As originally published in the IPC APEX EXPO Conference Proceedings.

Circuit Technology Crossovers

Where PCBs and Printed Electronics Meet

Chris Hunrath,
Insulectro, Lake Forest, CA, USA
chunrath@Insulectro.com

ABSTRACT
Printed Circuit Boards (PCBs) and Printed Electronics (PE) both describe conductor/substrate combinations that make connections. Both PCB and PE technologies have been in use for a long time in one form or another with PCBs currently the standard for complex, high speed electronics and PE for user interface, complex form factor or other film based applications.

New and innovative applications create the opportunity for promising structures. Taking advantage of the PCB shop's capability as well as the material set can help create these structures and indeed PE materials can find use in more traditional PCBs. New materials and new uses of existing materials open up many possibilities in electronic interconnecting structures.

PCB manufacturers have a complex manufacturing infrastructure, well suited for both additive and subtractive conductor processing. While built around rigid material processing (flex PCB being the exception), there are opportunities for PE substrate processing.

As electronics devices are applied to more and more parts of our lives, we need to continually push for better solutions. Fit, function, manufacturability, and cost are all important considerations. Crossing the PCB/PE boundary is a way to meet the challenge.

PCB BACKGROUND

Commercial Printed Circuits using one or more patterned metal foil layers goes back to the early part of the 20th Century. Commercialization of Radio sets, then other electronics made PCBs commonplace by the mid 1950's.

Copper has been the metal of choice for PCBs. Printed and etched foil (subtractive) and plated (additive) interconnecting vias became the standard conductors in a PCB.

With the exception of flexible circuits, dielectric materials are typically composites of various resins and a reinforcing fabric. Patterning and combining in a layered structure, the PCB can be very complex handling everything from power circuits to high speed interconnects (transmission lines) between processors.

While PCBs are becoming ever more complex in density and layer count, the principles for using both subtractive and additive conductor formation has been the same for decades. New dielectrics like Low loss materials continue to increase in use but the conductors, etched copper, remain unchanged.

PE BACKGROUND

Printed Electronic (PE) structures based on polymer thick film (PTF) tend to be exclusively an additive process. A filled ink or paste is selectively applied to a substrate which is often PET (polyethylene terephthalate).

While there may be more than one layer of conductors, they are typically not applied to both sides of the substrate like traditional PCB's. Interconnects are made by applying the next layer of conductors over the first which is encapsulated by a printable dielectric. Windows in the dielectric allow the second layer of conductors to contact the first making the electrical connection. This may be repeated over and over.

There are a number of methods used to apply both the conductive and dielectric layers. Screen printing, Gravure, Flexographic (Flexo) and Ink Jet to name a few that are in production today.

It is interesting to note that currently, screen printing is the most popular method used to apply PE conductors. This is something most PCB shops are quite capable of.

Screen printing is not as fast as roll type processing, but web stretch does not have to be managed which makes multiple layers/images easier to deal with. In addition, smaller runs are easier to accommodate versus a roll to roll process which is better suited for tens of thousands of parts.

Figure 1. ***Screen printing equipment can range from manual to semi-automatic (pictured) to fully automatic.***

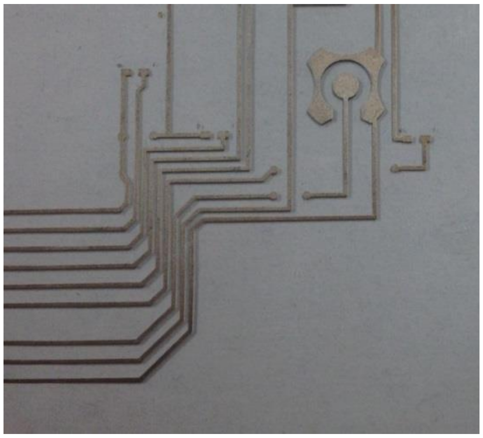

Figure 2. ***Printed Touch Pad and Circuits***

Applications for Printed Electronics are wide ranging and ever changing from very simple to complex. These include, but are not limited to sensors, touch switch/screen, solar, antennas, heaters, lighting and energy harvesting (electronic tattoos anyone?).

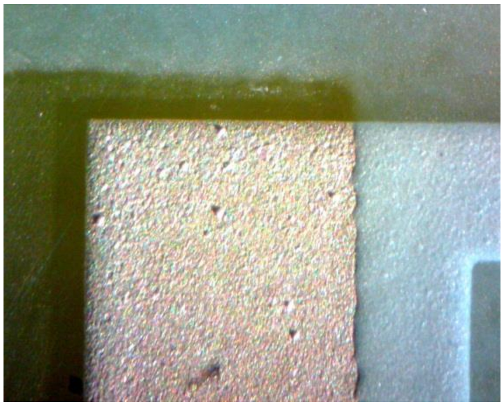

Figure 3. *Pad partially covered with UV dielectric*

Figures 2 and 3 are some examples of PE circuits. They look quite familiar when compared to simpler PCBs. Indeed, if the ink and substrates are solder compatible, they could easily be substituted for a etched foil PCB.

