Advances in Piezoelectric Deposition of Organic Electronic Materials

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Abstract

Piezoelectric DOD (drop-on-demand) ink jet offers a promising combination of high productivity, high reliability and jetting uniformity characteristics (drop volume consistency, velocity characteristics and jet straightness) that are appropriate for jetting organic electronic materials. Because current commercial printheads do not meet the extremely high tolerances necessary for practical manufacturing processes, Spectra is designing a 128 jet printhead specifically for flat panel display (FPD) manufacturing. This paper describes the target specification and technology advancements required for the manufacture of flat panel displays. We will demonstrate the effect of fluid, waveform and head modification on the jetting properties of real polymer OLED (organic light emitting diode) fluids and show that this technology is a viable process for OLED display fabrication. This combination of tailored operating conditions with a purpose-built piezo printhead is proving to be key to meeting the goal of manufacturing high quality FPDs.

Introduction

Organic light emitting materials are used in the manufacture of high resolution flat panel displays. These OLED materials can be applied with a series of imaging and coating processes, but this approach has many steps and is inefficient in its use of the valuable OLED material. A flat panel display is comprised of many ordered pixels. To create RGB color displays, each pixel must be filled with a precise amount of OLED material. Conceptually, ink jets are ideal precision metering devices in that they enable a data-driven, additive process for dispensing a variety of materials without contacting the substrate. Thus, the individual layers and pixels of a flat panel display could be printed with an ink jet system jetting solutions of OLED material. It is not surprising that the display industry is evaluating various ink jet printheads as manufacturing tools.

Ink jet printheads are designed to eject small drops of material which create complex images with near photographic quality. Office and industrial ink jet printers operate with the high reliability rates required for production equipment. This makes the technology an ideal match for FPD manufacture where the precise metering and deposition requirements of OLED material and the reliability requirements for a robust production process are of great importance. A practical functioning system for the manufacture of polymer-(PLED)-based flat panel displays requires the integration of precision hardware, "electronic" inks and specially designed ink jet printheads. Such a system should enable the production of low cost, efficient, high quality displays. This paper focuses on the ink jet technology that is essential to this ideal system.

Printhead Attributes for OLED

Drop size, uniformity and placement accuracy are determined by the desired resolution of the target display. A typical pixel size for a high resolution display is 50 μm for each RGB color on a 200 μm superpixel center. The remaining area is used by a structured photoresist coating, that keeps the RGB color cells separate. The important requirements for material deposition include: uniform pixel fill, even pixel wetting, and no cross contamination between color subpixels. These requirements can be translated into printhead specifications.

Drop Uniformity

OLED materials produce emitted light. Standard print on paper invokes reflected light. Because the eye is more sensitive to changes in emitted light than reflected light, the uniformity requirements for OLED material dispensing are significantly more stringent than typical ink jet printing applications. Drop mass uniformity of 2% per nozzle is the target value for FPD manufacture.

Drop Size

Another important parameter is drop size. A 20 pl ink droplet has a calculated diameter of 34 μm. With a 50 um pixel size, very few drops are needed to fill the cell with fluid, as shown in Figure 1. As the drop size decreases, more drops are used per cell. By adding additional drops, any variation in drop uniformity created by the ink jet head can be decreased. This results in a greater ability to control film thickness.

