Manufacturing OLEP Displays with Piezo Ink Jet

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Abstract

Ink jet printheads are proving to be practical tools for the precise deposition of light emitting polymers in the construction of flat panel displays with glass substrates. Purpose-built piezo ink jet printheads are now embodied in integrated manufacturing equipment installed in R&D centers and pilot production facilities of major flat panel display manufacturers around the world. This paper will present results of modifications to the printhead and to electronic fluids to improve display yield.

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. However, for the production of high resolution RGB displays in a manufacturing environment, the printhead must be able to reliably jet the desired electronic fluids with a jet straightness better than 1 degree and drop volume consistency of 2%. Improvements in electronic fluids and in printheads were required to meet these goals.

The consistency of drop volume has been improved by redesign of the jetting assembly itself, which has reduced crosstalk to non-observable levels. We will also demonstrate how the LEP fluids have been modified to overcome the rheological properties which otherwise renders them unsuitable for ink jet processing, without destroying their desired electronic properties. In addition to implementing printhead and ink changes to improve performance in the LEP printing application, modifications to the drive pulse can be used to increase uniformity on a channel-by-channel basis. In the new printhead design, it is possible to address each jet individually, such that by using precise volume measurements coupled into a feedback loop, a unique fire pulse can be sent to each channel to ensure a drop volume uniformity of 2%. The effect of these printhead and fluid changes on display yield will be discussed.

Introduction

Organic light emitting materials are used in the manufacture of high resolution flat panel displays (FPD). These OLEP 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 OLEP 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 OLEP material.

A practical functioning system for the manufacture of OLEP-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 and fluid technology that are essential to a successful system.

Printhead Attributes for OLEP

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 ~200µm superpixel center. The remaining area is used by a structured photoresist coating that separates the RGB color cells primarily by surface energy forces. 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 and materials specifications.

Drop Uniformity

OLEP 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 OLEP 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 10 pl ink droplet has a calculated diameter of 27 µm. With a 50 µm pixel size, very few drops are needed to fill the cell with fluid and 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.

Jet Straightness

The jet straightness requirement can be calculated using assumptions about pixel size and drop volume. For a 10 pL drop, a 27 µm sphere is placed in a 50 µm pixel, leaving only +/-11 µm for positional tolerance. Unfortunately, machine and substrate error use up a portion of the 11 µm tolerance, which increases the desirability of small drop volumes. Also as drop size decreases, the straightness requirements become more tolerant. Also, the flatness of the precision substrate allows for small standoff distances, reducing the impact of trajectory errors.

Drop Formation

The shape of the droplet is another important attribute for OLEP display 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.

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 OLEP display manufacture.

Printhead Optimization

To meet requirements for OLEP flat panel display manufacturing, a printhead has been designed with new printhead materials for compatibility with OLEP fluids, changes to nozzle geometry for straightness, and scaling of the pumping chamber to reduce drop size.

The four curves in Figure 1 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. The performance of the jet is unchanged over the frequency range of interest from 0-10 kHz.

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

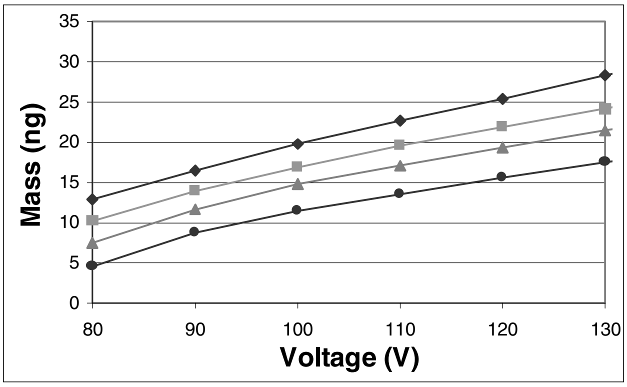

Figure 1. Change in drop mass as a function of four different nozzle diameters.

Drop Formation

The ability of the LEP fluids to give the excellent droplet formation is very dependent on both the rheology of the polymer solution and the driving conditions of the printhead. The images in Figure 2 illustrate the effect of optimizing both these parameters. Figure 2a) 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 behavior 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 2b). 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 2c) can be obtained with this ink jet grade LEP solution.

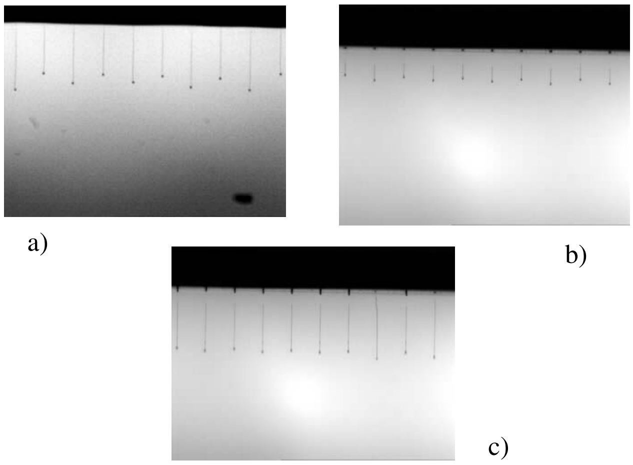

Figure 2. a) In-flight droplet image of a standard red LEP solution. b) Drop formation observed following adjustment of ink rheology. c) Final drop formation following optimization of drive conditions.

System Optimization

In addition to implementing printhead and ink changes to improve performance in the OLEP 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 3 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.

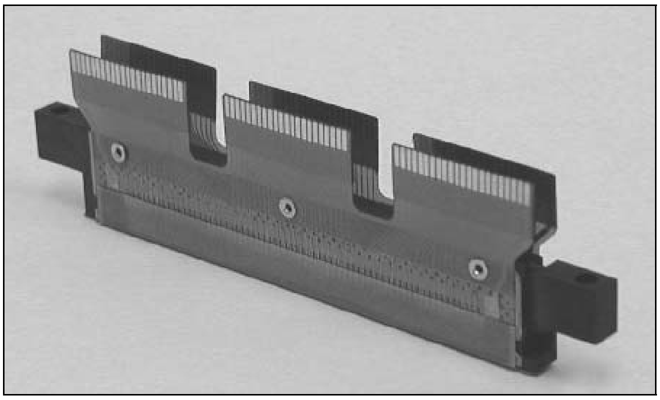

Figure 3. SX-128 printhead with per channel connectors

Conclusion

This paper has described 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.