

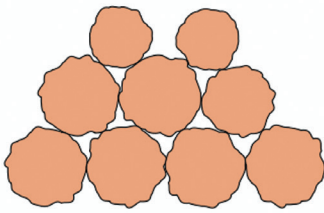
# MAKING THE TRANSITION FROM GRAPHICS TO ELECTRONICS

Ryan Banfield explains the basics of working with conductive inks

Printed electronics is a large and fast growing industry driven by much new research and development into new applications. With a bit of training, it is possible for any graphic ink printer to print the functional inks required in these new applications. Learning about and printing conductive inks (or functional inks) for printed electronics' applications is very much the same idea and this article aims to provide an introduction to companies looking to get into the printed electronics' market or learn a few things about the basics of the materials they use day in and out for current printed electronics' jobs.

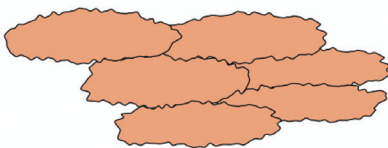
A conductive ink can be summarised as a medium to low viscosity thermoplastic paste designed to conduct electricity from point A to point B. The ink is comprised of usually three, sometimes four parts. The binder holds everything together and provides the backbone to the product. The conductor is the functional part of the ink and allows the electricity a path to flow through, the solvent puts the ink into a solution and determines drying/working conditions of the material, and optionally, the surfactants, or the add-ins for the material makes it more compatible with the printing process and substrates.

Often, in a traditional conductive material,



**Conductive spheres only have one point of contact between particles**

Figure 1: a particle of silver in a sphere shape contacts the adjacent particle in one point only, limiting the flow of electricity and increasing the resistance of the ink



**Conductive flakes have greater surface to surface contact between particles**

Figure 2: when silver is in a flake form, more of its surface area can come in contact with the adjacent particle allowing electricity to flow more readily

the conductor is silver based. Silver is chosen because of its unique properties, despite the higher cost. In order to explain this, we can compare copper to silver. Picture an exposed copper rod with no protective coating on it. That copper wire is very conductive and will be for its lifetime, as it's a pure metal. Over time, the exterior of the wire will begin to change colour and go through a chemical reaction as it's exposed to oxygen and turn into copper oxide. Copper oxide is extremely nonconductive, but since the core of the wire remains solid copper, the wire still conducts extremely well.

Now, take the same copper wire (before oxidising) and cut it up into a million tiny pieces. Take those millions of tiny pieces and suspend them in a non-conductive polymer and do the same with a silver. Take these new materials and print these ink traces side by side. In measuring conductivity, one will notice that they are extremely similar in numbers, however, over time these materials, even if covered and protected, will eventually start to oxidise. In the case of copper, this now means that the electricity must travel across one particle (highly conductive) through the oxide layer (non-conductive) through the polymer (non-conductive) through another oxide layer (non-conductive) just to get back to the highly conductive layer of the next particle. Silver oxide layers, as well as gold and platinum, are still highly conductive, so inks made from these particles remain highly conductive even after the metal powders oxidise on their surfaces.

The shape of the conductive silver particle contributes to electrical properties; making those particles is a very precise science. To start, silver bullion is shredded and dissolved in nitric acid to form silver nitrate, which then goes through an electro-chemical process to force the silver metal to drop out of solution in precisely shaped and sized spheres. If an ink was made out of

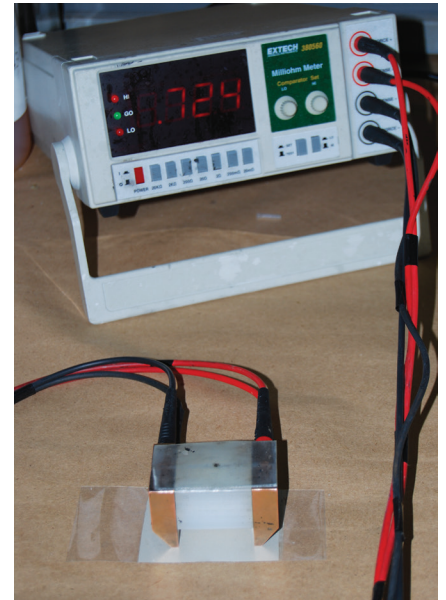


Figure 3: The box electrode is a standard tool that is cheap to make for testing finished inks in order to meet ASTM F 1896-98's test procedure

these round spheres as is, the silver particles suspended in the ink solution will then only make contact at one point where the spheres touch, which does not positively promote the travel of electricity through the trace (see Figure 1), so the spheres are treated with a further step. Once the spheres are deposited, they are collected and measured for consistency and then placed into a grinding mill (attritor, ball media, etc), covered in a fatty acid such as stearic and oleic acid. The fatty acid behaves as a lubricant and allows the spheres to be carefully flattened into thin flakes. These flakes, when printed as an ink, lay face to face touching across a larger surface area than the spherical silver could; therefore they decrease the resistance of the ink while using the same volume of silver as the spheres (Figure 2).

