Using Conductive Thermal Transfer Ribbons for Printed Electronics

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Abstract

Thermal transfer printing is noted for its ability to produce a uniform line, and it is used extensively for high reliability bar coding around the world. Thermal transfer is capable of printing on a wide variety of flexible substrates including paper, film, fabric, etc. These characteristics make thermal transfer ideal for printed electronics.

IIMAK has developed conductive ribbons based on metal nano-particles (silver, silver / copper composites) and on vapor deposited metals (aluminum, copper) that provide the potential to print flexible circuits, membrane key boards, RFID antennas, etc. on a number of substrates (paper, vinyl, polypropylene, polycarbonate, polyimide, etc.). Dielectric ribbons based on insulating polymers are also available and can be used to provide insulating layers between conductive layers. Characteristics of the ribbons, prints and some model applications will be discussed along with the benefits and limitations of thermal transfer.

Potential to adapt these ribbons to the closely related technology of laser thermal transfer will also be discussed.

Introduction

Printed electronics has the potential to revolutionize the creation of devices in a myriad of ways. The promise lies in the ability to use well-established production processes to reduce costs and to expand the range of applications where electronics can be applied. The cost reduction comes from a process of device manufacturing that can be additive in nature rather than the traditional subtractive processes currently used to produce electronics (with all of the process steps and chemical wastes that that implies). New applications can include wearable printable displays, biocompatible electronics for food and drug traceability, lightweight military gear, reprogrammable books, magazines, newspapers, fuel cells, OLEDS, and photovoltaics. The range of potential printed electronics applications is limited only by the imagination. The technical challenges, though, are many, including good control of feature size (both width and thickness), the production of small and reproducible features, registration of layers and features, and integration with other traditional electronics processing techniques.

There are two broad categories of printing technologies in use today; analog and digital. Analog techniques include offset lithography, flexography, screen, and gravure. Digital technologies include laser, ink jet, and thermal transfer. Many of these printing technologies are under investigation for printed electronics, including gravure, flexography, screen printing, and ink jet printing. Gravure printing is limited to about 50 micron lines and has been used to produce low resolution displays. Screen printing is also about 50 micron resolution and has been used to produce some printed circuit boards and membrane keyboards. Flexography has been shown to be capable of features about 30 microns in size, but dot distortion and degradation issues have limited its use. Analog printing technologies generally require a master to be produced for each design, and hence they are most suitable to a large number of units where the cost of the master can be shared amongst the units.

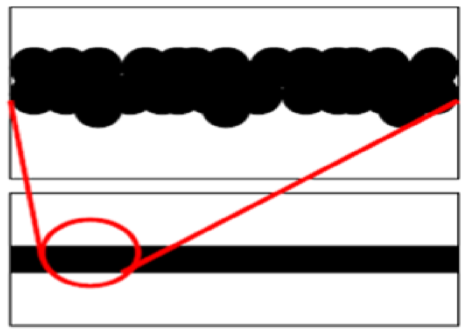

Figure 1 - Ink jet line uniformity is hard to obtain.

Ink jet is digital technology where each unit can be unique without incurring further cost penalty. Ink jet is currently the most investigated technology for printed electronics. It is capable of producing very small features (as small as 10 microns have been demonstrated), but has several challenges in jetting metal particles. First, it is difficult to maintain dense metal particles in stable suspension. Second, these metal particles and tend to clog in the nozzle during the jetting process. One potential alternative is to incorporate conductive polymers. This approach is severely limited by the low concentration at which the polymers are soluble. A third issue with ink jet is that the uniformity of the printed line is poor because of the disposition's dot nature and the surface tension /collision kinetics. The result is dried dots that can look like craters (the well known "coffee stain effect") and have poor edge definition (see Figure 1). Lastly, ink jet has substantial substrate limitations. Ink drying, spreading, etc. must all be considered and designed for on a given substrate.

Thermal Transfer Printing

One digital printing technology that has not received much attention in the printed electronics arena is thermal transfer printing. Like ink jet, thermal transfer printing is a digital technology and each print can be unique allowing for the production of prototypes with rapid design cycles for printed electronics as well as the production of a small number of units. Large numbers of units can also be produced, but other print technologies can be more cost effective at sufficiently large volume.

Thermal transfer technology has been employed in the world of automatic identification for many years now. Some of the strengths thermal transfer brings to barcode imaging also apply to printing for electronic applications. These include:

- The ability to print very sharp, well defined lines (necessary for production of bar codes with extremely high readability rates)
- Controlled and uniform thickness of the lines (achieved during the thermal transfer ribbon coating process)
- Minimization of chemical waste (the coating is created and applied by the ribbon manufacturer and is printed by the end user in the solid state)
- Robust processing on a proven printing platform (widely used for printing on loading docks, factory floors, etc.)
- Thermal transfer is an additive process that minimizes the process steps associated with subtractive methods, such as plating, masking, exposing, metal removal, mask removal, etc.

Aided by recent technology developments in conductive materials, particularly nanoparticles, thermal transfer printing can be used with the appropriate ribbon design to produce many types of printed electronics.