Unlike PCB, changing the material set does not require the extensive changes in process, chemistry or both. This makes it easier for the manufacturer to make parts with very different applications. Switching from making heaters to antennas to switches is as simple as switching the jar of paste and printing on the correct substrate.

MAKING THE CONNECTION

The table in Figure 4 is a comparison of PCB and PE conductor and dielectric applications and structures. This represents what is more typical of the two technologies.

Technology	PCB	PE
Additive (plating/printing)	✓	✓
Subtractive (etching)	✓	
Gravure imaging		✓
Screen Printing	✓	✓
Photo imaging	✓	
Rigid Substrate	✓	✓
Film Substrate (Flexible)	✓	✓
Multilayers	✓	✓
Embedded Components	✓	✓
Soldered Components	✓	✓
Sintered Inks	✓	✓
High temperature lamination	✓	
UV cure dielectrics (excluding soldermask)		✓
Thermal cure dielectrics	✓	✓

Figure 4

The two technologies have much in common. So why use one technology over the other? The reality is both will work fine in some applications. The choice may be driven by certain performance factors, or by habit.

Form factor, cost, and signal integrity are some reasons to use one over the other. For example, you would not use silver ink conductors as transmission lines for high speed digital. Also, you would not print and etch a membrane touch panel when conductive inks work well, costs less and requires no wet process chemistry.

A fully additive multilayer PE circuit may be fabricated simply by layering conductive inks with a UV curable dielectric. This may be done with a very fast, highly automated process without plating or etching.

While PE does have the potential to replace some PCBs if the ink is solderable, and on the right substrate and the application does not require low loss, but the real opportunity is in new applications. Adding electronics to things (3D shapes) that are hard or impossible to process like a traditional PCB or combining disposable sensors with a PCB that has the "brains" are some examples.

The PET is the most common substrate in PE. This can be limiting especially as new inks are developed. Combining new inks with the material set already familiar to PCB opens up additional possibilities.

One familiar example is embedded passives. Printed resistors on PCB innerlayers are not new. They have been largely displaced by subtractively processed resistive foil technology due in part to the familiarity of the PCB shop with subtractive processing. That said, printing technology and ink formulations continue to progress and printed passives could be used more extensively.

Better emulsions and imaging techniques enable 100 micron (4 mil) lines in most shops. With the right type of squeegee, this can be pushed down to 30 microns. While fine line circuitry may not be required for PE applications, this kind of precision is beneficial to a PCB shop printing passives.

New inks can go beyond embedded passives. Functional devices printed directly on the PCB can save cost, time and can even enhance performance.

Examples included heaters, sensors (Ag/AgCl), lights (EL) and antennas.

APPLICATIONS - <u>Heaters</u>

Heaters are an interesting example. In PCB, we often look for ways to eliminate heat, but analytical devices, sensing equipment and various tools are some systems that need heaters. These can easily be added to the PCB.

Figure 5 is an example of a silver/carbon printed heater connected to PCB copper traces.

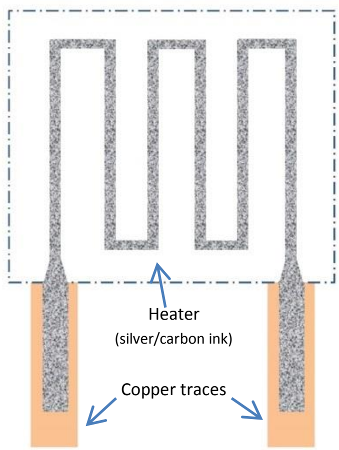

Figure 5

PET (polyester) film is a popular PE substrate, even for printed heaters. PET is somewhat temperature limited (Tg<100°C). Kapton is always an option, but another way to kick it up a notch is to use thin core FR4, something quite familiar to the PCB shop. Not only is FR4 higher temp capable than PET, it's also flame retardant. You could also incorporate connection and control circuity in the copper foil.

<u>Antennas</u>

RFID antennas are done with both subtractive and printed processes. However, there are many other applications for antennas as wireless finds its way into every electronic device.

Printing the antenna allows many more material and construction options. As inks with better characteristics come out, signal performance can approach that of copper foil.

PET film has decent characteristics, but as thickness goes up, the cost rises dramatically. This may be an opportunity for low loss, unclad PCB material if a specific dielectric spacing is needed. PCB shops familiar with the materials can print the antenna, bypassing all of the wet process chemistry steps (imaging, etching, plating).

Figure 6 shows a printed RF test coupon. Copper ink on FR-4.