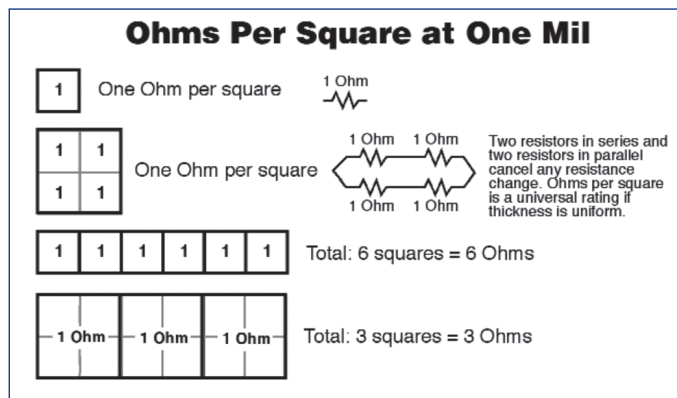
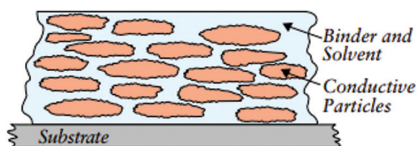
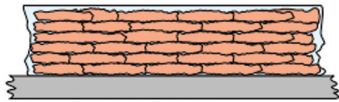


Figure 4: describing the measurement of ohms/sq/mil seen on a conductive inks data sheet and how it translates to manufacturing a circuit



**Before drying – low volume of conductive particles relative to binder and solvent. Minimal particle contact/high resistivity.**



**After drying (solvent evaporated) – high volume of conductive particles relative to binder. Maximized particle contact/low resistivity.**

Figure 5: how drying affects the final conductivity of an ink and why completeness of drying is so crucial to a finished part

### PARTICLE SIZE DISTRIBUTION

Along with particle shape, there is a ratio known as a particle size distribution that heavily controls the conductivity of the ink. In an ink, you want large particles in order to carry current long distances without having to jump through so many particle to particle junctions, but if you only use the large particles, there will be large spaces where the particles can't pack efficiently. To minimise these gaps, a distribution of large and small particles is used in order to optimise the flow of electricity. One

thing to keep in mind when selecting an ink is that if you plan on doing an application where Ph levels might affect your completed circuit (often times seen in the medical diagnostic field), fatty acid coatings on silver may have an adverse effect on your completed part.

While silver is the principal conductor used in functional inks, there are other low cost solutions. Carbon is often used in place of silver when high conductivity is not needed, or the two can be blended together to reach an intermittent electrical resistance value. The trade off is that carbon is notoriously difficult to work with and electrical resistance changes are higher than in a silver ink. Electrical resistance will drift over the course of the production run. If you don't accommodate this drift in your process set-up over the course of a long press run, you'll find yourself scrapping parts after they've been processed in the final QC stage.

One of the main causes of ink failure on press is solvent selection. Solvent choices and availability are translated relatively cleanly from graphics to conductive ink printing. The ink manufacturer will provide solvents that provide the best balance between on screen working time and minimising drying time and temperature in the oven. Keep in mind that if you request a solvent change from your supplier in order to decrease drying time in the oven, but increase working time on the press,

you're asking for something that is not feasible.

Drying time in the oven and working time on press work against each other. The best way to decrease your drying time while maintaining working time is to increase oven temperature or decrease belt speed. Keep in mind, the only purpose of the solvent is to turn the binder into a liquid form so it can be passed through the screen and nothing else. It is important to keep a watchful eye on an ink the first time you run it to make sure there are no solvent incompatibilities with your substrate or other surfaces that the ink will come in contact with that will create problems like mud cracking or de-wetting, a problem seen by most printers that have ever worked with polycarbonate substrates.

### PRODUCT FUNCTIONALITY

Once an ink has been established that meets all the requirements for properties like viscosity and thixotropic index, you need to start looking at the functionality of the product as a whole as well, and that requires looking at resistance numbers. The industry standard for measuring electrical conductivity in a printed circuit is surface resistance, a test method made popular by the rubber industry many years ago.

The unit of measurement on ink data sheets is ohms/square and measured at one

*Continued over*

mil (.001 inch, or approximately 25 microns) thick using a device called a box electrode. The box electrode is two conductors that are a distance of a certain measure long and spaced by a non-conductive spacer that's that same unit of measure wide (Figure 3). This distance can be one centimetre long spaced one centimetre wide or it can be ten centimetres long by ten centimetres wide; it does not matter, so long as the electrode forms a perfect square.

