating voltage for the M300/10 is 44volts, 8 nanogram drops traveling 8 m/s can be produced with less than 20 volts. Figure 5 is a plot of drop velocity versus drive voltage for a population of 63 M300/10 jetting modules measured at five different drop velocities. The relationship between drive voltage and drop velocity is approximately linear over the presented range and averages 1.2 volts per m/s for the population of modules shown. An 8 m/s drop velocity testing standard is used as an optimum balance between drop formation characteristics and drop momentum. Figure 6 shows a histogram of voltages that attain an 8 m/s drop velocity over the population of M300/10 jetting modules shown in Figure 5. The average voltage to attain 8 m/s drop velocity is 17.2 volts with a standard deviation of 1.1 volts.

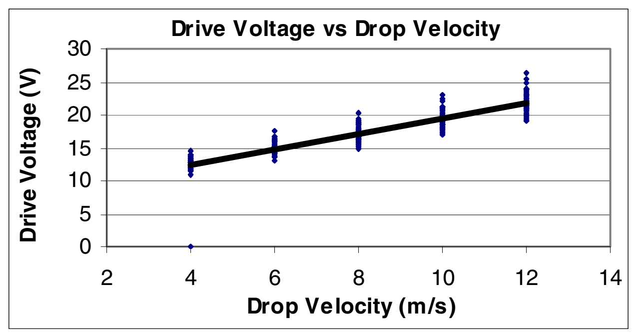

***Figure 5**. Drive Voltage versus Drop Velocity for Population of M300/10 Jet Modules*

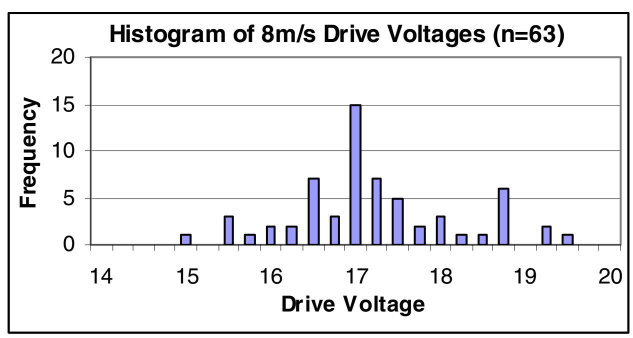

***Figure 6**. Histogram of 8m/s Drive Voltages (n=63)*

Drop Mass Uniformity

The uniformity capability of the Shaped Piezo Silicon manufacturing process of the M300/10 MEMS jetting structure enables repeatable drop size production from module to module. Figure 7 shows the drop mass versus drop velocity relationship for a population of modules. The drop mass versus drop velocity relationship is approximately linear over the drop momentum range shown averaging 0.6 ng per m/s with drop mass ranging +/-1 ng for a given drop velocity. Figure 8 shows a histogram of drop masses for an 8m/s drop velocity over a population of 147 modules. The average drop mass for this sample of M300/10 jetting modules traveling at 8 m/s drop velocity is 8.2 ng with a standard deviation of 0.4 ng.

