Membrane Keypad Printing Using Only Inkjet Technology

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Abstract

Many processing steps in the manufacturing of flexible membrane switches require solution processing. Inkjet printing is a facile method for depositing solutions into patterned thin films. Piezoelectric inkjet printing is an open controllable process, thereby enabling the use of a variety of fluids deposited on a variety of substrates to produce the desired product. We have taken several steps back from device manufacturing and worked out the details of inkjet printing of conductive, three dimensional dielectric and adhesive components. Each individual layer has its own set of requirements on how the fluid jet from the piezo-based printhead and how it perform on the substrate to give the desired results to produce a functioning device. In addition, it can be demonstrated that these individual layers are applicable to a variety of other products utilizing digital printing technology. In these applications they are applicable for discrete unique devices or mass production of thousands of devices using the same digital fabrication technology. We will show the successful thin film patterning of these fluids, and we will also show their electrical and physical properties. Finally, we will show other patterned thin films of relevant materials including other conductive nanoparticle inks and dielectrics used in photovoltaic and display applications, carbon nanotubes used as transparent conductors, conjugated polymers used in the active layer and quantum dots, band gap acceptor materials that also function in non-white light environments. Finally, this talk will discuss the impact of inkjet printing on printed electronics and highlight the research efforts of leaders in this field.

Introduction

Inkjet printing has proven to be a simple and efficient method of coating large areas with highly controllable deposition of functional fluids. As the usage if inkjet technology has developed, the need to broaden the range of functional fluids has increased dramatically as well as intricate patterning is in demand. The demand is stemming from the need to do feasibility testing and rapid prototyping of functional devices. Inkjet printing of functional devices works well because of the digital imaging or file creation and the method of additive non-contact jetting of a wide range of jettable fluids have become an accepted method.

Much like printing of graphical images with today's digital printers, the usage of variable printing is common place. Using the same methods in jetting functional fluids to create working devices, inkjet printing can produce unique objects or variable patterning to create one or thousands of devices without any screens or other fixed method of printing.

However printing a single functioning device on a development printer is simple compared to going into production on a RTR (roll to roll) printer for high production. The complete development process must be developed before a production system can be implemented. This development process is typically broken down into three categories;

[Fig. 1]

1. Fluid
2. Substrate
3. System

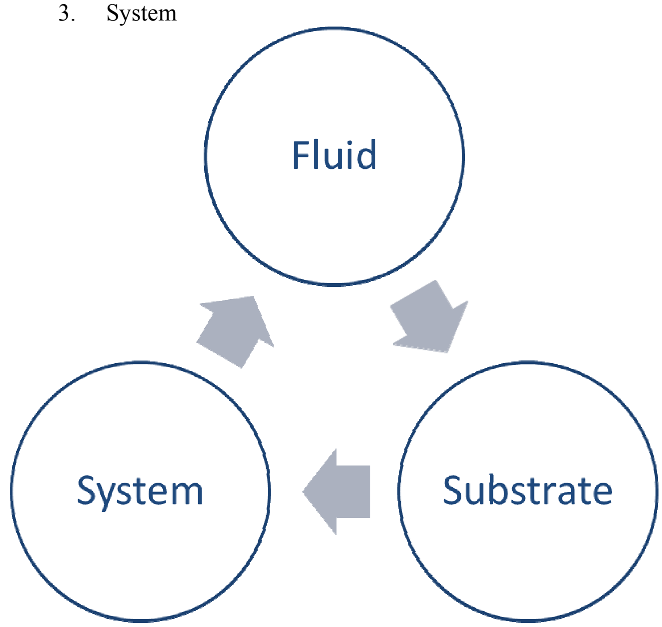

Figure 1 *Fluid Development Process*

FUJIFILM Dimatix, Inc. realized the need to make this development process feasible at a low cost and the Dimatix Materials Printer (DMP-2800) was created and has been used by chemists, material scientists, fluid formulators and many other scientific sectors to evaluate whether they can transfer piezoelectric DOD inkjet printing of functional materials from the laboratory to a high throughput manufacturing process. [Fig. 2]

Jetting Tunability

Fluid flow properties like low viscosities, low boiling points, high surface tensions and non-Newtonian behaviors are hallmarks functional materials required for patterned inkjet printable functional fluids and are all generally unfavorable chemical characteristics for printing. For this reason, the Dimatix Drop Manager software was created to tune jetting parameters for these liquids. This software manipulates the parameters that generate the electronic signal to drive the movement of the PZT, including its frequency, wave shape, wave duration and voltage. Directing these parameters has provided a significant advancement in printing an array of functional materials and has been one of the areas of our research.

