UV Curing for Printed Electronics

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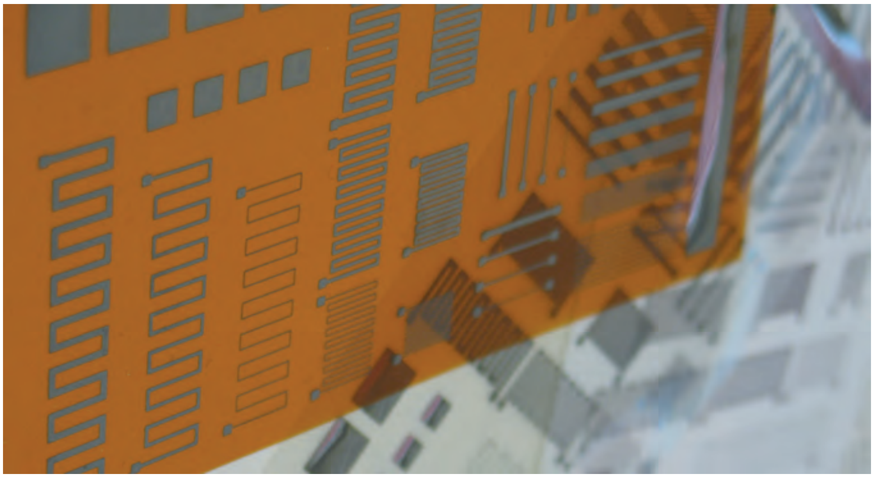
The primary function of printing has traditionally been the delivery of data and information for visual inspection and further interpretation by humans or machines. The advantage of printing is that it enables cost-efficient mass manufacturing of electronics and other functionalities on large and flexible substrates such as plastic, paper and fabrics. New printable functional materials, print production processes and reading mechanisms are expanding the role and function of printing toward printed electronics. In printed electronics, new advanced materials in liquid phase—printable inks—are the cornerstones of future development. The variety of materials and their numerous application possibilities introduce novel applications far beyond those offered by traditional silicon-based electronics (e.g., large-area sensors, etc.). Examples of these materials are conductive polymers, organic semiconductors, nanoparticulate materials, and electromechanical and bioactive materials. Another generic cornerstone is the high throughput, cost efficient manufacturing methods such as continuously running roll-to-roll printing, hot embossing, coating, laser processing and their combinations. The third important generic capability is the integration of those multifunctional components, circuits and systems on web, sheet or foil. The capabilities of these processes and new advanced manufacturing equipment and automated production lines are key when developing and commercializing products where new intelligent functionalities are embedded to high throughput, large surface areas.



Inkjet printed conductive silver nanoparticle structures on polyimide, polyester and paper substrates.

Printed electronics is a rapidly growing technology field that has huge market potential. Different printed electronics market analyzers forecast massive growth in this market during the next 10 years. For example, NanoMarkets[1] forecasts that the top five printable electronics categories will reach more than $10 billion (U.S.) by 2010. RFID tags ($300 million) and OLED displays ($290 million) are the key categories today. Frost & Sullivan[2] estimate that the market for organic and printable electronics is expected to be a $35 billion industry by 2015 and reach more than $300 billion in 2025. Moreover, IdTechEx estimates that the growth will be faster than the silicon markets, exceeding $300 billion during the next 20 years.[3] There are differences in numbers, but the trend is clear and the importance of this field cannot be denied.

Printing Methods

The most typical printing methods for printed electronics include flexography, gravure, offset, screenprinting and inkjet printing. Flexography, gravure, offset and screenprinting are considered as conventional printing methods where a physical master (i.e., a printing plate) is needed for forming the image. Recently, a ring oscillator fabricated using a combination of offset, gravure and flexography printing has been demonstrated.[4] Inkjet printing is a digital printing method where the image is formed from a digital image file.

Flexography

In flexography, the printing elements of the plate are raised above the non-printing elements. The printing elements are coated with a layer of ink by the application roller or more commonly known as an anilox roller. The doctor blade helps to fill the cells evenly. The ink is transferred to the printing plate that is attached to a plate cylinder. The substrate travels between the plate cylinder and impression cylinder. The ink is transferred to the substrate with the help of pressure between the cylinders in the printing nip. Flexography uses flexible printing plates, which enable the use of a wide range of substrates. Flexography is usually used in packaging, labels and sometimes in publication printing.

Gravure

In gravure printing, the image elements are engraved into the surface of the cylinder whereas the non-printing elements are at a constant level. Before printing, the entire printing plate is inked. The ink is then removed from the non-printing elements by a wiper or blade. The ink is only in the engraved cells. During printing, the ink is transferred to the substrate by high pressure between gravure and impression cylinder. In addition, the adhesive between the ink and substrate are important. Gravure printing usually results in high print quality and is used to print magazines, catalogs, plastic films, metal foils and bank notes.