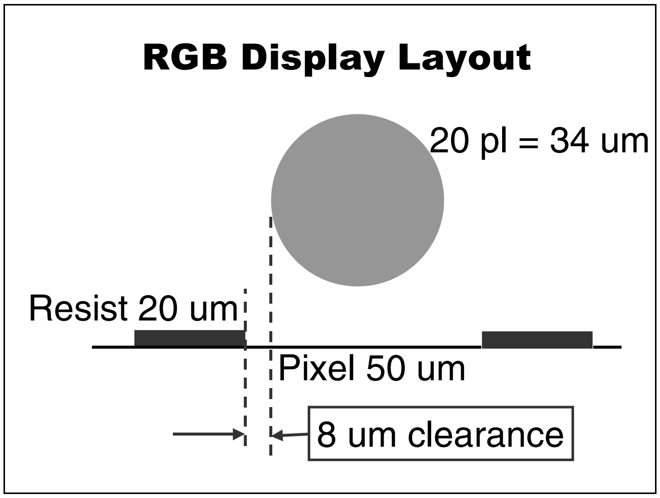

Figure 1. Pixel geometry for RGB deposition

Jet Straightness

The jet straightness requirement can be calculated using assumptions about pixel size and drop volume. For a 20 pL drop, a 34 um sphere is placed in a 50 um pixel, leaving only +/-8 um for positional tolerance, also shown in Figure 1. Unfortunately, machine and substrate error use up a portion of the 8um tolerance. This increases the desirability of the smaller drop volumes. Also as drop size decreases, the straightness requirements become more tolerant, as shown in Table 1. If the pixel is filled using 5 pL drops, then the positional tolerance increases to +/-14 um. Also, the flatness of the precision substrate allows for small standoff distances, reducing the impact of trajectory errors.

Table 1. Predicted diameter and required straightness as a function of drop volume.

Drop Volume (pL)	Drop Diameter (um)	Required Straightness (@ 1mm standoff)
30	39	.31° (5.5 mrad)
20	34	.46° (8 mrad)
10	27	.66° (11.5 mrad)
5	21	.83° (14.5 mrad)

Drop Formation

The shape of the droplet is another important attribute for OLED manufacture. The elimination of tails and satellites to improve yield and quality can be achieved through jet design, ink formulation and drive pulse shaping. Round drops with minimal satellites will fill the subpixels without cross-contamination. Uniform wetting of the channel will be more predictable.

Target Specification

Combining the above criteria creates Table 2, which describes the target specification for an ink jet printhead targeting the RGB display application.

Table 2. Desired characteristics for ink jet printhead

Characteristic	Desired Value
Straightness	<1 degree (all jets)
Drop Volume	5-15 picoliter
Drop Velocity	3 to 8 m/s
Volume/ Velocity Uniformity	±2% from all sources
Operating Temperature	Ambient to 55°C
Materials Compatibility	Weeks or a few months may be acceptable
Life	>10 billion actuations / channel
Maximum Frequency	Up to 10 kHz

Advances In System Performance

Using a system approach, printhead improvements are coupled with new ink formulations, and wave form modifications to meet the requirements for OLED manufacture.

Printhead Optimization

In order to satisfy the production requirements for OLED flat panel display applications with a robust print engine that can be produced with high yield, a series of design changes is under investigation. These include new printhead materials for compatibility with OLED fluids, changes to nozzle geometry for straightness, and scaling of the pumping chamber to reduce drop size.

The chart in Figure 2 shows the effect on drop mass of changing drive voltage. The four curves represent four nozzle diameters, with a single pumping chamber design. This simple change demonstrates the ability to reduce drop mass by 50%, from 20ng to 10ng. Though there can be performance penalties associated with acoustic reflections created by detuning the jet, the frequency response curves in Figure 3 show results for the four nozzle designs mentioned above. The performance of the jet is unchanged over the range of interest from 0-10 kHz. Further changes in pumping chamber design are under evaluation. The goal is to continue to optimize performance of the small drop jet design. Results are not yet available.

In addition to drop size, improvements in drop straightness are critical to enabling the success of this application. In Figure 4, per nozzle straightness of a 128 jet printhead with the new nozzle design is shown. Straightness error of all jets is within +/-0.25° (5 mrads).