The resistance measurement is taken from these two conductors placed on top of a wide trace, big enough to cover the area of the box electrode. One of the probes acts as the anode and the other the cathode. Since they are the same unit in length and width, the actual length units cancel itself out, giving the unit a reading of ohms (resistance)/square (unit of measure)/mil or, on paper,  $\Omega/\square/\text{mil}$ . This becomes key when selecting an ink for your application.

Let's say your customer has specified that they want a resistance of less than 100 ohms on their longest trace (a standard number) that is 50 centimetres long by .5 centimetres wide. If we go back to the ohms/square example before and work it backwards, we can find out what the resistance of the ink needs to be. If I dictate that the square in ohms/square is .5 cm long and .5 cm wide, then I know that I can fit 100 squares into that trace. In order to meet the customer requirement, each of those squares has to be one ohm or less in order to have a reading of 100 ohms point to point assuming a 25 micron thickness.

**SIMPLE ALGEBRAIC FORMULA**

The following formula can be used to calculate this as well using simple algebra. The legend is as follows: TRCL is the total length of the trace, TRCW is the width of the trace, TRCT is the thickness of the trace,  $\text{INK}\Omega/\text{SQ}$  is the resistance of the ink normalized out to 1 mil and finally,  $\Omega T$  is the total resistance of the trace point to point.

$$\left(\frac{\text{TRCL}}{\text{TRCW}}\right) \left[\frac{\text{TRCT}}{\text{TRCT}}\right] \text{INK}\frac{\Omega}{\text{SQ}} = \Omega_T$$

This is the formula to be using with SAE measurements; if you want to use metric and measure in microns, the trace thickness must be divided by 25 (example: (12 microns thick) / 25 = .48). (Figure 4)

The next hurdle that a printer/designer must overcome is application of the product. Applying a conductive material using screen-printing is extremely similar, to printing graphic inks and won't be a focus of this article other than a few general comments. There are really only two main differences between the tool selection for printing of conductive materials versus graphics; the first is mesh/encapsulant selection. When printing conductive inks, keep in mind thicker is always better to a certain limit. Usually when

SPECIFICATION	DESCRIPTION
ASTM F 1896-98	Test Method For Determining The Electrical Resistivity Of A Printed Conductive Material
ASTM D 4496	DC Resistance Or Conductance Of Moderately Conductive Materials
ASTM D 257	DC Resistance Or Conductance Of Insulating Materials
ASTM D 991	Volume Resistivity Of Electrically Conductive And Antistatic Products
ASTM D 2739 90	Volume Resistivity Of Conductive Adhesives

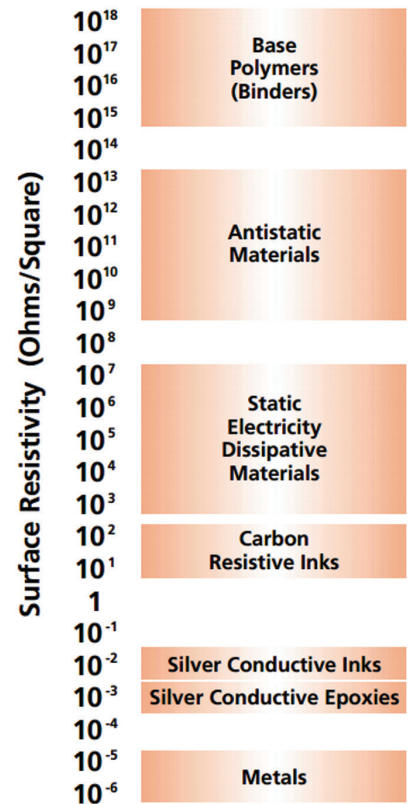
Figure 6: for the ASTM testing specs, listed here are the basics specs used in the printed electronics market

you're printing, you don't want to go much thicker than 40 microns dry film thickness, or about 125 to 150 microns wet, as you will start to observe a phenomena called skinning, especially if using rapid drying methods like IR. This is when the ink is dried on the surface trapping solvents underneath, and can usually lead to decreased conductivity levels, failure in adhesion testing, and in extreme cases, sheets of substrate sticking together. It is generally a good idea to print multiple passes, each with its own drying stage, if a large thickness is needed.

One thing to keep in mind when selecting a mesh is particle size of the silver in the ink. The rule of thumb is that the mesh opening needs to be at least three times larger than the largest particle present in the ink. However, most often printers can easily get away with two times larger than the specified particle size in their ink; they just need to be mindful and watch for clogged holes and pin holes on their prints. Again, this is an option to be discussed with the ink manufacturer.