***Figure 2** FUJIFILM Dimatix, Inc. DMP 2831 Materials Printer*

Bridging Development to Production

However, while it has been beneficial to jump-start new projects at the academic setting, the DMP-2800's limited substrate size and limited fluid volumes have required us to develop new Dimatix Materials Printers, the DMP-3000, DMP- 5000 [Fig. 3], and the DMP-5005 which can be set up with 5 print heads and utilize

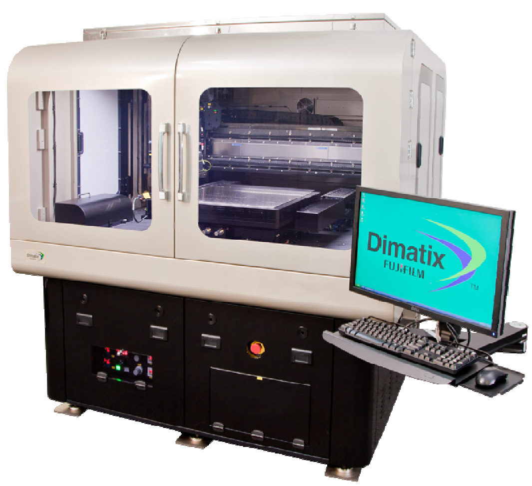

***Figure 3** FujiFilm Dimatix DMP - 5000*

up to 5 different functional fluids. These larger print area development printers can aid in the transfer to high speed inkjet production but these printers can also be used in production of lower quantities of functional devices.

Inkjet Printing Employing Piezo MEMS Devices

The required heating process for thermal inkjet printing (300°C) will damage thermally-sensitive materials, thereby limiting their use in devising functional devices. [1, 2] In contrast, using piezoelectric inkjet printing, temperature sensitive, functional materials are deposited under ambient conditions. Piezoelectric printheads contain a lead zirconate titanate (PZT) piezoelectric ceramic, nozzles, and a fluid chamber. When a voltage is applied to the PZT, mechanical vibrations create acoustic waves that in turn force fluid out of the chamber through the nozzles. [11] Piezoelectric printheads are categorized based on the deformation mode of the PZT (e.g., squeeze mode, bend mode, push mode, or shear mode). At FUJIFILM Dimatix, the MEMS fabrication method for printhead production was adopted to increase the precision and resolution of the deposited materials. These silicon devices increase jet-to-jet uniformity and drop placement accuracy. The inertness of the silicon expands the operating ranges to allow higher chemical diversity and fluid throughput expanding piezoelectric inkjet printing from the ability to print graphic inks to the realm of printing functional fluids required for display manufacturing.

Lowering the Cost of Development

With regards to the technological advances incorporated into the DMP from FUJIFILM Dimatix, a unique feature of this table-top printing system is the printhead itself. For the first time, FUJIFILM Dimatix is producing high performance MEMS printheads that are intended to have a limited lifetime, filled once by the user, and then discarded. The silicon chip that comprises the disposable printhead consists of 16 individually addressable jets that generate drops.[Fig. 4] These nozzles are spaced 254 mm apart, but actual drop spacing during printing is determined by the lateral resolution with tuned head angle. The inkjet printhead is powered by a piezoelectric unimorph, which is constructed in the plane of the wafer and consists of patterned PZT bonded to a silicon diaphragm. [3] The silicon chip is bonded to a molded liquid crystal polymer frame with an electrical interface. This construct is the jetting module portion of the printhead and snaps to the fluid module to complete the FUJIFILM Dimatix disposable cartridge. The fluid module is fabricated with a flexible polypropylene reservoir and protective rigid polypropylene housing. The volume of the reservoir is small (1.5 mL) to conserve expensive fluids. Fluid flows directly from the reservoir through a small column into the device in the plane of the wafer through a silicon acoustic terminator and then into a pumping chamber. The fluid then flows down a descender and out the nozzles perpendicular to the wafer plane. The silicon nozzle/air interface is coated with a proprietary non-wetting material to reduce wetting of low surface tension fluids and to facilitate printhead maintenance. The effective diameter of the nozzle is 21.5 mm; this nozzle size is approximated to generate 10 pL drops. An important operating parameter of this device is the negligible void volume due to the direct fluid/printhead interface.