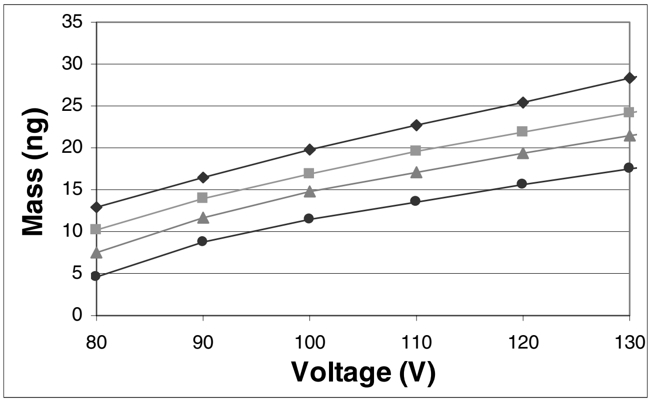

Figure 2. Change in drop mass as a function of four different nozzle diameters.

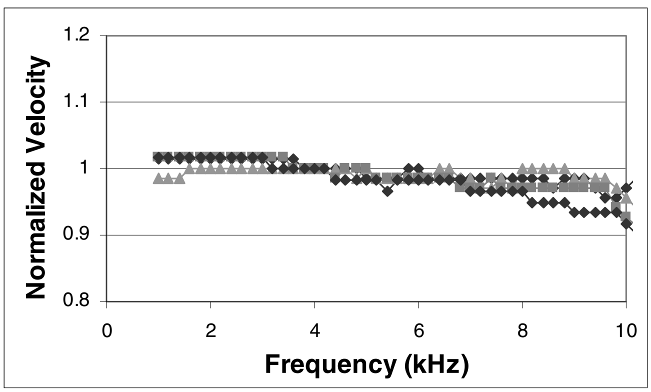

Figure 3. Frequency response for four different nozzle diameters.

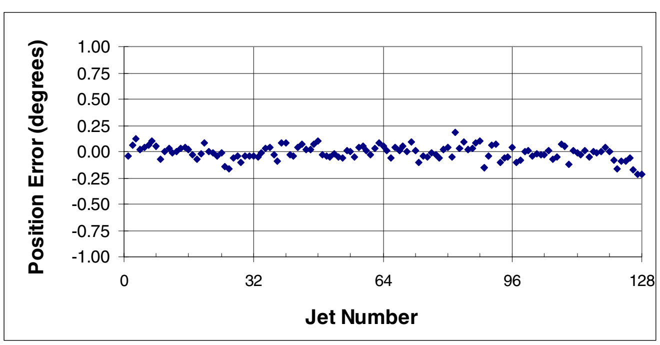

Figure 4. Straightness error of new nozzle design,with model fluid

The histogram in Figure 5 gives a comparison between the old and new nozzle technology. Over a population of printheads, the new nozzle technology is more capable of meeting the straightness requirement than previous designs. Also, in Figure 6, a visualization of two nozzle designs is shown. The new nozzle design is shown to give improved drop trajectory, as compared to the old design.

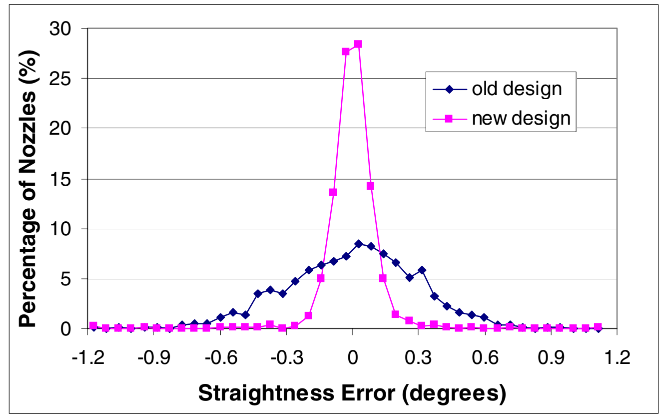

Figure 5. Comparison of straightness error of two nozzle designs.

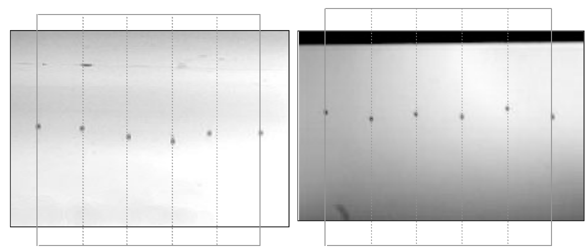

Figure 6. In-flight droplet images of an LEP solution fired with the old design (left) and the new prototype design (right), demonstrating improved straightness of the new design.

