Advances in Piezoelectric Ink Jet Micropumps for Precision Deposition Using Silicon Nozzles

Will Letendre and Amy Brady
Spectra, Inc.
Lebanon, New Hampshire, USA

Abstract

Piezoelectric ink jet micropump devices offer the capability to precisely deposit fluids within microscopic structures. Manufacturers of flat panel displays, using light emitting polymers, have employed piezoelectric ink jet micropumps in their fabrication process to accurately and consistently place fluids within the pixel structure of displays. As an integral tool in this manufacturing process, the piezoelectric ink jet micropump must maintain tolerances necessary for adequate fluid placement in the display pixels and provide jetting operability for reliable functioning with a robustness to attain sufficient life. An industry push to increase display pixel resolution, demand for improved jetability of complex fluids, and the requirement for longer ink jet micropump service life has mandated the advancement of new technologies to meet these demands. State-of-the-art MEMS techniques have been developed to fabricate high quality silicon nozzles for these demanding applications. This paper describes how new silicon nozzle technology has been applied to a piezoelectric ink jet micropump to improve drop placement accuracy, jetting operability, and chemical resistance.

Introduction

The manufacturing of light emitting polymer (LEP) flat panel displays (FPD) requires the precise deposition of fluids within the pixel structure of the displays. Piezoelectric ink jet micropumps offer the ability to deposit fluids without impacting the substrate. By directly dispensing these fluids within a display pixel structure, the imaging and coating steps required by spin coating processes are eliminated. Another advantage of directly dispensing fluid within the structure is that different fluids can be deposited in their respective wells without any intermediary treatment steps to protect previously filled wells. This allows for the dispensing of red, blue, and green LEP fluids within the sub-pixels of each pixel using a single process. Current LEP RBG FPD pilot manufacturing lines use four inline printers for manufacturing.[1] The first printer applies an electron distribution layer in all of the wells within a substrate and the subsequent three printers dispense red, blue, and green LEP fluids in their respective wells. The two steps in the process are the deposition of fluids and the transporting of the substrates between printers. Figure 1 illustrates this fluid deposition process by showing three nozzles aligned above a substrate dispensing red LEP fluid within the pixel structure that already has green and blue deposited in the appropriate sub-pixels. At the conclusion of this deposition step, all of the pixels will be filled and the display is then ready for encapsulation.

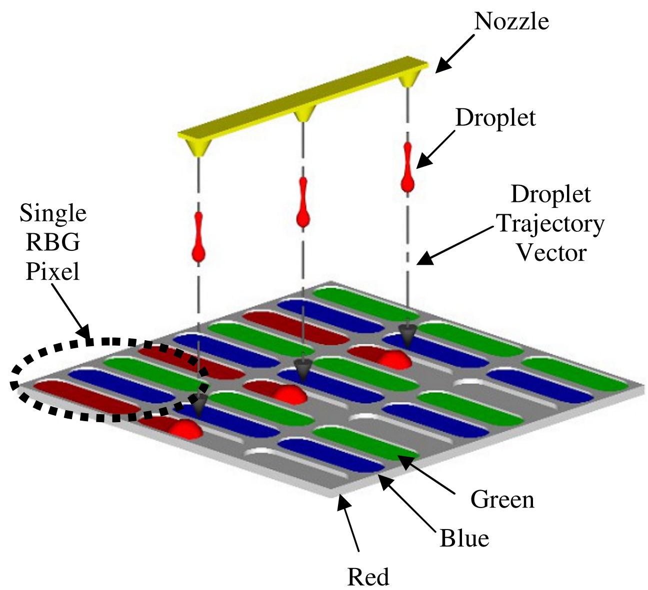

Figure 1. LEP RBG FPD Fluid Deposition Process

The challenges in the LEP FPD precision deposition manufacturing process lie within the precise placement of the fluid on the substrate, reliable jetting of the fluid, and the robustness of the ink jet micropump to the aggressive properties of the display manufacturing fluids. Spectra's SX-128 printhead has been designed to meet the needs of the LEP FPD manufacturing process. A gold plated electroformed nickel nozzle plate is used on the SX-128. Market demand for improved drop placement capability, fluid jetability, and ink jet micropump longevity has driven the development of an improved nozzle technology. The SX-128 has reached the capability limit of electroformed nozzle technology. Silicon nozzles offer the opportunity to expand the limits of the SX-128 capabilities.

Drop Placement Accuracy

Adequate drop placement accuracy is paramount in a precision deposition process. If fluid for one sub-pixel is misplaced in the LEP FPD manufacturing process, the display is considered a failure. Overall drop placement accuracy relative to the piezoelectric ink jet 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.