As with any printing technology, thermal transfer also has its limitations. Resolution of the print in thermal transfer is controlled by the thermal printhead. Currently 200 and 300 dpi printers are common; 400 and 600 dpi printers are also readily available. Printhead manufacturers like Kyocera are working on higher resolutions 1200 and 2400 dpi, but these have not yet been incorporated into a commercial printer. Thermal transfer printers are typically designed to print on a flexible substrate. Paper, polyester, polyimide, fabric, etc. can all be used. Printers for rigid surfaces, though, are not readily available. Oyo Instruments LP, is developing printers for rigid, flat substrates (like silk screens), and decal technology where thermal transfer is used to produce the decal that is then transferred to the rigid substrate (like Decotherm® for glass) could be used for other rigid substrates for both flat and three dimensional objects (pad printing of decals onto bottles, for example).

Ribbon Construction

A typical thermal transfer ribbon is constructed on polyester film that is generally from 3 to 9 microns thick. On one side of the film, a heat resistant slip layer is coated that allows for smooth movement of the film under the thermal printhead. On the opposite side of the film, the functional material is coated. This side of the ribbon may be as simple as a one layer construction (common in a wax thermal transfer ribbon used for bar coded labels with short life spans) to a complex, multi-layer construction (common in resin ribbons which require chemical resistance, UV resistance, and longer life spans). Layer structures can include an adhesion modification or promotion layer, a release layer, and one or more functional layers. All of these layers are designed to ensure the ribbon has good adhesion to the film before printing, good adhesion to the receiver after printing, good printing characteristics, and the desired resistance to chemicals or mechanical abrasion after printing.

Figure 2 - Conductive thermal transfer ribbons

The Printing Process

The thermal transfer printer works by conveying the ribbon and flexible receiver in pressure contact with one another under a thermal printhead (Figure 3). The functional side of the ribbon is in contact with the receiver and the heat resistant slip layer of the ribbon is in contact with the thermal printhead. The printhead consists of a line of heatable elements typically 200 to 600 per inch, and the printhead width is typically 2 to 8 inches, but commercial printers are available as wide as 40 inches. As the media and ribbon are passed beneath the line of elements, selected elements are heated image-wise to effect the transfer of the appropriate layers from the ribbon. The layers can transfer by melting (as for a wax) or by softening to a point where the adhesion to the receiver exceeds the adhesion to the ribbon carrier

film (as for a resin ribbon). The elements heat to about 400ºF, but the speed of the ribbon receiver package is generally from 2 to 16 inches per second so the residence time under the line of elements is very short.

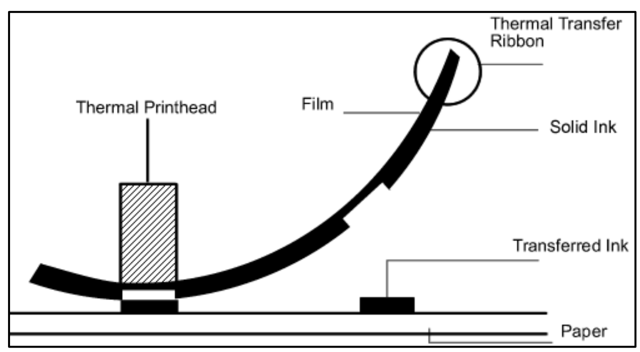

Figure 3 - Ink is transferred from the ribbon to the substrate using heat

There is a variation on the commonly used thermal transfer printer often referred to as laser thermal transfer. In this case, the thermal printhead is replaced as the heat source by a laser beam. Ribbons for laser thermal transfer are typically coated on thicker films for ease of handling, and there is no need for a heat resistant slip layer as the thermal printhead has been eliminated. One layer in the ribbon construction (which also may be the functional layer) must be capable of absorbing the laser light and converting it to the heat necessary to effect the thermal transfer. The cost of such a printing system is much greater than a typical thermal transfer printer, but the resolutions that can be achieved are greatly improved by controlling the width of the laser beam.

Thermal Transfer Ribbons for Printed Electronics

Thermal transfer ribbons for either type of thermal transfer printing can be formulated to be very resistive or very conductive (resistivities can range from 10^{14} to 10^{-2} ohms/square) and can be engineered to print on a wide variety of substrates, such as paper, fabric, PET, polyimide, polypropylene, and other synthetic films. A highly resistive ribbon is generally composed of a polymer that also has quite high resistance like polyacrylate, polyester, or polyethylene. Fillers, process aids and other additives may be incorporated to provide appropriate coating and thermal transfer properties. Transferable layer thicknesses from 0.01 to 25 microns are readily achieved with 1 to 10 microns thickness typical.

Conductive carbon blacks can be easily incorporated into thermal transfer ribbons. The carbon loading is limited by the viscosity of the solution to be coated. Resistivities in the range of 10^8 to 10^1 ohms/square can be obtained with conductive carbon blacks.