Drop Formation

The ability of the LEP fluids to give the excellent droplet formation depicted in Figure 6 is very dependent on both the rheology of the polymer solution and the driving conditions of the printhead. The images in Figure 7 illustrate the effect of optimizing both these parameters. Figure 7a) shows the droplet formation observed for a standard red LEP solution (Covion Red CR-01) jetted through a prototype SX-128 printhead. This solution had not been adjusted to the rheological requirements of ink jetting with the exception of using a higher boiling point solvent. Due to the rheological behaviour of this ink, very long ligaments are observed which do not easily break off from the meniscus, leading to erratic firing behavior. The physical properties of the fluid were modified to yield a much more uniform drop as shown in Figure 7b). By then optimizing the drive waveform to minimize ligament formation, while retaining all other desirable jetting characteristics such as jetting directionality, the excellent drop formation shown in Figure 7c) can be obtained with this ink jet grade LEP solution.

System Optimization

In addition to implementing printhead and ink changes to improve performance in the OLED printing application, modifications to the drive pulse can be used to increase uniformity on a channel-by-channel basis. In the new SX design, it is possible to address each jet individually to allow tuning of the drop volume and achieve uniformity of 2% per channel. First, an accurate measure of the volume produced by each nozzle must be obtained. Then, using a simple calculation, it is possible to send a unique fire pulse to each channel to ensure an extremely high rate of uniformity. Figure 8 is a representation of the new package, showing 128 connections to the 128 jet printhead. This interface allows the end user complete flexibility in the electronics design.

a)

b)

c)

Figure 7. a) In-flight droplet image of a standard red LEP solution. b) Drop formation observed following adjustment of ink rheology. c) Final drop formation following optimization of drive conditions.

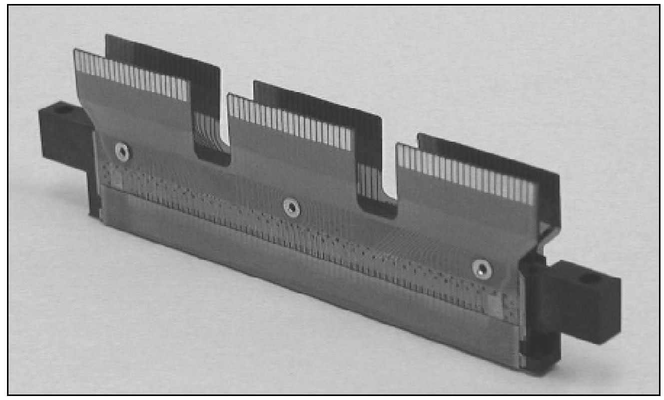

Figure 8. SX128 printhead with per channel connectors.

Conclusion

This paper has described the ideal specifications for an ink jet printing system targeted at the flat panel display manufacturing market. It has described printhead development activities intended to satisfy this market. The influence of the rheological attributes of the LEP solutions has been identified. Opportunities of pulse shaping and drive pulse optimization have been described. The result is a production system capable of meeting the demands of the flat panel display manufacturing application.

Biography

Marlene McDonald received her BA from Dartmouth College and her MSME in Fluid Mechanics from the University of Massachusetts at Amherst. Since 1994, she has worked as a development engineer at Spectra, Inc. in Hanover, NH. She has focused on computational modeling, jet design, and new product development.

Susanne Heun has a PhD in physical chemistry from the University of Marburg, Germany. She has been in the field of organic optoelectronics since her Master´s thesis in 1991 and is now the group leader Polymer Technology in the Covion Application Lab.

Neil Tallant received his BSc and PhD in Chemistry from University College London. He joined Avecia's originating company ICI in 1992 as a Research Chemist, and has since been involved in various aspects of colorant synthesis and formulation. His current interests are in developing ink-jet formulations of electronic materials with a specific emphasis on OLED fluids.