An error in nozzle placement can occur by physically deforming a line of nozzles. Design intent for the SX-128 is to have 128 nozzles evenly spaced along a 6.54 cm (2.54 inch) line. Maintaining that straight line is critical in attaining precision drop placement. If the nozzle line is bowed 10 µm from true, then the middle nozzle will place fluid 10 µm away from the end nozzles. As shown in Figure 2, changing standoff does not change nozzle placement error. Figure 3 compares the drop placement accuracy of an SX-128 with a 7 µm magnitude curvature in Y to an SX-128 with a straight nozzle line jetting from a standoff of 1.5 mm. For the bowed SX-128 at 1.5 mm standoff the magnitude of the jet trajectory error component is approximately equivalent to the nozzle position error component on the overall drop placement accuracy.

Figure 4 compares the drop placement accuracy of the SX-128's shown in Figure 3 with the standoff decreased to 0.3mm. By decreasing the standoff to 1/5 of the original height, jet trajectory error is decreased, making nozzle placement error the dominating component of overall drop placement error.

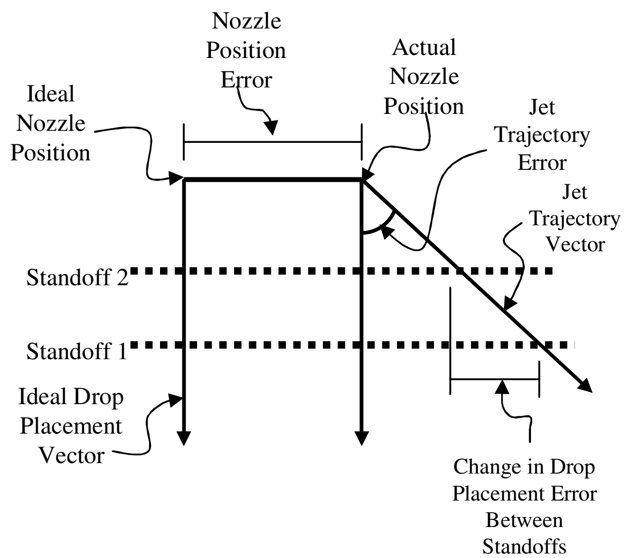

Figure 2. Drop Placement Error at Two Standoffs

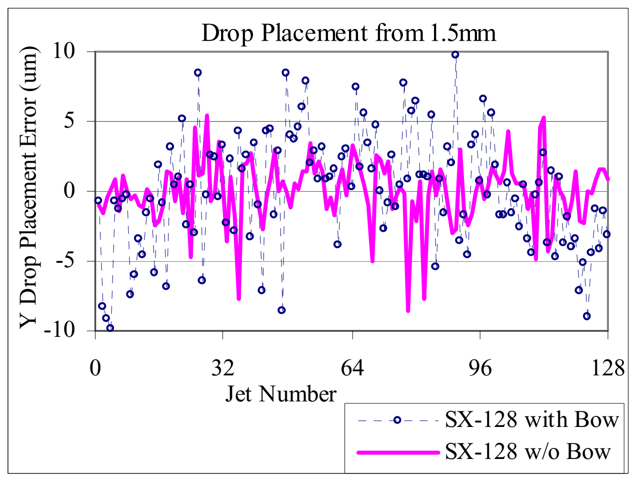

Figure 3. SX-128 Drop Placement from 1.5mm Standoff

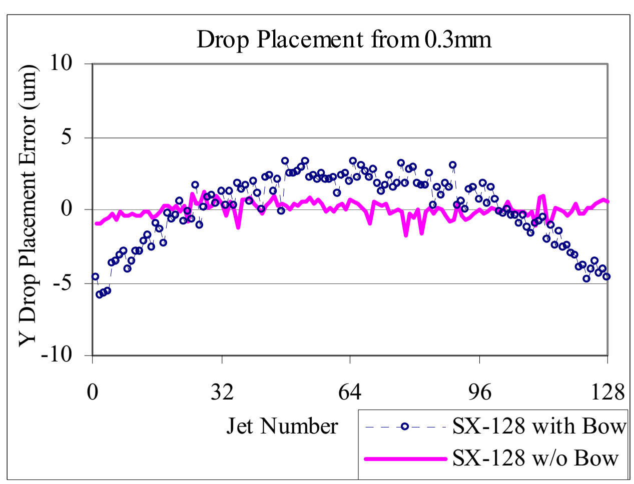

Figure 4. SX-128 Drop Placement from 0.3mm Standoff

Silicon nozzles offer an improvement over electroformed nickel nozzles in both jet trajectory error and nozzle placement error. Figure 5 shows each jet's trajectory across an exemplary SX-128 ink jet micropump with an electroformed nozzle and Figure 6 shows each jet's trajectory across an exemplary SX-128 ink jet micropump with silicon nozzles. The silicon nozzles enhance the already capable SX-128's jet straightness, but the improvement in nozzle position error provides the more significant benefit to overall drop placement accuracy. The electroformed nickel nozzle plate is less than 25 µm thick. This delicate part can bow during its fabrication