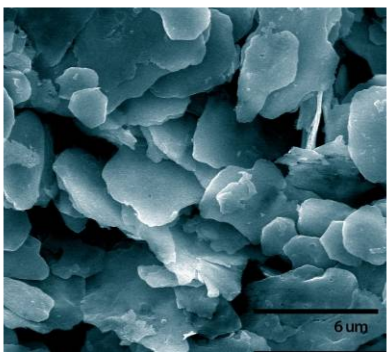

Figure 4 - Silver-copper coated flakes shown magnified here. **(Photo courtesy of NanoDynamics, Inc.)**

Metal particles are also easily incorporated into thermal transfer ribbons. For years, iron oxide particles have been used to provide MICR (Magnetic Ink Character Recognition) ribbons for encoding information onto checks that are sorted by machine. Silver, silver-copper composites, copper, and gold are available as flakes and nano-particles that can be incorporated into thermal transfer ribbons.

Nano-particles, like those available from NanoDynamics, Inc., are an excellent choice for incorporation into thermal transfer ribbons. They are easily dispersed in coating solutions, and the solution stability needs to be maintained only until the solution is coated onto the thermal ribbon carrier. The particles are then shelf stable for months or years in the thermal transfer ribbon. The small size of the nano-particle lowers the sintering temperature for the metal. A post printing curing or sintering process helps meld the particles into continuous conductive paths.

Figure 5 - Inside view of a common thermal transfer printer

The ease of sintering nano-particles can be further exploited in thermal transfer printing in that the heat associated with the printing process is generally enough to accomplish the sintering and no post processing is required.

Because the coating solution is manufactured and applied to the film by the ribbon manufacturer, the printer of the electronic device using such particles does not need to worry about solution stability (the dense metal particles tend to gravitationally separate over time in solution) as they would with an ink jet ink. Additionally, high metal loadings are possible as there are no cloggable nozzles that have to be negotiated in either the ribbon coating process or by the device manufacturer. The high metal loading combined with the thermal energy imparted in the thermal transfer printing process generally make any post printing sintering process unnecessary.

Similar to nanoparticles, metal flakes are easily incorporated in a thermal transfer ribbon formulation. The flake morphology has some advantages in that inter-particle contacts are more frequent so a conductive path is more easily established than with spherical particle morphology. These also would not require any post processing after thermal transfer printing to provide conductivity. Silver, copper, and composite flakes from 1 to 20 microns are commercially available and can be formulated into thermal transfer ribbons with good conductivity. Conductive layer thickness can range from 0.5 to 15 microns.

Conductive ribbons can also be produced by the vapor deposition of an appropriate metal onto a properly prepared film. Usually, a release layer is necessary between the polyester carrier of the thermal transfer ribbon and the metal layer. An adhesion promotion layer may also be coated on top of the deposited metal to aid in the thermal transfer process and to promote adhesion to the desired substrate. Deposition of aluminum, copper, or nickel, as is common in capacitor construction, is readily usable in a thermal transfer ribbon.

Thicknesses of the metal deposition layer can range from about 50 Angstroms to 5000 Angstroms. As with capacitors, the resistivity of the metal layer decreases with increasing thickness, typically from about 10 ohms/square to 0.01 ohms/square depending on the metal composition as well as the thickness. Thickness can also be built up for greater current carrying capacity with these ribbons by overprinting with a thermal transfer printer configured for such use.

Metal containing thermal transfer ribbons, whether based on nanoparticles, metal flakes, or vapor deposited metal layers, can be used to print RFID antennas, membrane keyboards, other printed circuits, or seed layers onto which further plating can be done to build up the metal thickness. This capability could also be useful in the design of RFID antennas and printed circuit boards; since each print can be unique, the prototyping of circuit boards and other electronic devices could be very rapid with this approach.

Summary and Conclusion

Thermal transfer printing has the possibility of contributing greatly to the field of printed electronics. It brings an inherent ability to provide uniform line widths and thicknesses and with the development of higher resolution printheads or laser thermal transfer, feature size could be quite small. Resistive ribbons can be created using insulating polymers and conductive ribbons using either metal particles or vapor deposited metal layers have been demonstrated. RFID antennas, membrane keyboards, printed circuit boards, and other printed electronics and are all possible using thermal transfer printing technology.

About IIMAK

IIMAK is a multinational company that develops, manufacturers, and markets all types of printing, imaging, and marking consumables including inks, thermal transfer ribbons, specialty papers, cartridges, and cassettes. In 2008, IIMAK launched a full line of Metallographic Conductive Inks for screen, gravure, flexo, and digital printers. For more information about IIMAK and its products, visit www.iimak.com or call 888.464.4625.

About the Author

Claire Jalbert, Ph.D., has worked at International Imaging Materials Inc. (IIMAK) for the last 10 years as director of the Research and Development Group.

She previously worked for 3M / Imation in the Graphics Research Laboratory and for Rogers Corporation in the Elastomeric Products Group. Claire received her Ph.D. in Polymer Science and Engineering form the University of Connecticut and has a B.S. in Chemical Engineering from MIT.

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