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Conductive Polymer Imaging For Communications and Electronics

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Abstract

Conductive inks and polymers based on metals were originally envisaged for quick repairs to Printed Circuit Boards (PCBs) and semiconductor chips. Increasingly these materials are being used to replace traditional copper circuitry. Modern PCB production suffers from high capital expenditure in process set-up and ever growing environmental and legislative constraints, which can be replaced with quick, affordable and environmentally friendly polymer based manufacturing. New chemistry and imaging techniques have led to the development of an increasing variety of means to deposit and pattern these materials. Substrates include glass and FR4 as well as flexible materials such as nylon, polyester and Kapton. Conducting inks and polymers include those based on Carbon, Silver, Copper and Gold. The resulting combination of polymer and substrate leads to a large number of solutions for interconnects and circuitry on surfaces as diverse as battleship hulls, mobile phone casings and clothing. In the example of a mobile phone it is possible to connect chips to packages to PCBs to displays to batteries to antennae on the casing of the object itself using a single polymer material. Many of the subsystems such as the PCB and the antennae can also be made from a conducting polymer deposited and patterned on the casing. The natural extension of this is to use flexible substrates and turn the casing into a 2D sheet and thus manufacture a mobile phone that can be rolled up. By way of example the manufacturing process for a polymer antennae within a mobile phone case is demonstrated using silver-based ink.

Introduction

Conductive metal-based polymers and ink have been in use since at least the 1950's when they were originally used by the military to repair damaged PCBs in the field during operations. Naturally the first place in which the use of these materials could be extended was within the PCB market. It is possible to use their conducting properties in a number of areas, not least of which in manufacturing PCBs and PCB prototypes. To date there is no known mass-production use of conducting polymers as a complete replacement for PCBs, but in the area of prototyping several manufacturers use them for through-holes instead of using plating baths, and some use them to create complete double-sided boards. As an additive process the use of conducting copper-based polymers uses less metal and creates considerably less waste. Figure 1 illustrates the waste producing steps in traditional photolithographic processes. It is possible that using conducting polymer materials instead of bulk metal could save 50% of waste costs. As we look forward to legislated Lead-free electronics, conducting polymers are primed to replace existing Lead use through clever chemistry. This chemistry enables a variety of different metals and polymers to create custom made properties for conducting polymers which in turn can be printed, patterned and processed on a large variety of different substrates which include mobile phone housings, clothing and household walls. Any PCB wiring can be replaced and integrated into the physical structure of any other object eliminating the need for a separate board and enabling localised processing. It is intended to give an over-view of these conducting materials, the different methods currently available to print, pattern and process them, as well as the different environments in which they can be found. Subsequently an example of manufacturing in development for commercial use will be presented.

Figure 1 - Sources of Waste in Photolithographic PCB Production

Substrates and Polymers

Conductive inks and polymers come in a number of different varieties, so many that it is worth establishing what we mean in the context of this paper. Firstly there is the difference in what is conducting the electric charge. While there may be more categories the principle split is between inherently conducting polymers and metal-based conducting polymers. Inherently conducting polymers tend to be composed of organic semi-conducting plastics, which due to their chemical composition have an electrical charge and hence can be used to conduct electricity. On the other hand the metal-based inks and polymers are made from a polymeric binder matrix within which metal atoms are suspended, these materials conduct electricity in the same way that metals do. While the applications and techniques which will be considered may be suitable for both types of conducting material it is the latter metal-based polymers which will be focussed on.

The second distinction is between inks and polymers. Inks are composed of a thermoplastic material that has already been polymerised. It is suspended within a solvent that evaporates during curing creating a layer of conducting particles. A conducting polymer is composed of thermosetting material that cross-links during the curing step. Polymer is more resistant than ink to solvents and high temperatures where it will not re-melt. Ink can be cured at low temperature and tends to have greater flexibility as it hasn't bonded into the substrate.