Offset

Offset printing is a widely used printing technique where the inked image is transferred from a plate to a rubber blanket, and then to the printing surface. When used in combination with the lithographic process, which is based on the repulsion of oil and water, the offset technique employs a flat (planographic) image carrier that obtains ink from ink rollers. The non-printing area attracts a film of water that keeps the non-printing areas ink-free.

Screenprinting

In screenprinting, a stencil is used instead of a printing plate. The ink is forced through the screen, which is typically made of natural silk, plastic or metal fibers. The screen consists of an image-specific, open mesh that is not covered by the stencil. There are a wide variety of different ink types with different ink properties for screenprinting. Typical screenprinting products include packages, textiles, printed circuit boards and large-format posters.

Inkjet

Inkjet is the only non-contact printing method thus enabling the use of a variety of substrates. The principle behind inkjet printing is to transfer small ink drops through the printhead nozzles to the substrate thus forming the desired image. The final print quality depends on ink, substrate and printhead properties and the interactions between them. Inkjet techniques are divided into continuous and drop-on-demand inkjet. In drop-on-demand inkjet, the ink drops are formed only when needed. Typical drop-on-demand inkjet technologies are thermal and piezoelectric inkjet. The latter has the most potential in printed electronics. Inkjet applications have ranged from home and office printing to industrial applications such as wide-format printing, package and publications printing and surface decoration.

The key to UV printing in any of these methods is the printing ink, which contains photoinitiator. When the printed area is exposed to UV light, the polymerization process begins and instantly dries the wet ink. UV curing is typically used with flexography and offset (sheetfed) techniques.

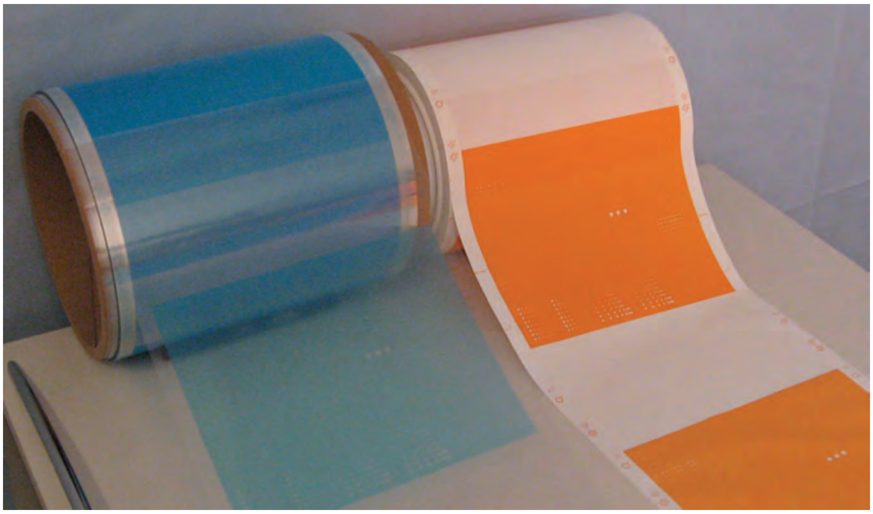
Materials for Printed Electronics Inks

Typical ink materials for printed electronics include conductive and semi-conductive polymers, metallic conductive inks and dielectrics. Typically, dielectric inks are UV curable.

Metallic Conductive Inks

In the most common type of metallic conductive ink, a metallic nano- or microparticle component (e.g., silver) is dispersed into a polymer vehicle. The nanoparticle ink is usually cured by heat, which melts or sinters the metal particles into a continuous metal layer and decomposes all or part of the polymer vehicle. The required curing temperatures are typically in the range of 100-400°C and recommended curing times are from 5-60 minutes, depending on the temperature. The microparticle ink is dried by heat, which removes the binder and the solvent and forms a conductive layer. The conductivity with these inks is based on contact between particles and is lower than with sintered nanoparticle inks. However, the drying is much faster, tens of seconds. These materials can be used in printing velocities up to several meters per second.

Other sintering methods, such as laser and microwave, are also being developed. These have the benefit of considerably reducing the sintering time. In another type of ink, a metallic precursor, such as $AgNO_3$, is embedded in a carrier system. After printing, the film is heated and the precursor decomposes into nearly pure metal.



Gravure printed dielectrics.

These organic, metal-complex, compound inks have a slightly shorter curing time (1-30 minutes) at a given temperature than particle-based metal inks. Silver and copper metallic precursor inks exist for the inkjet and offset printing methods.