process causing permanent deformation of the line of nozzles. MEMS manufacturing processes allow for a silicon nozzle plate to be made in an impervious state with no physical deformation of the nozzle line. Silicon nozzle plates can also be fabricated to a thickness more suitable to handling. Relative to the thin electroformed nickel part, the silicon nozzle plate is a more robust part for use in the ink jet micropump manufacturing process.

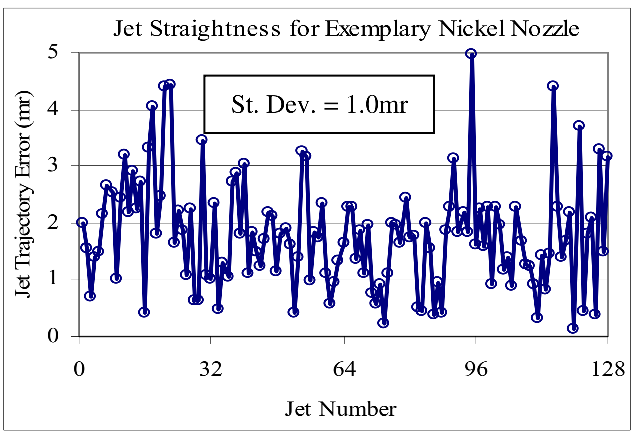

Figure 5. SX-128 Jet Straightness for an Exemplary SX-128 with Electroformed Nickel Nozzles

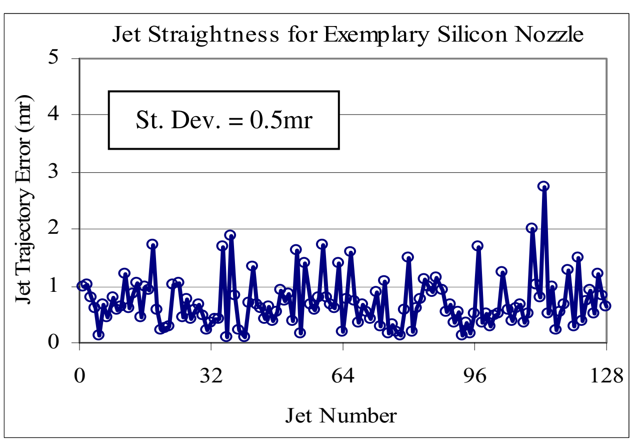

Figure 6. SX-128 Jet Straightness for an Exemplary SX-128 with Silicon Nozzles

Jetting Operability

The LEP FPD precision deposition manufacturing process requires uniform and stable jetting of the display manufacturing fluids. To maintain the dimensional control necessary to meet the uniformity demands of the SX-128 with an electroformed nozzle, a straightbore nozzle must be used. Straightbore nozzles have high fluid resistances and lower volumes compared to shaped nozzles. This leads to meniscus instability and results in poor jet sustainability and lower frequency response ranges. The fluidic resistance of a nozzle also affects the voltage required to produce a droplet and the final drop formation. High resistance nozzles require more voltage to produce a drop and increase the difficulty of producing single droplets at acceptable drop velocities. In order for the SX-128 to produce droplets with acceptable drop formation, its electroformed straightbore nozzle plate must be made less than 25 µm thick.

Silicon micro-machining technologies create opportunities for shaped nozzles within the necessary tolerance range that the SX-128 demands. Figure 7 shows a cross section of a shaped silicon nozzle where the inlet bore throats down to a smaller diameter outlet bore. Shaped silicon nozzles have demonstrated improved jet sustainability over a broader frequency range than the straightbore nozzles currently used on the SX-128.