Both polymers and inks have a range of properties that allow us to characterise them and determine which is suitable for a given application. Examples include Resistivity, Adhesion, Curing Temperature, Thermal Conductivity, Flexibility and Solderability. Naturally a Silver-based polymer with a greater proportion of Silver atoms in its construction has a higher conductivity than a Copper-based ink with a low percentage of Copper atoms. While the majority of metal-based inks and polymers on the market are based on Silver and Copper, there are some based on Nickel and Gold. Platinum and Palladium may be included within the mix to help with solderability, for example, but they are not typically found as the metal upon which the material is based. Silver's advantage beyond its inherently greater conductivity is that its oxide is also conductive, unlike the oxide of Copper which is produced around 200°C and acts as a barrier to electron flow. 200°C is also typically the temperature around which a polymer has to be cured. Consequently a Copper polymer may also need to be cured in an inert atmosphere making production processing more difficult. An additional factor is that a great many plastic substrates will melt before the 200-degree point is reached. Henceforth the terms ink and polymer will be used interchangeably.

There currently appears to be no limit on the types of substrate that can be used as a base for conducting circuits made from inks and polymers. A full range of plastics from Cycoloy to Mylar, as well as laminates like standard FR4 and Polyimide have all shown they can be used as surfaces for inks. Textiles are currently proving to be difficult but by no means impossible; effectively the issue depends on how thick and flat the material is. A cotton t-shirt is much more suitable for printing on than a fleece. Naturally metals would need an insulating layer to be laid down first but in many applications such as a battleship they are likely to be painted anyway. By far the most interesting aspect of the substrates is not what they are made of but their geometry. Polymers allow us to print electronics on the surfaces of three-dimensional objects; this opens up a whole range of design possibilities.

Printing and Patterning

Polymers can be printed using a number of different techniques many of them familiar to the graphic arts industry in their basic principals but creating new industrial engineering challenges for the specific chemistries of the current range of conducting inks. For example a typical 'web' printing process used to print newspapers relies on the ink and water not mixing on the printing plate. While this may apply to some conducting materials it will still remain a difficulty ensuring the polymer and water remain separate and on the appropriate parts of the printing plate. A web process prints inks of only a few microns in thickness. Many polymers will need to be printed much thicker to enable a fully conducting path to be created. Essentially there is a minimum thickness that is required to be printed.

The easiest and perhaps most well known option for production printing is the use of screen-printing. A metal or plastic mesh is created through which ink is squeezed as it comes into contact with the substrate. The drawback of screen-printing is the same as with web-printing: it can only really be used in two dimensions.

Pad printing is a high-speed printing process that typically prints up to 3 microns in depth. Pad printing involves placing an etched cliché over a pot of ink, where a large silicon tampon, the tampon picking up the image to be printed, stamps it. The image is then transferred by the tampon onto the surface taking the print. The speed at which this works at allows a thicker film to be built up by using several prints on the same surface. Too many prints, however, will begin to remove material as some of the earlier ink dries.

The most flexible option is to use digital printing such as ink-jet printing. This can be more easily controlled and used on 3D surfaces if the appropriate machinery is used. Typically only a single micron thick layer is deposited once the solvents have been removed. This means that several passes would be required to build up a thick enough layer for conductivity and this can lead to stacking errors. At the time of writing jetting has not yet been fully realised for micron-scale metal-based conducting inks but has been recently demonstrated for the nano-scale materials [1] In this instance a 20-layer circuit was created using alternating layers of conductor and insulator to create a PCB a few microns in thickness. Ink jet can now also operate at a much higher speed than in the past, for example, having successfully been incorporated into web-printing presses.

Applications

With the ability to stick to almost any two or three-dimensional surface the possibilities for using conducting polymers to produce circuits on almost any object are boundless. For mass-produced two-dimensional circuits the RFID market is an ideal vehicle. It is certainly possible to create the antenna and interconnect to the chip from conducting polymeric materials and to print these on a flexible substrate as can be seen in Figure 2. We have high-speed processes such as traditional web and now ink-jet printing, even pad and screen-printing, which could be used. The only real question is price. Right now the cost of the polymers would suggest that the single cent range of costs is not achievable but as more polymer is produced cost reductions from bulk purchasing could make this possible. However, perhaps slightly more expensive RFID tags could be printed on demand at tills, airline check-in counters or the pick-up point of parcels by express couriers.