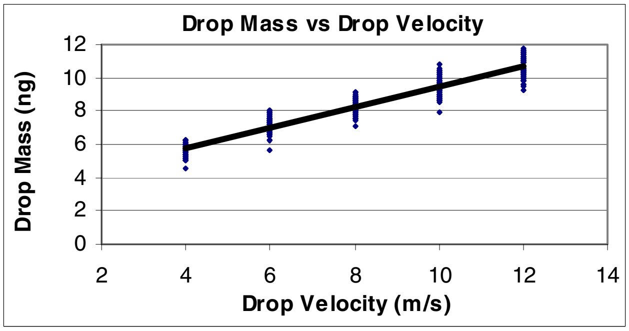

***Figure 7**. Drop Mass versus Drop Velocity (n=63)*

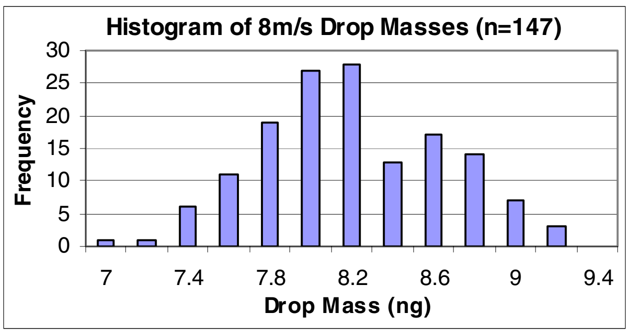

***Figure 8**. Histogram of 8m/s Drop Masses (n=147)*

Drop Velocity Uniformity

The uniformity capability within an individual M300/10 jetting structure provided by Shaped Piezo Silicon manufacturing techniques is evidenced by the jet-to-jet drop velocity uniformity across M300/10 jetting modules. Figure 9 is a histogram of the % velocity standard deviation over a population of 121 M300/10 modules. This population has an average of 4.1% velocity standard deviation with a standard deviation of 1.3%. Imaging work mentioned below has confirmed this high uniformity enables excellent text and line quality in graphic images.

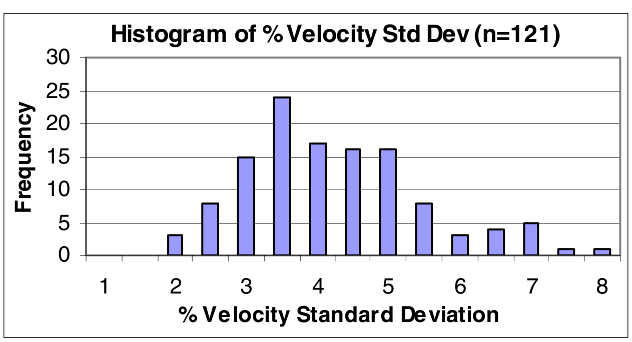

***Figure 9**. Histogram of % Drop Velocity Std. Dev.*

Drop Trajectory Uniformity

The Shaped Piezo Silicon MEMS manufacturing techniques and jet structure provide an excellent foundation for high drop trajectory uniformity across each M300/10 module. Nozzle geometries are highly repeatable, with irregular shapes that can cause drops to jet crooked virtually non-existent. Drop trajectory error is measured by printing lines on paper at a 1mm standoff. Figure 10 is a histogram of the jet trajectory error over a population of 150 304-jet M300/10 jet modules. Our imaging work, described below, determined a maximum allowable jet trajectory error for very high quality UV ink images to be +/-15 milliradians. The standard deviation for this population is 1.2 milliradians.

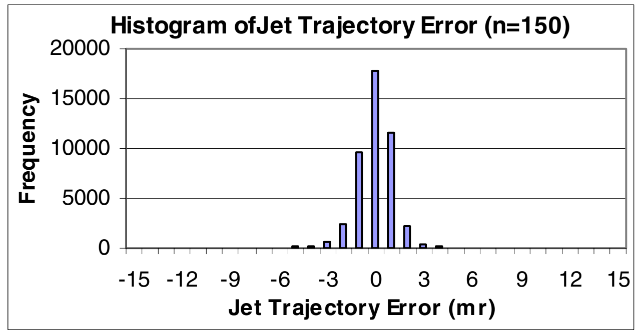

***Figure 10**. Histogram of Drop Trajectory Error (n=150)*

Jet Frequency Response

The M300/10 ink jet is designed for high jetting frequencies and complex arbitrary waveform capability. Figure 11 shows a decaying pressure pulse in an M300/10 jet module jetting Dimatix 7060 Model Fluid. A natural frequency of 110 kHz is shown for this particular fluid and pumping chamber system. This fast dynamic response creates a platform where complex waveforms can be used to create various size drops.

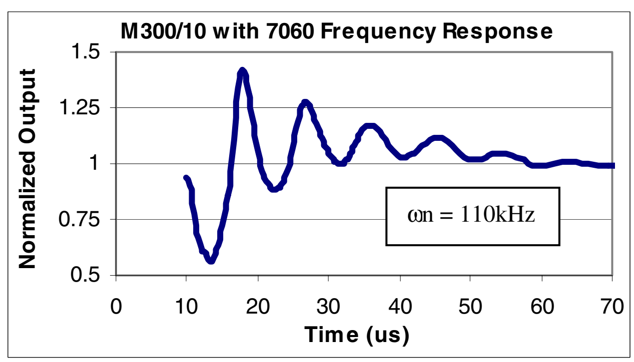

***Figure 11**. M300/10 Frequency Response*

Imaging and Applications

The M300/10 jet module offers high image quality with small native drop size and responsive dynamic performance which enable complex waveforms. High frequency small drops (8-10ng) can be used when near photorealistic image quality is required, and the same printhead can then operate at much higher imaging speeds using larger drops (20-30ng) to produce draft mode image quality. This provides higher printer flexibility by addressing a wide range of image quality targets and substrates from a single printhead.