Inkjet Printed Electronics

Once the development tools are in place, the process of choosing the functional fluids remains. As seen in Figure 1, the process is not a single fluid choice but a system approach as the fluid must

Figure 4 *FUJIFILM Dimatix, Inc. Development Print Head*

match the substrate surface tension. If the fluid is not able to produce high quality lines or drops, the fluid or substrate will need to be modified.

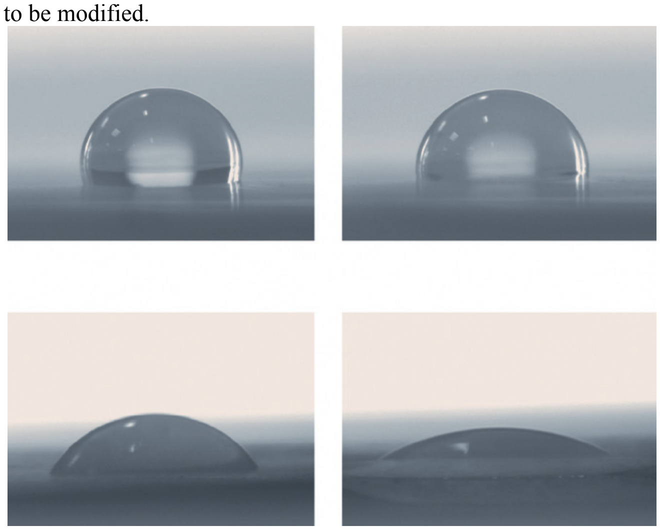

Figure 5 *Substrate Surface Tension Wetting Modifications*

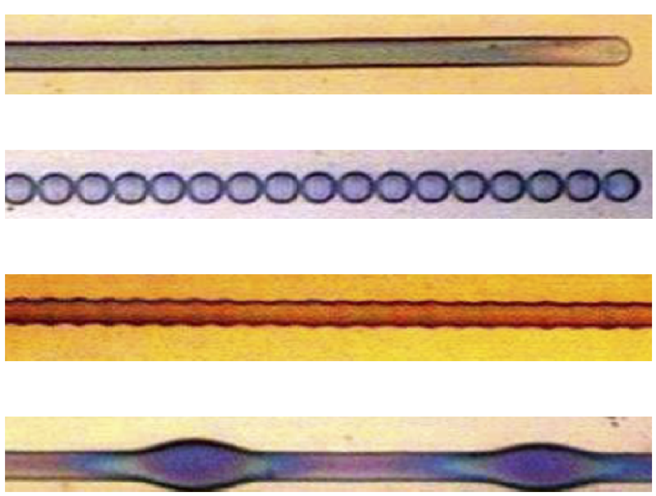

Figure 6 *Varying line results depending on the surface tension*

The same fluid on different substrates can cause wide varying results depending on the surface tension. [Fig. 6]
If the fluid produces dots and not lines, then the sabre angle or printed resolution may not be adequate. The surface tension could also be hydrophobic causing a line to break up into individual droplets.

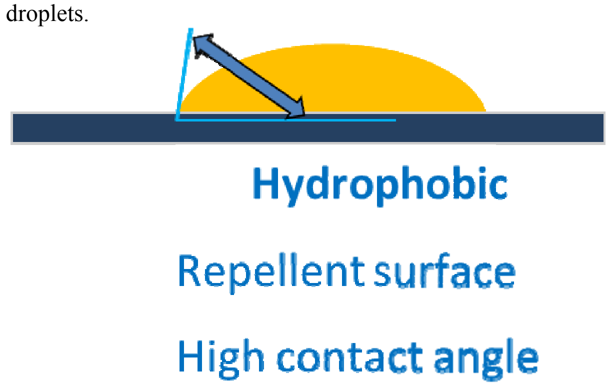

Figure 7 *Hydrophobic Surface Tension*

If the substrate wets too much, the fluid will spread uncontrollably which would be too hydrophilic. [Fig. 8] This will lead to lines which could come in contact with adjacent contacts causing electrical. Therefore the matching of the fluid and substrate surface tension is vital in order to produce repeatable features.

