Catalytic Ink Printing: The REAL Printed Circuit

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Since the beginning of the digital printing era, methods have been sought to employ this knowledge for use in an elegant approach for producing circuitry. As long ago as the early 80s, companies were working with inkjet printing to apply a conductive or catalytic ink to standard circuit substrates in the quest to build an additively printed circuit.

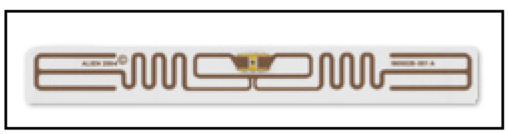
In 1983, I visited a small Silicon Valley startup company, Elf Technology, owned by Joe Fjelstad. In this small office park, Joe had taken a standard desktop inkjet printer and developed an ink with high enough conductivity to support electroplating. He was able to go from CAM file to inner layer on a desktop followed by electrolytic plating. Unfortunately, the technology never made an impact on the market.

In the mid 1990s, while working at Litchfield Precision Components (now Innovex), I was involved in a development project with a spin off of Bayer AG called AMEG. This small engineering company had developed a UV curable ink that was catalytic to electroless copper and could be photoimaged. We discussed inkjet application at the time, but the project stalled because of continuing problems with the stability of the ink bath.

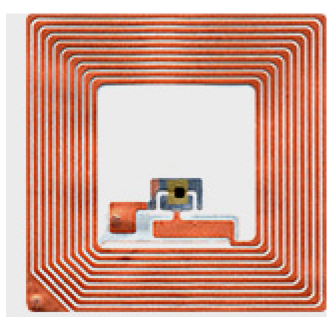
With advances in both inkjet head technology and ink formulations, the pursuit of this ultimate "printed" circuit has advanced to the point that in 2007 we should an impact in the market.

Printed Electronics: The Second Coming of the Semiconductor

We have watched with interest the development of printed electronics for years. The best definition for this diverse term is the printing of electronics on common materials such as plastics and papers using conventional printing technologies. Membrane switches and keyboards are among the earliest applications that would fit into this general category. From those somewhat humble beginnings, Printed Electronics has exploded into an emerging market with broad reaching consequences for the circuit world as well as that of general electronic manufacturing.



The most well known Printed Electronics applications is the RFID tag. The first acknowledged use of this technology was a covert listening device invented by a Russian scientist in the 1940s. Today there are a wide variety of applications using a transponder and remote reader to store and retrieve information using radio waves. The applications for this technology range from highly complex, active tags with on board power to simple item level tags for inventory control that will sell for pennies.



Although the potential exists for literally trillions of RFID tags to be built annually, it is not one of the largest Printed Electronics market opportunities. Even today, Organic Light Emitting Diodes (OLEDs) represent a much larger market. These are a family of products based on organic emissive layers that has found wide use in displays and lighting.

Traditional incandescent and fluorescent lighting are 5 to 25% efficient in their use of energy. Current OLED solid state lighting exceeds 50%. In a world where 22% of the total electricity generated is used to power lighting, the impact can obviously be substantial. This has the potential to completely revolutionize an industry and is a rare example of Printed Electronics as a disruptive technology. For the most part these technologies are creating new applications and functionalities that replace nothing.

The only limitation to the application of Printed Electronics continues to be the imagination of the product design community. Games, sensors, packaging, memory and many other applications will be expanded and transformed by this technology. The Printed Electronic revolution will have the same profound transformational impact on industry as the silicon wafer did many years ago.

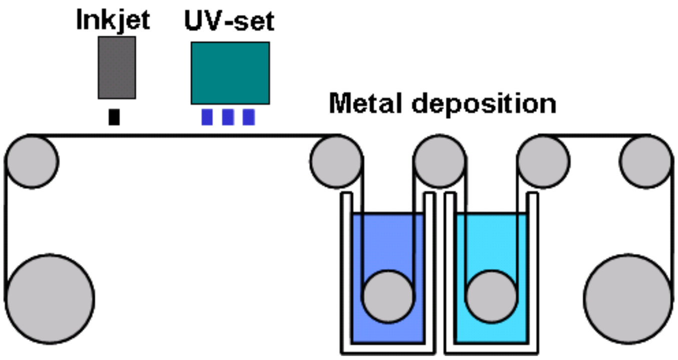
Making Printed Electronics Work: The Emergence of Inkjet Printing

The key to the emergence of Printed Electronics is the presence of technologies that support low cost manufacturing on flexible substrates in roll form. Many of today's applications utilize either screen printing or traditional subtractive processing. New manufacturing approaches are needed for this market to reach its full potential.

There are many different techniques used in the printing world; screens, offset, gravure and others. All of them, except for inkjet, require tooling to create the printed image. While there are advantages and disadvantages to each technique, the ability to digitally create an image without tooling was a main driver for the development of inkjet technology.

Inkjet printing is already in use in a wide variety of Printed Electronics applications, from MEMS to displays and solar cells. These applications use a wide variety of inks and deposit multiple layers of materials to create these structures. For creating circuits, most of the work that has been done has involved conductive particles in some type of carrier solution. After deposition, these solutions are heated to drive off solvents and coalesce the conductive materials into a structure that provides conductivity. For the most part these inks have been silver or aluminum.

Printable conductive metal pastes have always had to reach a compromise between the rheological and conductive properties of the material. Binders and carriers used to provide flow during printing and adhesion to substrates impact the conductivity of the final composite layer and impede current flow through the conductive track. Through a collaborative development effort between ink and process equipment companies, a process has been developed that can support the direct creation of solid-copper designs using an additive, inkjet printing line.



The solution is a web-based, high speed digital printing system combined with an innovative tank based electroless copper plating process that allows for the creation of solid-copper printed circuits at speeds up to 30 meters per minute. With web widths of up to 305 mm on the current generation of equipment, this system has the capability of producing enormous quantities of material rapidly and at a low cost. Gone are the cost and struggle associated with photoresist application and definition, etching, stripping and the waste treatment challenges associated with all of those processes. Maybe more importantly, the time between circuit development and actual production is minimized as digital printing can be changed on the fly.

The only limitation to the ways in which this process can be utilized is the imagination of the engineers involved. This paper will discuss future applications that include through-hole technology and printing dielectric materials to create multilayer features. We will also discuss the exciting possibility of reversing the order of manufacturing RFID tags by placing chips first then printing afterwards.

The two-stage process allows the ink to be separately optimized for different substrate materials and different printing vehicles without impacting the conductivity of the final process. Most standard electroless metals can be used, including nickel, but most commonly and widely used is copper. The two stages of the process can be implemented in-line or the electroless plating can be performed later as a batch process.

Typical growth rates for copper range from around 20 nm/min to 90 nm/min (bulk copper equivalent), giving a 30 mO/square sheet resistance in around 10 minutes of plating. Testing has shown that this thickness is adequate for many applications. Evaluation of a 2.45 GHz antenna showed a drop in gain from 3.7 dB to 2.5 dB but was still deemed more than adequate. Bend testing and accelerated thermal aging tests have been passed at several qualification sites.

Conclusion

Fully additive circuitry based on inkjet technology will have a significant impact on the future of the electronics market. Both catalytic and conductive inks are in advanced stages of development that can be applied directly to a variety of substrates to avoid the challenges of subtractive and semi-additive processing. The performance of thin copper circuits built by roll to roll application of a catalytic ink has been demonstrated to be adequate for many low current applications.