Silver particle inks for gravure and flexo printing are available as solvent- and water-based formulations. The substrate determines what curing temperatures can be used for sintering the metal particles together. Copper- and carbon-based inks are available although their conductivity is lower than silver. Nano-sized particles have the benefit of reduced sintering and melting temperatures. Nanoparticles can also be suspended in lower viscosity liquids, enabling them to be used in inkjet printing. A polymer shell to prevent aggregation and remain evenly dispersed, and to promote adhesion to the substrate protects the individual metal particles. A wide range of nanoparticles can be manufactured from materials such as pure metals, metal oxides, ferro magnets, paramagnetic particles and luminescent particles.

In inkjet printable conducting nanoparticle inks, the solids content is between 20-50 wt % in order to meet the rheological requirements for stable jetting in the printhead. Decreasing the particle size, which is typically between 10-100 nm, can dramatically reduce the sintering temperature of the metal particles. The sintering temperature of metal nanoparticles is considerably lower than the melting point of the bulk metal, enabling printing on substrates such as paper that can only withstand temperatures of about 100°C.

For screenprinting, polymer thick-film inks are used. These are a combination of polymer and metal, and produce a film with good electrical and thermal conductivity. The ink uses a combination of continuous micro-soldered metallic chains and interfaces interwoven with tough thermosetting polymer, and requires curing for about five to seven minutes. Another type of screenprintable conductive ink contains silver flakes, a phenoxy resin system and a proprietary additive to enhance conductivity.[5]

UV-Curable Dielectrics

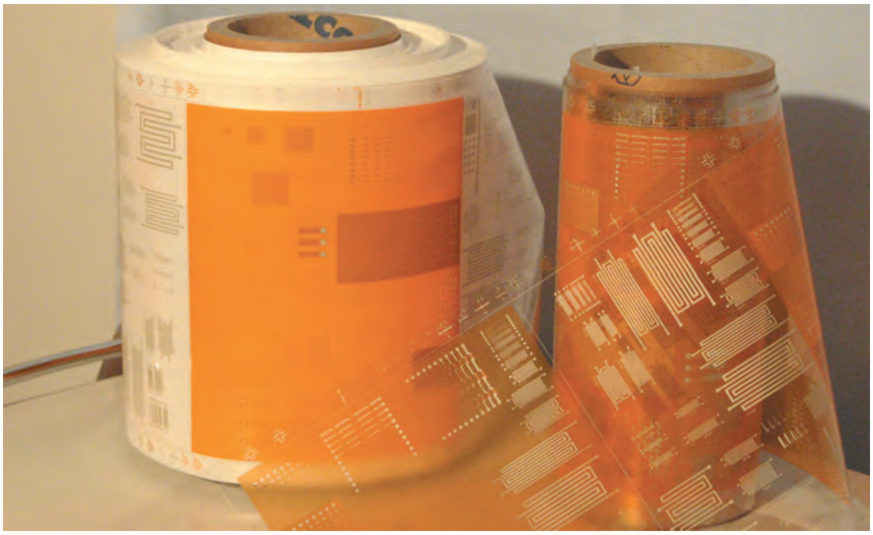
Dielectric materials are important when electronic and optoelectronic components are developed. For electronics, their function is to provide good electrical isolation between conductive layers to avoid short circuits and reduce electromagnetic coupling that might interfere in the operation of the printed electronic circuitry.

For printing, the materials must have good properties. In addition, the compatibility with the substrate and other materials used in the circuitry must be good. Viscosity of the dielectrics must be adjusted correctly so that, for example, in gravure printing the doctor blading is successful. The dielectric layer in a printed electronic circuit typically needs to be homogenous and thin. Its surface roughness must be as low as possible because it has to serve as a substrate for upper layers. The surface tension must be correct to avoid droplet formation so that the printed dielectric ink wets well. In many electrical applications, connections are needed through the dielectric layer. There must be holes in the dielectric layer. These holes are generated during the printing of the dielectric. If the wetting of the ink is too good, these holes might be blocked. Sometimes additives are used to affect the printing properties of the dielectric ink, but these usually affect the electrical properties of the dielectric material, reducing its performance.

Discussion

UV-curable inks are very suitable for printed electronics since they require a few seconds curing time compared to metal nanoparticle inks that require from five minutes to one hour sintering in high temperature. An area of 10 cm can be printed in a fraction of a second with a web moving at 10 m/s. However, if five minutes heat curing is needed, there has to be a 3,000 meters long oven after the printing unit. At the same speed, one second UV curing needs a UV chamber that is only 10 meters long, thus making the press footprint smaller.

Many substrates cannot tolerate high-curing temperatures for a long time. For example, paper cannot be kept above 130˚C for a long time while PET cannot be above 150˚C. Higher curing temperature typically results in faster



Gravure printed multilayer structures.

curing so preferred curing temperatures are usually around 200˚C. On the contrary, different substrates tolerate UV curing well since they don't have to be exposed to UV light for a very long time.

Another benefit of UV curing is working safety. Some solvents may be unsafe to use with IR or hot air curing. For example, acetone should not be used in the IR-curing process. However, UV curing is safer to use.

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