Figure 2 - Flexible Silver Ink on Kapton™ RF Tag

A growth area for conducting polymer circuitry is in clothing; this is for both so-called 'smart' clothing and for fairly simple heating systems that also use carbon-based conducting polymers. These have a range of uses from ski boots and jackets that have heating elements printing inside them, to sensory feedback vests monitoring heart-rates and helmets wired up to send and receive battlefield data in a way that reduces the weight load and pieces of kit a soldier has to worry about.

Case Study

One particular area in which a three-dimensional circuit printing process is being developed is for mobile phone antennae. Currently these are created by cutting metal and forming it round a plastic carrier. In the first instance the metal can be replaced with a polymer and in the second the carrier is no longer required as the antenna is printed directly onto the casing, as can be seen in Figure 3. This is currently being developed using a series of pad printers to deposit ink onto a particular surface and create the 3D film on the carrier surface. A laser can be used to alter the antenna to accommodate any last minute design changes or to tune the antenna. The further development of ink jet will enable the instantaneous change of design and add further tuning possibilities.

Figure 3 - Polymer Antenna on a Mobile Phone Casing

This however makes the manufacturing process sound trivial, but to produce several million units using novel processes requires ongoing development. For example a polymer chemistry that will allow printing, drying and curing in as short a time as possible but will also then be stable and can be ablated without damage to the substrate needs to be refined. The mechanics of transportation through the system as well as using printing processes not used to these materials all creates interesting challenges and opportunities.

Conclusion

It has been seen that conducting metal-based polymers and inks each have their own useful characteristics. Combined with a variety of printing process for which a lot is already known from the graphics arts world a new breed of circuitry can be created in two and more interestingly three dimensions. With the current development of polymer mobile phone antenna technology it is possible to combine this with polymer-based LCD displays and touch pads, polymer based PCBs and print all of these onto flat flexible substrates to create a roll-up mobile phone.

References

1. http://www.epson.co.jp/e/newsroom/news_2004_11_01.htm

INVINT
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Conductive Polymer Imaging for Communications and Electronics

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Introducing Conducting Poymers

Substrates and Polymers

Printing and Patterning

Applications

Case Studies

Conclusions

Introducing Conducting Polymers

- PCB repair in 1950s
- Used today in prototyping
- Additive processes – less waste
- Lead free polymers
- Replace wiring on a variety of substrates

Substrates and Polymers

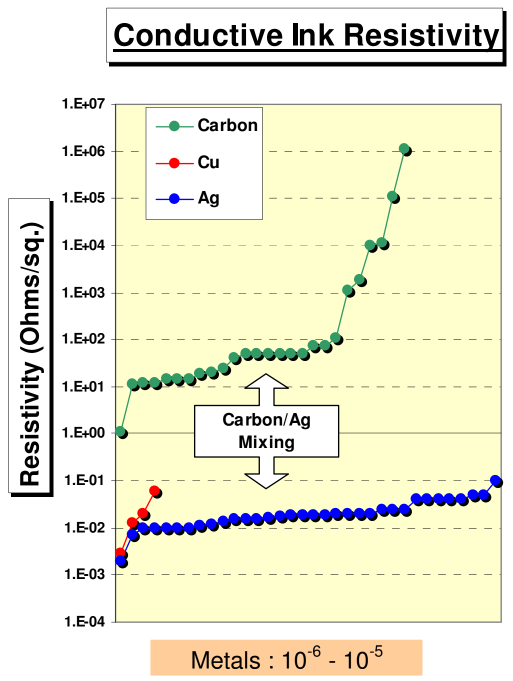
- Inherently conducting semiconductor polymers vs metal based polymers
- Inks vs polymers
- Thermoplastic vs thermosetting
- Plates vs cross-linked
- Cu, Ag, Au, Ni
- Binder and solvent