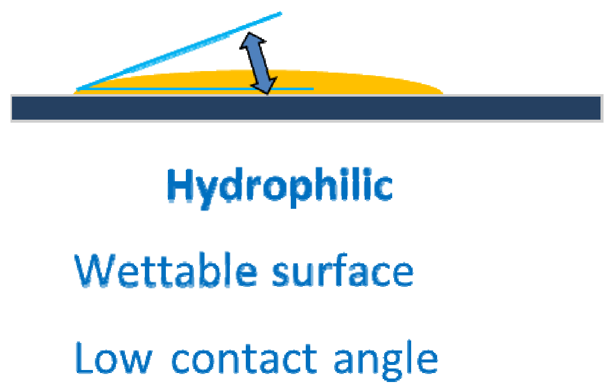

Figure 8 *Hydrophilic Surface Tension*

Functional Keypad Using Inkjet Printing

Once all of the fluids have been developed along with the substrate, the system process needs to be developed. The system process involves any curing or sintering of the conductive fluids as well as any layering of secondary insulating fluids. The system process also may include any maintenance of the print head and fluids as well as and material handling.
In our example of a functioning keypad, keeping the process to its simplest form during the development process helps eliminate complex issues. Our basic keypad is going to use off-the-shelf materials to simplify our process initially. We chose a matching low sintering / curing silver fluid and PET material which will handle 100 degree C temperatures. We used a readily available UV curable graphics ink for the dimensional insulation standoff.

Printing the First Conductive Sheet

Using the FUJIFILM Dimatix, Inc. DMP-3000 and development cartridges the first silver conductive layer was printed and cured.[Fig. 8] The conductive silver printed layer was cured in an oven set for 100 degrees C for 30 minutes.

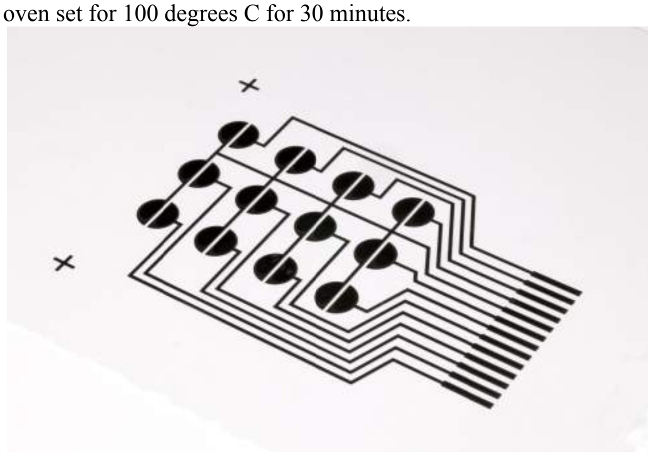

Figure 8 *First Conductive Sheet*

Printing the Second Conductive Sheet

A second PET sheet was printed with the contact pattern using the same conductive silver. Once the image was printed it was placed in an oven for 30 minutes at 100 degrees C.

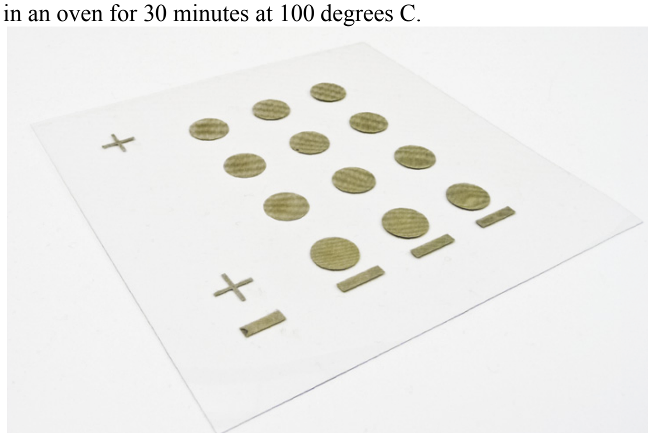

Figure 9 *Second Conductive Sheet*

Printing the UC Curable Insulation Layer

Once the second conductive sheet has been printed and cured / sintered, the sheet is inserted back into the Dimatix printer and the UC Curable insulation layer is printed. [Fig. 10] A UV light source was attached to the printer carriage assembly to pin the UV ink to keep the desired feature dimensions. The sheet was then placed into a UV light curing cabinet for final UV curing. Depending on the UV light source, the final curing could be performed while printing for production printing.

