PIEZOELECTRIC INK JET AND ORGANIC ELECTRONIC MATERIALS

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Piezoelectric DOD (drop-on-demand) ink jet offers the 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. In addition, this technology is the only ink jet technology that offers compatibility with the advanced organic fluids used in the semiconductor industry. This paper will discuss recent advances in the field of piezoelectric DOD ink jet technology, including the use of the piezoelectric printheads for application of light emitting polymers used in flat panel displays (FPD). In addition, this paper will assess the feasibility of using this technology as the application method for organic electronic devices in a manufacturing environment.

Introduction

Manufacturing high resolution FPDs requires precise metering of materials to specified locations on substrates that may already have a variety of special coatings. Today, the substrate is typically glass but future displays will be printed on plastic. 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. Some of today's ink jet printheads eject drops of ink only a few picoliters in volume onto paper substrates to produce complex images of almost photographic quality. Other types of ink jet printheads print characters and codes onto products at assembly line speeds in commercial situations where a failure of the ink jet printhead stops the production line with obvious economic impact. Thus, it is not surprising that the display industry is evaluating various ink jet printheads as manufacturing tools.

A practical functioning system for the manufacture of PLED-based flat panel displays requires the integration of precision hardware, various jettable "electronic" inks and ink jet printheads with processes and procedures. Such a system should enable production of low cost, efficient, high quality displays. This paper focuses on the ink jet technology that is essential to this ideal system and does not discuss in detail these two vital aspects of a successful PLED manufacturing process.

Types of Ink Jet Printheads

There are two fundamental types of ink jetting: the generation of a continuous flow of drops and the ejection of drops as they are required. In continuous ink jet printheads, drops are charged and then either deflected by a charged plate to the desired print location or deflected to a gutter. Typically only 1 or 2% of the drops are required to make an image and the remaining drops are either captured for Recirculation or for disposal. Inks are required to have some conductivity and are generally low in viscosity. This class of printhead is not currently being considered for use in manufacturing PLED displays.

A wide variety of ink jet printhead structures are utilized to generate drops on demand as indicated in Figure 1. The most common are the printheads found in desktop printers such as sold by HP, Lexmark, Cannon and many others. Although these printheads differ in detail, they all operate by rapidly heating water to form a bubble, which causes a drop of ink to be ejected. These thermal ink jets (TIJ) are unsuitable for display manufacture primarily because of this boiling process.

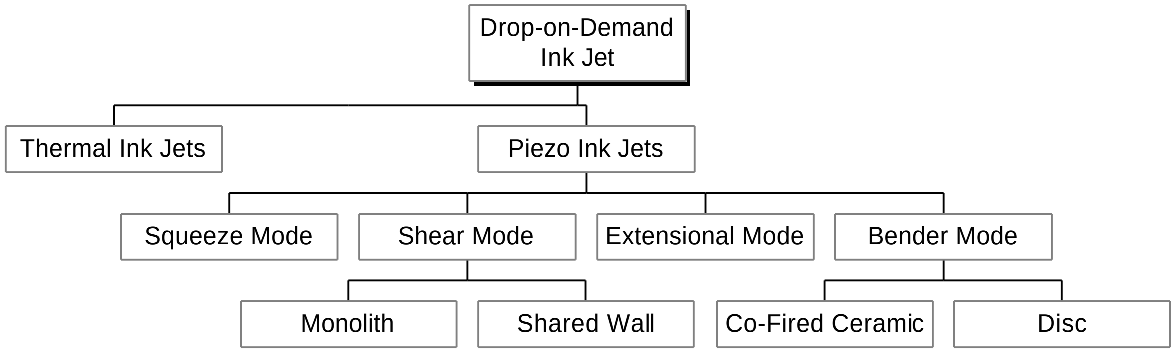

Figure 1. Schematic of various types of Drop-on-Demand Ink Jets.

Piezo-based ink jet printheads function similar to an oilcan in that a piezoelectric material is used to change the volume of the ink chamber and a drop is expelled from a nozzle. Today, most ink jet printheads consist of an array of pumping chambers, nozzles and ink delivery passages. Commonly there are 32 to 512 nozzles in these arrays because use of many jets improves throughput. The details of construction vary greatly even within a general class. Piezo-based DOD inkjet printheads can, in theory, jet any fluid of appropriate physical properties, but in practice the materials used in construction limit the chemistries that can be handled reliably. Performance characteristics also differ widely depending on the method and materials of construction. For these reasons, many different types of DOD ink jets are used commercially. Although most experience has been with jetting colored fluids, or inks, we are now seeing many opportunities to capitalize on DOD printheads as precision metering devices. In other words, rather than talk about "printheads," we might consider these electromechanical devices as piezo micro deposition tools.

Regardless of the mode of construction, there are essential attributes of a given piezo micro deposition tool that need to be considered in selecting a device for use in manufacturing PLED displays. Table I gives examples of some of these relationships.

Display Requirement	Piezo DOD Attribute
Throughput, productivity	Number of usable jets Jetting Frequency Reliability
Feature Size	Drop Volume Drop Spread (mostly substrate)
Feature Precision	Placement Accuracy Drop Volume Control
Yield	Consistency of performance Sustainability of performance Reliability and Maintainability
Compatibility with fluids such as PEDOT and PPV in aqueous and aromatic solvents	Robust material set

Table I. Relationship of Piezo DOD Attributes to Application Requirements

Display Requirements

Sustainable deposition uniformity is a critical measure of performance for ink jet printheads used to manufacture PLED displays. In general the flatness of the substrate allows for small standoff distances, lessening the impact of jet trajectory deviations. Note, also, that the smaller the drop, the easier it is to have it fall within the matrix boundaries. It is important that the operating parameters of the jetting assembly have sufficient range so that they can be adjusted to minimize length of tails and number of satellites that are a natural consequence of jetting high molecular weight polymers. Frequency of operation may not be as important in this application as it often is in many ordinary printing applications. Table II briefly summarizes some important requirements.

