Innovations in Materials Deposition for Plastic Electronics

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Abstract
Ink jet printheads are now widely used in manufacturing processes that require precise dispensing of materials. Today, Dimatix manufactures a variety of drop-on-demand ink jet printheads for the industrial printing market, but emerging opportunities present fresh challenges to our technology. In response to requirements for digitally printing on flexible substrates and dispensing novel electronic fluids, we are developing next generation jetting technology based on our three-dimensional silicon MEMS technology with a piezo-driven pumping chamber integrated into the chip structure. This presentation will address the functional and physical design features and properties of Dimatix's MEMS process, its characteristics, reliability and usability. Examples of opportunities and applications for digitally printing electronic fluids on flexible substrates with MEMS-based ink jet technology will be presented.

1. Introduction
Customer demands for increased performance within the precision micro-fluidic markets, including high image quality printing, can be satisfied by designing piezoelectrically actuated ink jet printhead modules with single crystal silicon Micro-Electro-Mechanical (MEMS) manufacturing processes. The result is a highly flexible design and manufacturing space.

Piezoelectric micropumps offer the ability to place fluids without impacting the substrate. Thus ink jet micropumps are ideal tools for materials deposition on flexible substrates. By directly placing functional fluids to form patterns, structures, imaging and coating steps required by coating processes are eliminated. Another advantage of directly jetting fluid to the desired pattern is that different fluids can often be deposited in their respective patterns without any intermediary treatment steps, another potential savings in material handling.

There are unique challenges for direct deposition on flexible substrates. These include:

1. Compensating for substrate distortion due to handling, temperature, other coatings, etc.
2. Special fluid formulations are required so that processing to final requirements takes place at temperatures below the transition temperature of the substrate.
3. Distance between micropump nozzles and substrate must consider substrate roughness and thickness variability.

2. SX3: 128 Nozzle Micropump
Dimatix's SX3 micropump has been designed to meet the needs of a variety of manufacturing processes that utilize flexible substrates. Market demand for improved drop placement capability, fluid jetability, and micropump longevity has driven the development of silicon nozzle technology for this ink jet printhead, which is a derivative of our SX-128.

Figure 1 illustrates the SX3, showing a polymer cover to improve external robustness and the new MEMS-based nozzle plate.

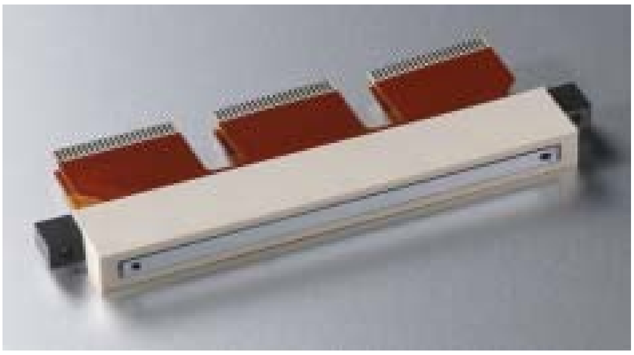

Figure 1. SX3 with Durable Non-Wetting Coating on Silicon Nozzle Plate

Specifications for the SX3 are given in Table 1. The durable non-wetting coating is designed to improve jetting characteristics and to make maintenance easier.

Table 1. SX3 Operational and Physical Parameters

Specification	
# of Addressable Jets	128
Nozzle Spacing	508 microns [0.020”]
Drop Volume	12 Picoliters
Adjustment Range	10-12 Picoliters
Drop Volume Variation	<2% w/ TDC electronics
Nominal Jet Velocity	8 m/sec
Spot Location (all sources)	+/- 10 microns @ 1mm
Compatibility	LEP/PEDOT/PPV, etc.
Drop Velocity Variation	+/- 5% without turning
Operating Frequency	Up to 10kHz to specification

3. Drop Placement Accuracy

Adequate drop placement accuracy is paramount in a precision deposition process. Overall drop placement accuracy relative to the piezoelectric micropump (excluding machine and substrate errors) is dependent on each individual nozzle’s trajectory error and each nozzle’s position relative to all nozzles. Jet trajectory error is the angle between the jet trajectory vector and the axis orthogonal to the nozzle plate plane. Nozzle position error is the distance between a nozzle’s position and the nozzle’s intended position. Minimizing jetting standoff will minimize the jet trajectory component of overall drop placement accuracy but will not change the effect of nozzle position error on overall drop placement.

Figure 2 illustrates how the components of drop trajectory error and nozzle position error can affect overall drop placement accuracy. At standoff 1, half of the total drop placement error is due to jet trajectory error and the other half is due to nozzle placement error. By decreasing the jetting distance to standoff 2, drop placement error is 25% less than standoff 1. The jet trajectory error component to the drop placement error is halved but the nozzle position error remains the same.