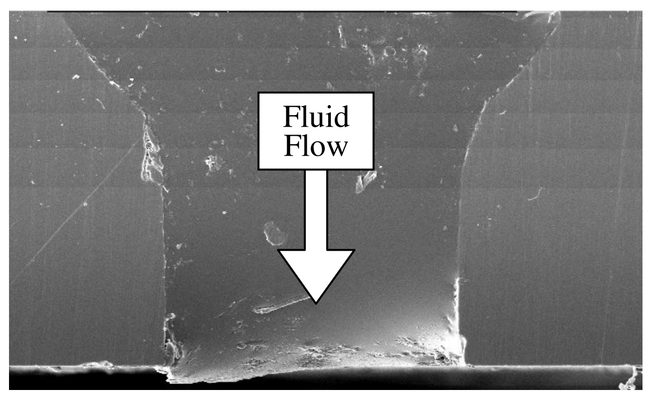

Figure 7. Cross-Section of a Shaped Silicon Nozzle

Chemical Resistance

It is important for the nozzle plate to be resistant to the fluids with which it comes in contact. Damage to the nozzle plate can adversely affect drop placement accuracy and fluid jettability. PEDOT is the fluid that is first applied in all of the wells within a substrate to provide the electron distribution layer in the LEP FPD manufacturing process. It is a polystyrene sulfonic acid (PSS) charge balanced acidic (pH 1.5) aqueous suspension. Because of it's acidity, PEDOT is an aggressive fluid that can etch the electroformed nickel portion of the nozzle plate. The SX-128 electroformed nickel nozzle plate is gold plated in order to protect the nickel from attack. Though gold is highly resistant to chemical attack, it is a relatively soft metal with limited abrasion resistance. When the gold plating on an SX-128 nozzle plate is compromised, PEDOT can dissolve the electroformed nickel and destroy the nozzle plate. Figure 8 shows a nozzle where the gold has been compromised and the nickel etched away. The photograph shows the remaining gold shell of the nozzle. Jet trajectory was severely affected changing from –3mr to 141mr.

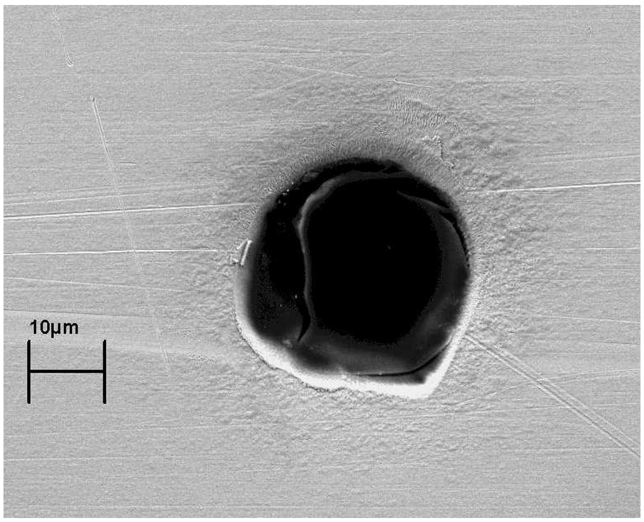

Figure 8. Au Plated Electroformed Ni Nozzle Damaged by PEDOT

Silicon has superior resistance to PEDOT and a wide range of other jetting formulations. Compared to the gold plated electroformed nickel nozzle, silicon's chemical resistance coupled with higher abrasion resistance makes it a more robust solution for jetting aggressive fluids such as PEDOT.

Conclusion

Silicon nozzle technology has been applied to SX-128 piezoelectric ink jet micropump devices to enable advancement in the demanding precision deposition application of LEP flat panel displays. A silicon nozzle plate offers improved drop placement accuracy by eliminating deformations along the nozzle line and enhancing jet straightness. Product precision and operability are advanced by the micro-machining of high tolerance shaped nozzles in silicon die. The robustness of a silicon nozzle plate also offers durability to extend product life. As the industry push for increased pixel resolution in displays continues, solutions to meet these challenges are being developed using silicon MEMS technologies.

References

1. M. Fleuster, M Klein, P. v. Roosmalen, A. d. Wit, H. Schwab, Mass Manufacturing of Full Color Passive-Matrix and Active-Matrix PLED Displays, SID Digest 2004, Session 44.2, pg. 1276 (2004)

Biographies

Will Letendre received his BSME from Rice University and MSME in Mechanical Systems and Design from The University of Texas at Austin. Since 2001, he has worked as a development engineer at Spectra, Inc. in Lebanon, NH. He has focused on performance testing, jet design, and ink jet micropump dispensing product development.

Amy Brady received her BS in Ceramic Engineering from the NYS College of Ceramics at Alfred University. Amy has been employed by Spectra as an engineer since 1992. She has been involved in the development and manufacturing of many Spectra, Inc. products. Her most recent focus has been in the development of silicon micro-machining technologies for piezoelectric ink jet micropump devices.