Small drop high-resolution image quality demands tighter mechanical system requirements such as higher encoder accuracy, better overall motion quality, accurate head mount adjust, etc. Besides providing higher image quality, small drops also minimize the need for using lighter color inks, resulting in higher productivity and lower system cost.

The high jet packing density of M-class printhead (141µm) enabled by the MEMS technology facilitates high quality images for two important reasons. First, fewer jetting modules are required for a desired resolution, which shortens the extent of the printhead in the process direction. This close packing minimizes sensitivities to common system errors such as carriage or substrate motion quality. Second, due to the sensitivities of the human eye, imaging errors created by variation in drop mass and velocity along the printhead will be less perceptible at 180dpi spatial period.

As presented earlier, the M300/10 module offers very high straightness and velocity uniformity. A higher velocity uniformity also means higher drop mass uniformity and lower drop position error in the process direction. Both straightness and drop mass uniformity mean lower contrast banding, lower color variation (dE), and streak-free image quality. The absence of banding and uniform color density across the image is a critical factor for higher image quality.

Imaging

The straightness and uniformity characteristics of M-class printhead, combined with a small native drop, enable new applications for ink jet, which we have explored printing on an internal test printer to demonstrate the potential image quality. We have jetted three important ink types (UV, solvent and aqueous) with both small and large drops, including operability work on maintenance and sustainability.

The UV test images were printed with four M300/10 modules printing black, cyan, magenta and yellow UV inks. Images were printed on a semi-gloss substrate widely used in the graphic arts industry. The images represent a set of standard ISO images, as well as custom test images. These images were printed using a fixed printhead, with a precision XY substrate flatbed. A trapezoidal waveform was used to generate 8ng drops. A complex waveform was used to generate large (20-30ng) drops.

In conventional single-pass or UV scanning printing, ink is partially cured, also called ‘pinning’, with a low-dosage UV light. Pinning limits the amount of ink spread and changes the surface chemistry of ink film so that the adjacent layer of ink would still wet the partially-cured film but would not bleed into it. Two different types of pinning methods were used during these tests: a UV light module consisting an array of light emitting diodes (LEDs) and a high pressure mercury arc lamp providing controlled UV dosage through fiber optics lines. Depending on the technology they offer advantages of either being monochromatic, able to be tuned for wavelength-sensitive inks (LED), or being compact in size with the option of multiple lines sharing the same power source (fiber). Images printed without pinning showed poor image quality with non-uniform ink spreading and blotches of areas with higher ink laydown. At the other extreme, with high UV pinning dosage, the images exhibited textured surface. A combination of UV lamp power and speed of substrate under the lamp was derived by analyzing the images to find balance between non-uniform ink spreading and textured surface.

To quantify and understand the benefits of the M300/10 jetting performance parameters values for typical errors such as jet straightness and uniformity, as well as mechanical system errors were quantified in each image. From these measurements the total allowable errors for each image type and ink was determined and the ability of the M300/10 to produce high image quality confirmed.

Images were printed at two resolutions, 720x720 and 900x960 dpi, using 8ng drops. These two images were compared to 28ng drop mass images printed at 720x720dpi. At present, 600dpi images printed with 30ng drops represent typical UV market. The comparison shows significant improvement in the image quality with small drops at both resolutions than the larger drops. 28ng images display high graininess with loss of details. With smaller drops, 900x960 dpi is required to obtain robust IQ against normal system errors. 720dpi images were acceptable, but left very little room for expected system errors. This shows that high-resolution photo-realistic images can be printed at higher carriage speeds. The large drops can be jetted in the draft mode to print lower quality images that consist of solids and line art objects at consistently high productivity.

The printing flexibility obtained from a wide drop size range available as choices of binary modes allows a single print engine to address a much wider range of applications than a conventional digital printer.

Conclusion

Precision MEMS manufacturing methods create a monolithic silicon structure which has reliably jetted a wide range of inks. Data presented demonstrates low voltage, high uniformity and excellent straightness across a population of jet modules. These design and performance attributes enable greatly improved performance in existing graphic markets and significant new applications through the use of a wide drop mass range with consistently high productivity.

