Materials and Process Development for Digital Fabrication Using Ink Jet Technology

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Abstract

Interest in the application of ink jet technology for digital fabrication and manufacturing has experienced major growth in recent years. In addition to printing on packaging and manufactured goods, ink jet offers an amazingly broad range of adaptability in the areas of passive and active electronics, biomedicine, pharmacology, micro-optics, stereo-lithography and many others limited only by our imaginations. The process of adapting ink jet to an industrial application can be a mysterious and daunting task to most developers and end users. Although there are consultants to help with getting started and integrators to help implement the processes, there is often a significant body of work that needs to be completed prior to specifying production equipment. As a result, there are a growing number of general development tools to help materials developers and end users to choose the correct materials and processes for a given application. Materials selection and process optimization is paramount to the success of any ink jet project. The purpose of this paper is to explain which measurable parameters are important and how the tools used to measure these parameters can help the developer or end user obtain a reliable and repeatable result for their application.

Digital Fabrication Using Ink Jet

Digital fabrication encompasses a broad range of technologies including ink jet and no matter what the technology, it is clear that analog manufacturing is moving toward and will one day be consumed by digital manufacturing. This shift is being driven by the desire for more customized products, on demand delivery and market factors that make digital manufacturing the long term solution to economic survival.

Is ink jet the right technology for the application? This is the first question that should be asked when contemplating ink jet as a potential solution for any application. Ink jet offers the advantage of being a non-contact additive process that can deliver metered amounts of a variety of fluids at a precise location in time and space. Although many applications have some commonality, the ways in which ink jet technology can be configured are endless. Ink jet has a broad appeal due in part to its deceptive simplicity. However, many projects have failed due to a lack of understanding as to how ink jet works and how to assemble ink jet components to perform the desired function.

Ink Jet Integration

Ink jet integration is generally defined as combining ink jet technology know-how and components into a system that satisfies the requirements for a given application. This is a simple concept that quickly embroils the unsuspecting user's canoe in a quagmire of complexity without the proverbial paddle. The application may be something as common as label printing or something as exotic as constructing a three dimensional lattice for growing artificial bone. Each application has its own set of intricacies and nuances that dictate process development and planned implementation.

The ink jet components consist of the print head, print head drive electronic, print head support and maintenance, ink or fluid, ink or fluid supply, and substrate. Motion control hardware, electronics and software are usually necessary to position the print head and substrate relative to each other. A curing or drying system may also be required to fix the jetted fluid to the substrate or to obtain the desired material properties such as conductivity. In addition, digital information must be communicated to the print head through electronic data interface hardware and software. Lastly, application unique software is required to glue the system together and provide a user interface.

No single manufacturer provides all of the components for every custom application. The print head suppliers will provide limited electronics and software together with generic application notes and technical support based on their experience. Ink and substrate suppliers may supply similarly based information for adhesion and durability for a few inks and substrates. The same holds true for most of the component suppliers. If the user's application falls within the bounds of what's available, then all may be right with the world. However, history has shown that serendipitous ink jet is an oxymoron. To date, most commercially available print heads and digital inks or fluids have been designed with traditional graphics printing as the target application. Thus, it is often necessary to fit the application to the print head that offers the least resistance to implementation.

Ink jet technology know-how is the last ingredient needed to complete the recipe for success. Each step along the way to completion presents many forks in the roadway to a solution. The wisdom to choose the correct fork comes after years of experience or after significant development to gain an understanding of each process. Anyone contemplating ink jet as a production technology must rely on personal experience and multiple knowledge resources such as consultants, integration companies and manufacturers. The most reliable pathway for gaining that knowledge and experience is the use of development tools based on ink jet technology.

Development Tools

Development tools for ink jet technology can generally be classified as visualization systems or printing and deposition systems. Visualization systems use microscopes, cameras and image capture to study the behavior of print heads, fluids and substrates under simulated operating conditions. The printing and deposition systems are used to develop production processes and produce sample output for evaluating fluid and substrate properties.

Visualization Tools

Typical visualization systems for evaluating drop ejection consist of a print head mounting and positioning mechanism with appropriate drive electronics and fluid supply, a microscope and camera with a frame grabber, and image analysis and user interface software. Characterizing the formation of the droplet during the ejection process is of principal importance to understanding the performance limitations of the print head and the fluid in any given application. Instruments like the iTi Drop Watcher shown in Figure 1 can be used to measure important parameters such as drop diameter, drop formation time, tail merge or coalescence time, and flight time from the nozzle exit to a virtual substrate surface.