The other part that is different between printing graphic and conductive ink is the inspection type, and this is the hardest part to teach someone. When printing conductive inks, you don't care about things like colour, hue, or intensity, only point to point resistance. Keep in mind, these printed circuits will probably be covered in a graphic laminate. It's not being implied that you can have contamination and smudges on your circuit, only that silver inks can look extremely different from each other based on particle size, lubricant present on the silver, and type of resin the ink is built around.

When testing inks, expect the shade of the inks to be different. One may be slightly blue, one slightly green, and yet another bright silver in colour. That being said, ink of the same part number should be very consistent in colour from print to print and lot to lot. One



the difference in volume resistivity of different binders and conductive fillers commonly used in functional electronic printing

other characteristic of some silver inks is that they will start to discolour and turn a gold-brown shade over time after printing. This is a cosmetic issue that does not affect ink performance.

**DRYING CRITERIA**

When looking at drying, keep this in mind. When the ink is exposed to heat, the solvent begins to evaporate and the volume of the ink trace starts to decrease. If you were to measure the resistance of a wet trace of ink, there would be an infinite reading, as the silver particles are spaced too far apart in the given volume of binder and solvent to conduct.

As the solvent evaporates and the ink shrinks and everything starts to pull together, all the silver particles start to pack and lay together making contact with each other and conducting electricity (Figure 5) One of the tests to check for dryness of your material is to take a resistance reading of the trace and then send it down the oven again. Check for resistance readings again and if you get less than a 5 to 10% drop, it can be considered dry after the first oven pass. Anything more and you have to either slow down your conveyor line, increase your oven temperature, or look at a new system with a faster evaporation rate. ASTM has a complete series of test methods for membrane switches and these procedures can be used within other printed electronics products (Figure 6).

Once you have your conductive trace printed out, there are a number of other

production processes that you can go through, the most common being a UV curable protective barrier. The purpose of this layer is to protect the silver ink trace from shorting out if it contacts another trace and to provide abrasion resistance. Processing a UV dielectric is similar to your UV graphic inks, but there are some differences.

Typically, it is recommended that when you print a UV protective layer, you print it twice, each layer targeting .75 mils or 18 to 20 microns. When the second layer is printed, a shift in the X and Y direction of a few microns is suggested in case there is a defect in the screen; that way, the defect is covered by the second pass and a pin hole is not placed over a pin hole. In order to dry these protective barriers, the most commonly used system is a mercury vapour lamp with no doping and an output of 750+ mJ/cm at a setting of 300 Watts. Due to the fact that it is almost impossible to create an in-line test to check for completeness of cure in a UV system, more energy is always recommended, in the range of 850 mJ/cm, but again, this is something that has to be discussed with your ink manufacturer.

A standard cross-hatch adhesion test is recommended to check for adhesion to substrate and interlayer adhesion of the products. One thing to keep in mind when printing UV-curable materials on top of a silver is that the low molecular weight monomers of

a UV system polymer can act as a solvent that often will eat its way into the silver ink. This means that the silver ink will eventually degrade and increase in resistance the longer that the dielectric sits on the ink uncured.

If you are noticing a slow creep in resistance over time, undercured dielectric can often be indicated as the culprit. One method to improve interlayer adhesion of the two dielectric layers is to slightly under cure the first printed layer by slightly speeding up the conveyor, and then fully curing both layers at normal belt speed after printing the second layer.

#### LAMINATING THE GRAPHIC LAYER

Another process that is typically done to the completed circuit is lamination of the graphic layer to the completed circuit. This can be a process that causes a large amount of problems if careful consideration is not made. It is highly recommended that the laminate does not come in contact with the actual silver trace, but rather, only the dielectric. This is because if you go through a laminating process, especially one that involves heat, and your laminate is a similar binder system as the silver you're using, the laminate adhesive may start to absorb into the silver ink in the same way that low molecular weight monomer from the UV dielectric will, causing an increase in resistance.

The transition of printing silver functional inks for printed electronics from printing graphics is not that difficult of a step to take, but it must be done recognising that there are some differences involved and a learning curve to understand test methods. This requires looking at the new ink systems, screens for the prints, and a point to point multi meter for the basic applications. Simple markets to approach are things like membrane switch and from there jumping off into the much more technical world of established markets like EL panels and medical electrodes or the R&D world for up and coming products like printed OLEDs and flexible solar cells. The possibilities are limitless with where you can go and it's all using equipment you already have in house.

Printed electronics is a large and fast growing industry worldwide with new applications in touch-screen, OLED and solar cells pushing this growth. ■

**Ryan Banfield is Sales Engineer at Conductive Compounds**

#### Further information:

Conductive Compounds Inc,  
Hudson, New Hampshire, USA  
tel: +1 603 595 6221 x 305  
email: ryanb@conductivecompounds.com  
web: www.conductivecompounds.com