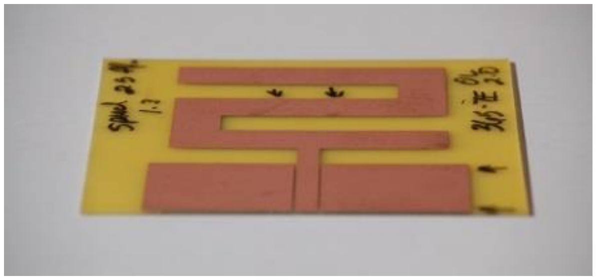

Figure 6

This copper ink is photonically sintered. Curing the ink in this way allows the ink particles to fuse without high temperature baking. The use of copper particles in conductive inks can be challenging because of the tendency to form oxides of copper. Photonic sintering solves this problem by rapid and selective heating of the ink. Figure 7 is a cross section photo of the particles after sintering. You can see that the bits of copper have "collapsed" together forming a very conductive structure.

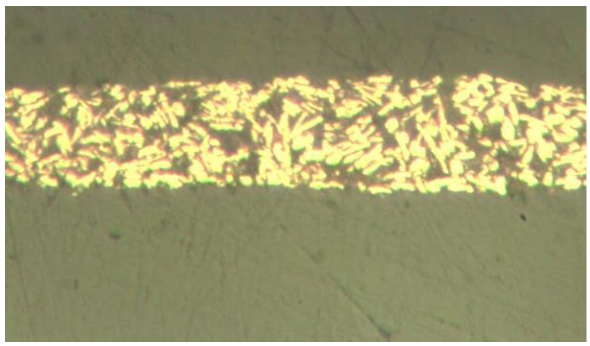

Figure 7

This ink is platable if bare copper is not desired.

Figure 8 is silver plated copper ink.

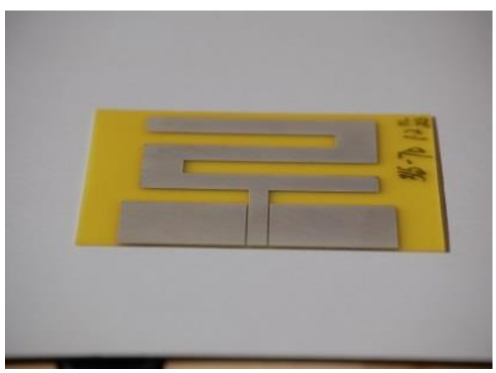

Figure 8

Below, Figure 9 shows antenna performance data comparing inks to etched copper.

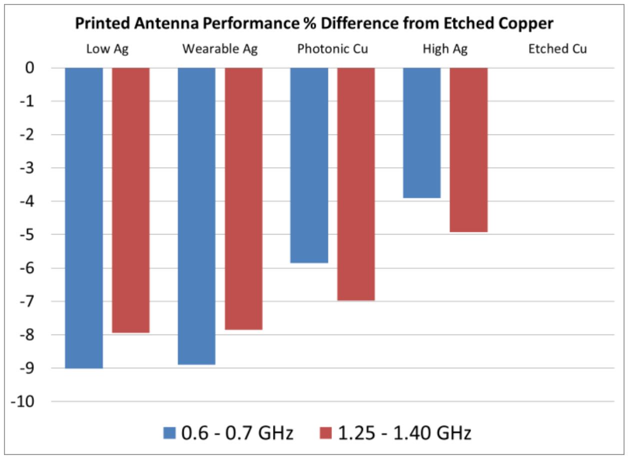

Figure 9

This testing was done with various inks on unclad FR-4. They were compared to a subtractively processed copper clad sample with the same antenna geometry. The copper clad sample is used as a reference.

Included in the testing were low and high silver content inks (low and high cost), ink for wearable conductors (stretchable), and photonically sintered copper.

Printing antennas rather than plating or etching can take many forms. Directly on the PCB, interconnected to fabric, a curved or complex shape, or device housing are just some examples.

Sensors

Printed Sensors are yet another area that can be applied to a PCB. Printing the right kind or combinations of materials can sense everything from pH to specific ions.

In PCB, we are familiar with ion sensing electrodes using silver/silver chloride. These inks are already in use and can be printed directly on the PCB. Silver/silver chloride inks can be used for ion sensing in all sorts of equipment. While done today as removable/disposable strips, applying directly to the PCB for more permanent applications could remove complexity and cost.

CONCLUSIONS

While it seems electronics are everywhere, new devices are being developed all the time. For example, wearable electronics in particular is an area that will likely see huge growth. Water conservation, energy harvesting, safety devices, not to mention communications, these are all areas of opportunity.

Too often, ideas are limited by what is familiar. We need step back and look at the materials and methods from two broad areas of electronic interconnect and view them as solutions.

The screening of resist to image conductors in the PCB has long been replaced by photoimaging. Screening technology elsewhere has not stood still. Fine line and image accuracy have both advanced. The ability to directly apply conductors or functional material could bring this technology back to the PCB shop.

New printed materials are being developed all the time. Material science makes things possible that were not, even a few years ago. Nano-particles, photonic sintering, calendering inks are just some examples.

PCB manufacturers have come to know circuit design very well. Imagine what they could do in combination with Printed Electronics.

Acknowledgements

The author would like to thank DuPont Microcircuit Materials (Research Triangle Park, North Carolina, USA) and Marcel Electronics(Orange, California, USA).