The user can then calculate important parameters such as the maximum drop ejection rate, drop volume, fluid usage, drop placement error and consistency across all the nozzles of the print head. In addition the user will be able to determine the operating window in terms of the drive waveform, environment, and fluid properties. A typical screen capture of drop ejection and user interface software is shown in Figure 2. Other manufactures such as Xennia offer a similar time averaged drop ejection visualization tools as shown in Figure 3.

A second type of visualization system is used to analyze the characteristics of the fluid on the substrate. These tools generally consist of a microscope, camera, substrate transport, and image analysis software for measuring physical, dimensional and optical properties of the fluid on the substrate after the curing or drying process is complete. These systems can also be used to examine interactions between different fluids when more that one fluid is used in the process application. Systems specifically intended for evaluating ink jet samples are manufactured by Quality Engineering Associates (QEA), Inc. and ImageXpert, Inc.

Figure 1. iTi Drop Watcher Model III shown with a Spectra print head.

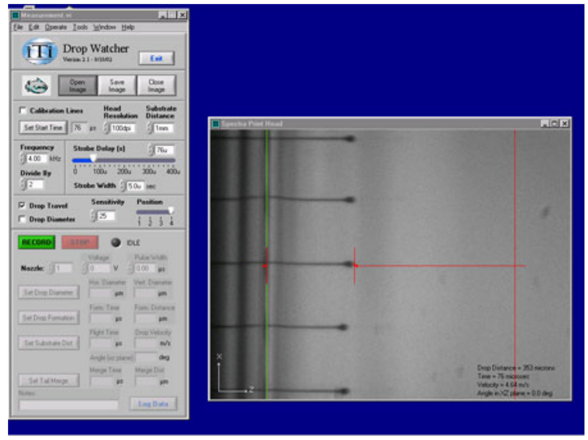

Figure 2. Drop Watcher screen capture & measurement software.

Figure 3. VisionJet Optica drop visualization tool.

Printing and Deposition Tools

Printing and deposition tools are used to develop processes and to study the interaction between the fluid and the substrate. Precise motion control of the components is necessary to isolate the characteristics of print head, fluid and substrate dependencies.

An Ink Jet Web Press system for working with flexible substrates such as paper, peal-off labels, and plastics is shown in Figure 4. Four to eight Spectra, Xaar and other manufactures' print heads can be mounted and adjusted relative to each print head and the substrate. The stationary print head can then deposit multiple fluids on a moving web at up to 90 meters per minute.

A second system for deposition on rigid substrates is shown in Figure 5. This XY Materials Deposition System can accommodate multiple print heads that can be positioned relative to each other. A rigid or non-porous substrate up to 50 mm thick can be scanned under the stationary print heads in raster or vector mode at up to 1.5 meters per second.

Figure 4. Ink Jet Web Press shown with two Spectra print heads.

Figure 5. iTi XY MDS shown with the Spectra Apollo II Printhead Support Kit.

Both types of systems can be used to produce samples for studying process speed, order of lay-down, resolution, and fluid to fluid and fluid to substrate interaction. In addition, curing or drying devices can be adapted to either system.

Production Systems

The application of development tools does not always lead directly to a completely specified production system. It is often necessary to build an intermediate production prototype to fill the gap between development and full production. Two such systems are shown in Figure 6 and Figure 7.

The VJET shown in Figure 6 is a derivative of the XY MDS that prints on rigid substrates such as glass, ceramic, metal, and printed circuit board at up to 800 dots per inch. Conductive fluids can also be used to print 50 µm lines and pads on 50 µm spacing. The VJET uses a scanning print head cluster on a moving gantry with a stationary substrate. Although the system is network enabled with a Windows driver for ease of use, it is not equipped with automated substrate handling and alignment that would be necessary in a production environment.

The Digital Web Press shown in Figure 7 is capable of printing on flexible media rolls up to 60 cm diameter from 75 mm to 150 mm wide using a variety of print heads and fluids at up to 50 meters per minute. The machine can operate as a production system although the DWP was originally built as a jet prototype.

Figure 6. VJET rigid substrate printer with four Spectra print head.

Figure 7. Digital Web Press with eight Xaar print heads.

The Future for Industrial Ink Jet

Ink jet has an amazingly broad range of industrial applications. Indeed it is very likely that the long term value of output, supplies and equipment in industrial ink jet will far outstrip that of the familiar small-office-home-office ink jet market. In the coming years, ink jet printing on two-dimensional and three-dimensional objects will begin to challenge and replace traditional printing methods such as screen, pad and offset.

The world is currently experiencing a major paradigm shift in the way that electronics and displays are manufactured. Digital fabrication in general and ink jet technology specifically are changing the way industry views this type of manufacturing. Figure 8 shows an artist's concept of a future Gen 7 ink jet production system for printing on 2.4 meter square glass sheets for display applications. Such systems will be used to print color filters for liquid crystal displays (LCD), displays using organic light emitting diodes (OLED) and organic thin film transistors (TFT) to name a few. Other optics applications include lenses and light pipes for lasers and optical computing chips.