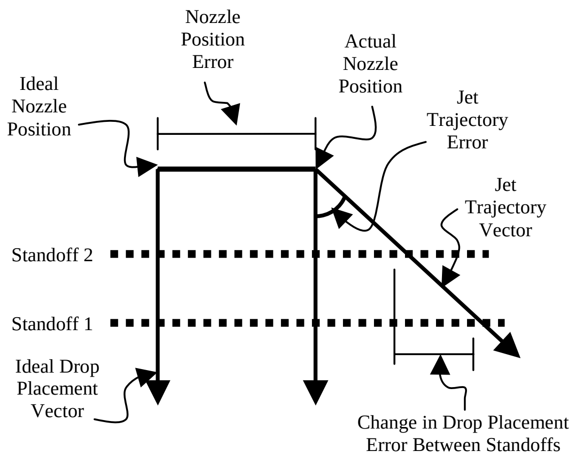

Figure 2. Drop Placement Error at Two Standoffs

An error in nozzle placement can occur by physically deforming a line of nozzles. The SX3 silicon nozzle structure is designed to have 128 nozzles in a precise straight line. Maintaining that straight line is critical in attaining precision drop placement. For example, if the nozzle line is bowed 10mm from true, then the middle nozzle will place fluid 10mm away from the end nozzles. As shown in Figure 2, changing standoff does not change nozzle placement error.

MEMS manufacturing processes allow for a silicon nozzle plate to be made in a state impervious to physical deformation of the nozzle line during fabrication. Silicon nozzle plates can also be fabricated to a thickness that improves handling. Figure 3 indicates jet trajectory error for an exemplary silicon nozzle plate.

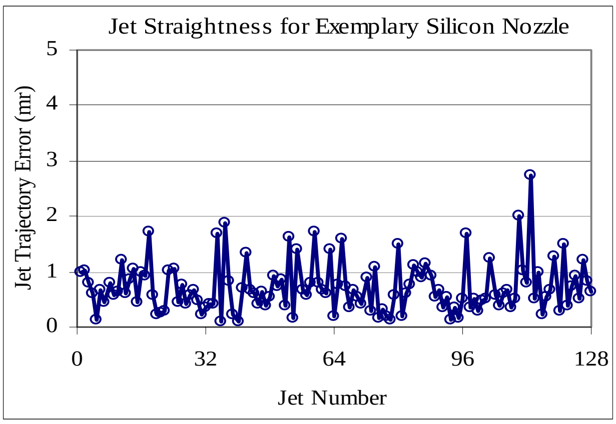

Figure 3. Jet Straightness for an Exemplary Silicon Nozzle Plate

4. MEMS-Based Material Deposition Technology and Micropumps

The major steps in Dimatix's fabrication process are the following:

1. Final wafer is fabricated from a three wafer stack-up, two silicon wafers and a PZT structure.
2. Dies are then separated from the wafer to produce deposition heads with the targeted amount of nozzles.

Other than the integration of the PZT into the wafer stack, all other processes are either IC-based or MEMS processes. Examples of these processes are metal sputtering, wafer grinding and chemical-mechanical polishing, as well as deep reactive ion etching (DRIE) and silicon fusion bonding. Photolithographic process is used to define the planar geometries. An example of the basic structure is shown in Figure 4.[1]

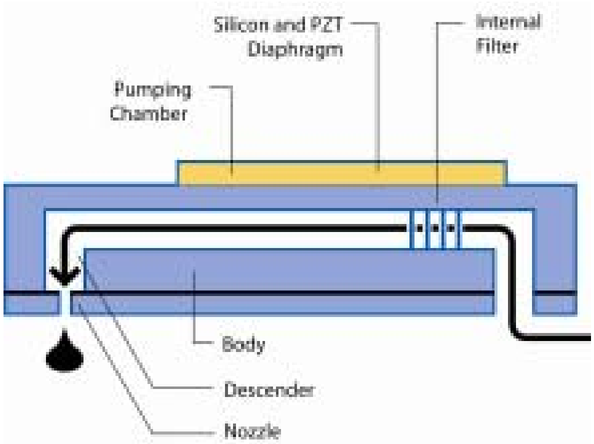

Figure 4. Schematic for new MEMS piezo ink jet

Silicon material, the base material for the MEMS processes, is a superior mechanical material with properties enabling a wide variety of deposition materials and inks. Dimatix has demonstrated superior resistance of the shaped piezo silicon to a wide variety of jetting formulations for aqueous inks, solvents and both highly acidic and basic fluids. In addition, the technology used to fuse the various layers of wafer material is also very resistant to chemical attack; a very common problem in many jetting systems used today. Finally and equally important is the fact that the outer surface is also made of silicon, which has been treated to provide a durable non-wetting exterior surface. This treatment allows frequent wiping and deposition of abrasive suspensions without damage.

5. Conclusion

New silicon nozzle technology can improve SX3 micropump performance for many precise manufacturing processes. The MEMS architecture, integrated with silicon processes, enables a highly flexible design of different nozzle diameters and droplet properties. This new architectural approach allows additional scaling of nozzle spacing, drop sizes as well as overall fluidic dimensions to be part of the product design, aimed towards specific applications.

6. References

[1] Menzel, Chris, Bibl, Andreas, and Hoisington, Paul. "MEMS Solutions for Precision Micro-Fluidic Dispensing Applications," Imaging Science & Technology Non-Impact Printing 20 Conference, November 2004.