Figure 10 *UV Curable Insulation Layer*

Final Keypad Assembly

Once the final UV insulation layer is cured, the assembly process can begin. LED lights were bonded using UV curable conductive adhesive. The top conductive layer and UV insulator sheet was punched to allow the LED light to lay flat. A UV Curable adhesive was printed on the first layer and then the second layer was placed aligning the registration marks. The assembly was placed in a UV light cabinet and bonded together. A color graphic overlay was printed and bonded to the top layer.+

Figure 11 *Final Assembled Inkjet Keypad*

Conclusion

While this example is a simplified keypad, fully functional working production ink jetted assemblies are a reality. With the continuation of functional fluids, jetting beyond simple conductive traces and insulators are realized. Functioning transistors, resistors, light emitting devices, memory, as well as thin film microprocessors are all inkjet printable.

The movement form development systems to high speed production are now available. [Fig. 12]

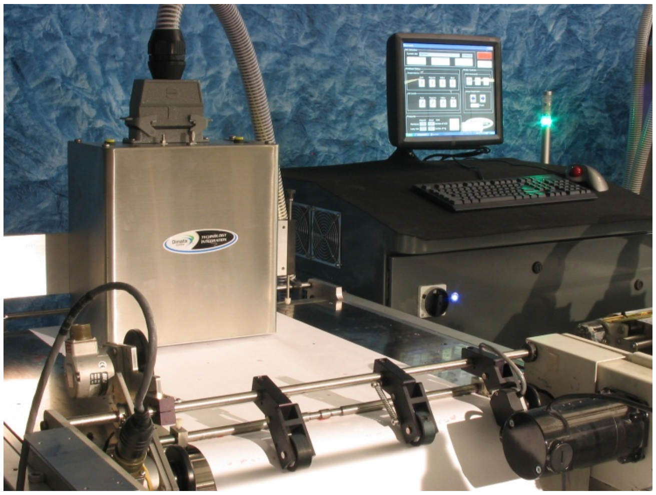

Figure 12 *FUJIFILM Dimatix, Inc. Merlin Roll to Roll System*

Figure 13 *3D-Micromac AG microFLEX RTR System*

Starting with a development printer is vital to completing the printing process. Moving into high speed production in a Roll-to-Roll system with multiple functional fluids and print heads are now available. The realization of true digital manufacturing is now going to open the process to smaller quantities with variable date which will reduce the cost of lower run volumes. By combining the lower volumes in a continuous system, will bring down the cost and make it more affordable to a wider customer base.

References

[1] P. Calvert, Inkjet Printing for Materials and Devices, Chem. Mater., 2001, 13: p. 3299-3305.

[2] T. Xu, et al., Inkjet Printing of Viable Mammalian Cells, Biomaterials, 2005, 26(1): p. 93-9.

[3] J. Brünahl, and A.M. Grishij, Piezoelectric Shear Mode Drop-on-Demand Inkjet Actuator, Sens. Act. A, 2002, 101: p. 371-382.

[Fig.5] Image courtesy of BYK Additives & Instruments, www.byk.com

[Fig.6] Image courtesy of Vivek Subramanian, Steven K. Volkman, and David R. Redinger, Department of Electrical Engineering and Computer Sciences University of California, Berkeley

[Fig.13] Image courtesy of 3D-Micromac AG, www.3d-micromac.com

Author Biography

Darrell Etter is a Customer Support Engineer for FUJIFILM Dimatix, evaluating inkjet technologies and fluids for the electronic, bio-medical, and micro manufacturing applications.

Darrell has over 30 years of digital printing experience and the last 14 years with inkjet technology. For the past 8 years, Darrell focused on the membrane touch switch color overlays and is now focused on printing the electronic flex panels for the panels.

Darrell Etter has worked for many of the digital printing innovators such as Versatec (a Xerox division), Raster Graphics (now Oce / Canon), Topaz Technologies, Mimaki, and EFI / Rastek.