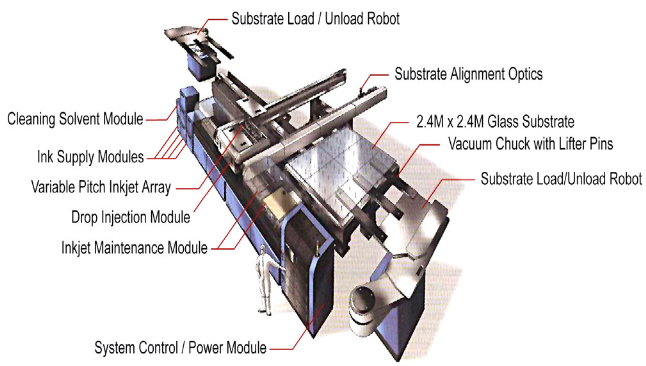

Figure 8. Litrex Corp. Gen 7 ink jet printing system (Courtesy of Litrex Corp).

Ink jet is also beginning to have an influence on the way that printed circuit boards and flexes are being manufactured. Ink jet'able white ink for legends and clear fluids for solder mask application are becoming available. Conductive "inks" for conductive lines, pads and interconnects are ideal for short run production and prototype electronics. Figure 9 and Figure 10 show conductive lines and interconnects with 30 µm to 50 µm widths printed by ink jets. Figure 11 shows ink jet printed lines connecting the pads on an integrated circuit silicon chip to a carrier. It is interesting to note that the conductive ink jet line is capable of making transition from the surface of the pad across the edge of the silicon down to the surface of the carrier without loosing continuity. These are just a few examples of what the future holds for ink jet.

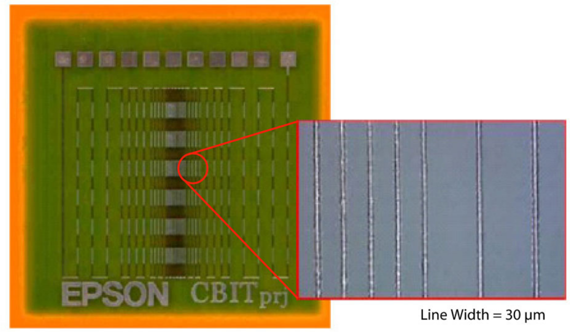

Figure 9. Multilayer circuit lines, insulator and inter-connects printed by ink jet (Courtesy of Seiko Epson Corp.).

Figure 10. Ink jet printed silver conductive ink on a polyimide substrate (Sample courtesy of Cabot Corp.).

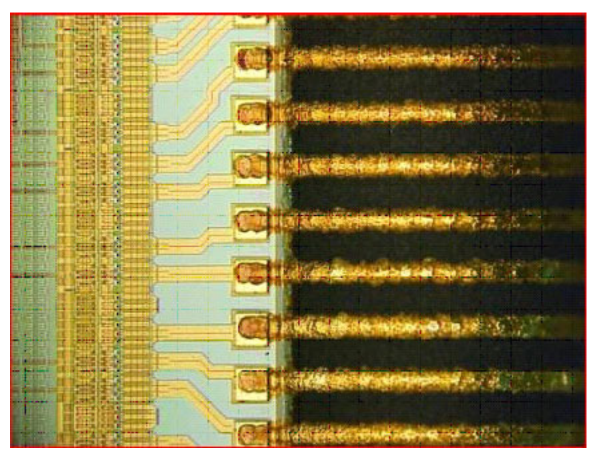

Figure 11. Integrated circuit pad interconnect lines printed by ink jet (Courtesy of Seiko Epson Corp.).

In addition to the preceding applications, ink jet is being used to print and form three dimensional objects and structures including lattices for growing biological tissue such as bone and skin. Ink jet technology is being applied in ways never dreamed of a few years ago and it is likely that researchers and entrepreneurs will dream up even more unheard of applications in the future. In the not too distant future, ink jet may become the first inanimate technology to replicate itself.

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Author Biography

Dr. Mills founded iTi Corporation in 1992 as an ink jet consultancy and developer of ink jet prototype print heads including iTi's proprietary ESIJET™ technology. Since that time, he has helped position the company as a leading ink jet integrator. Prior to founding iTi, he worked for IBM and Lexmark as a Researcher, Senior Engineer and Product Manager from 1978 to 1991. Dr. Mills received his PhD and MS in Engineering Science from the University of California Berkeley and BS Degree in Aerospace Engineering from the University of Texas at Austin.