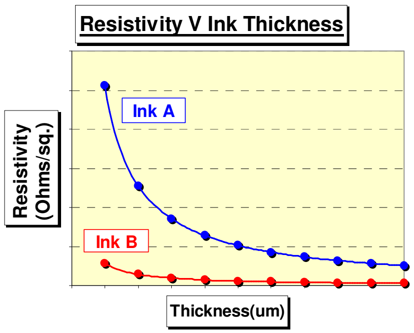
Substrates and Polymers

- Choose material for application

- Variety of characteristics: Resistivity, Adhesion, Curing T, Thermal Conductivity etc.

- May need inert gas curing due to oxidation



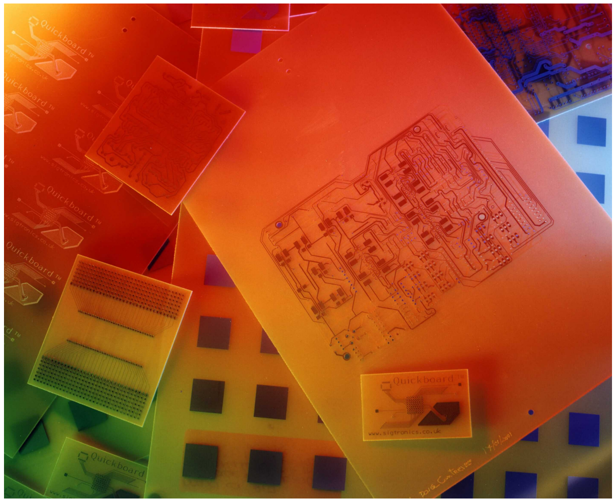


Substrates and Polymers

• Range of plastic substrates e.g. Cycoloy, Mylar

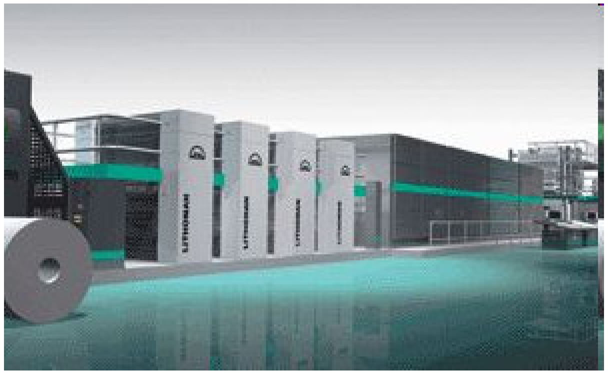
• Range of laminate substrates e.g. FR4, Polyimide, Kapton

• Novel substrates e.g. Textiles, 3D Objects

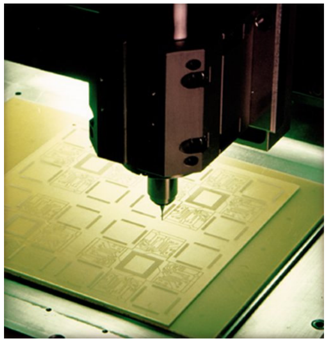


Printing and Patterning

- Contact and non-contact
- Web, tampon (pad), screen
- Ink-jet, spray, dip
- Film thickness restricts conductivity