Characteristic	Characteristic	Desired Value
Straightness	Jet trajectory angular deviation in x-and y-axis	<18 milliradians (all jets) depending on device resolution and drop diameter
Drop Volume		5-15 picoliters
Drop Velocity		3 to 8 m/s
Drop Volume/ Velocity Uniformity	May require using individual fire pulse adjustments for each piezo channel	±2% from all sources
Materials Compatibility	No degradation of jetting assembly components. No degradation of jetting fluids.	6 months to 2 years contact at operating temperature
Operating Temperature		Ambient to 55°C
Life	6 months to 2 years	10 billion actuations/channel is equivalent to 50 g/jet at 5 pL drop volume
Maximum Frequency		Up to 10 kHz

Table II. Desire Characteristics for Piezo Micro Dispensing Tools

Recent Improvements in Printhead Performance

No printhead exists today that meets all the requirements for the precise deposition of electronic materials as required for the manufacture of flat panel displays and color filters. Some time ago, Spectra recognized the potential opportunity for our ink jet technology in display manufacture, but we also had to acknowledge that our printheads did not meet all the requirements for a precision deposition tool. We were able to construct durable and reliable printheads that could handle the aggressive fluids required for PLED displays. Although printhead performance was very consistent day to day and although all the printheads had very similar operating parameters, jet trajectories were not sufficiently straight and drop volume and velocity varied too much from jet to jet within a printhead. To remedy these deficiencies, Spectra designed a new type of jetting assembly that is called S-class. The impact of one change is shown in Figure 2, which is the comparison of jet trajectory measurements for printheads made with stainless steel nozzle plates (orifices created by EDM) and nickel nozzle plates (orifices created by electroforming). Jet straightness for these S-class printheads with these special nickel orifice plates exceeds requirements for RGB displays with 75 micron wide elements.

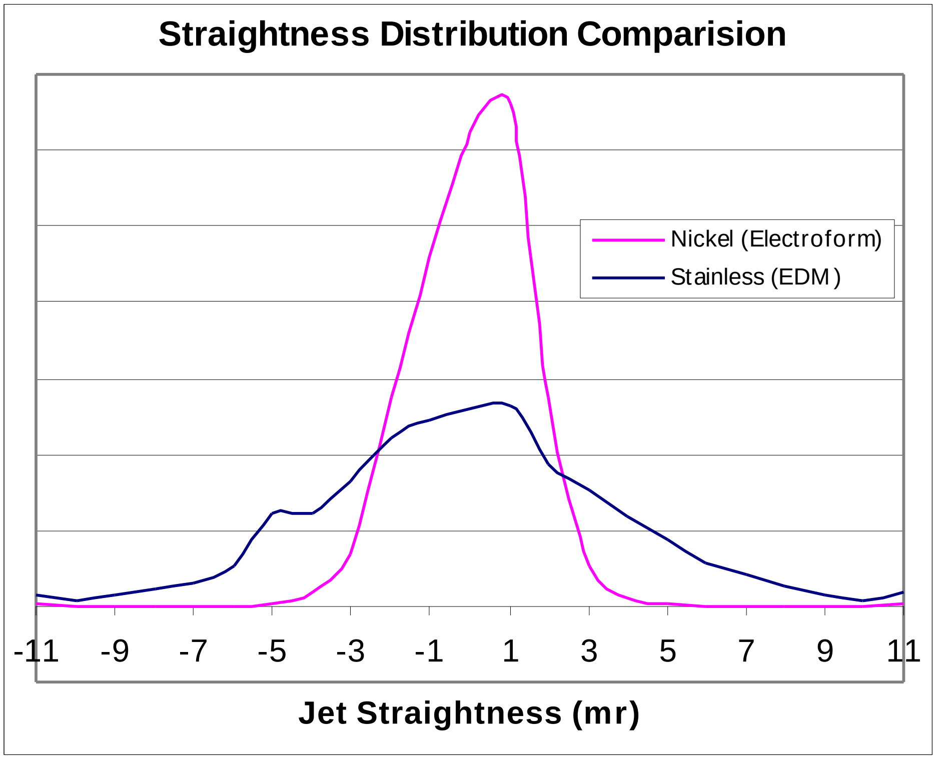

Fig 2. Jet Trajectory Data for Printheads Using Stainless Steel and Nickel Nozzle Plates

Spectra has made some design modifications to reduce drop volume and drop velocity variation within an array of 128 jets, but as yet has not met the target of 1-2% variation. It may be necessary to call on special electronics and software to solve this problem. In graphics arts, complex printing strategies are employed that effectively minimize or hide drop volume and drop velocity variations. It is likely that these types of strategies will be useful in display manufacture to average out drop volume variations, and the system may have to be calibrated periodically.

Conclusion

The dream of organic electronic materials has become a reality, but there are many technical challenges associated with developing practical volume manufacturing processes to capitalize on the advantages of these novel chemicals. Improvements in ink jet printheads are required. Spectra has improved the performance of their printheads, but significant challenges remain.

Acknowledgments

This report of printhead performance improvements would not be possible without the efforts of Spectra engineers, technicians, and dedicated manufacturing personnel. In particular I wish to recognize the core team of William Letendre, Phil Kelly, Susan Cooper and their leader, Marlene McDonald.