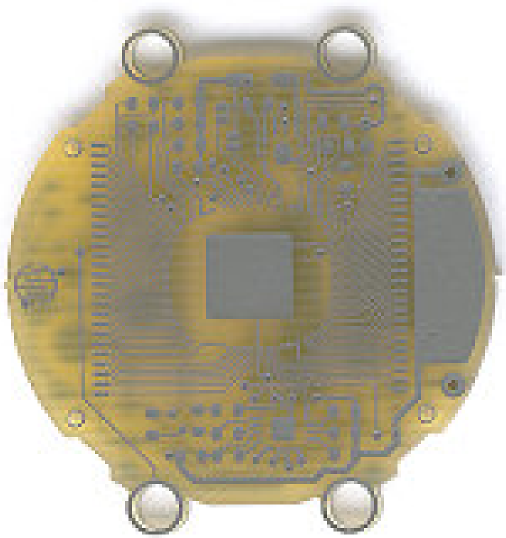
Printing and Patterning



- Routed surfaces

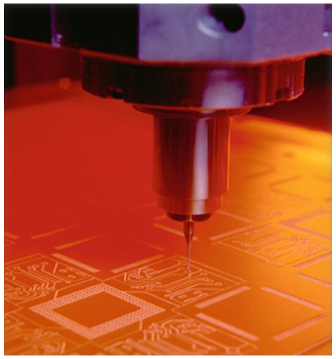
- Photolithography
  - Slow, wasteful, expensive

- Laser ablation
  - Raster and en masse



Applications - PCB

- PCB prototypes – mill and fill

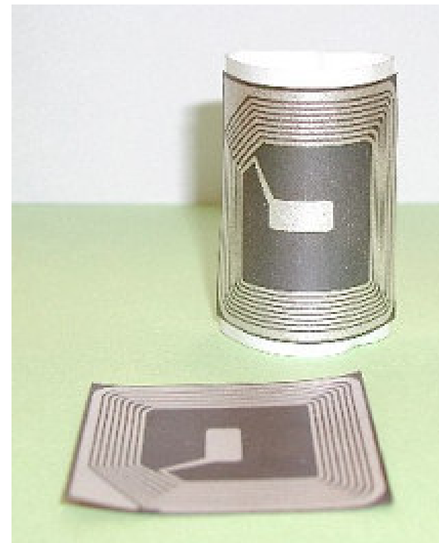


- Full process
    - Drill holes
    - Print or coat board
    - Dry
    - Laser ablation
    - Cure
    - Re drill through holes
    - Population

- Mass production

Applications - RFID

- Speed and cost
- Pad, web, screen, ink-jet?
- Integration of chip to antenna
- Curing temperature too high

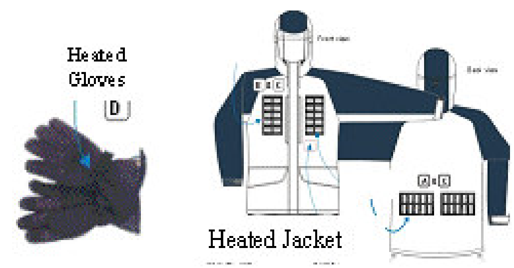


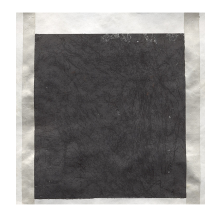
Applications -Textiles

• Unique range of substrates

• Absorbent, irregular surfaces

• Screen print common industry application method

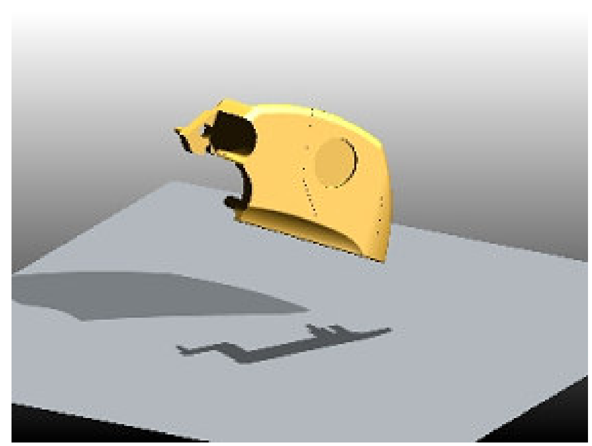




PTC Carbon Ink Heater on Tyvek™ substrate, with Ag Ink Bus-bars

Case Study - Mobile Phones

- 3D Geometry
- 3D Printing and patterning
- Array of pad printers
- Ink jet development
- Curing
- Laser and ink-jet tuning



Conclusions

- Materials challenges
- Adapting old printing technology
- Use flexible substrates
- Integrate with polymer LCDs, batteries etc
- Roll-up phone