APPLICATIONS METHODS AND MATERIAL SETS FOR PRINTED ELECTRONICS

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ABSTRACT
The field of printed electronics (PE) is becoming increasingly dynamic, with the technology garnering much interest as of late. Using printing processes to build a functioning electrical device is a very attractive option within many markets for several reasons. These include speed of production, cost of manufacture and very flexible form factors. In fact, PE currently has significant penetration in the white goods, membrane and capacitive touch markets. Current applications within the medical sector include printing EKG and defibulator pads, glucose sensors, drug delivery devices and printed heaters. Other well-established applications include RFID antenna for security devices and EL lighting.

PE is also beginning to gain ground in markets such as energy storage (printed batteries), solar cells (printed bus bars and lead frames) and lighting (micro-LED technology). This paper will focus on the current footprint in the Printed Electronics industry and the author will discuss the three primary printing processes currently used for printed electronics.

The paper will address evaluation and selection of various printing methods and the benefits and drawbacks of each. In addition, materials sets used in printed circuitry will be discussed.
The paper will cover products used in the fields of Medical, Display, Lighting, Solar and Security.

INTRODUCTION
The idea of using printing processes to produce electronic circuitry is not new. Companies have been using screen press equipment to make simple membrane switches and keypads for more than 20 years. As consumers push demand for smaller and less expensive products, manufacturers must incorporate high-volume, low-cost solutions. As one of the most cost-effect production methods, PE is helping to address this high throughput, reduced cost scenario and it will likely continue its dramatic growth as a viable solution. Currently, there are few stand-alone printed electronics methods. Each technology in use today currently incorporates some type of interconnect with other electronic components, or are the base components in assembly. Surface mount technology (SMT) is required for the majority of current applications. This hybrid approach of PE with some assembly is the predominant approach today and will likely be the preferred methodology for some time to come.

PRINTING METHODS
There are many different types of printing processes used for a variety of applications. These include ultra high speed “off set lithographic” printing used for daily publications of newspapers and magazines capable of running up to 20,000 sheets per hour to manual hand printing presses that make one or two impressions per minute.

For the bulk of the applications in PE, the three most commonly used technologies are flatbed (screen/stencil), flexographic and rotogravure printing.

FLATBED (SCREEN PRINTING)
Flatbed screen printing is the oldest printing method and is thought to have originated in China close to 800 years ago. The oldest screens were made from silk, hence the reference to “silk screening”. Today’s screens consist of a woven mesh screen that is made up of either polyester or stainless steel. The screen is then stretched over a metal frame. Ink is placed onto the screen and a rubber squeegee is drawn across the screen, pushing the ink through the screen leaving an image on the substrate on the opposite side of the screen.

Flatbed printing one of the most versatile and widely used of all printing methods, including within the PE markets. Types of printers vary by application and throughput rates and include clamshell *(See Figure 1)*, four post, and a modified type of screen press called a cylinder press.

Figure 1 Typical clamshell flat bed printer

With screen sizes and different emulsion thicknesses, substrate deposit thicknesses can be manipulated with a great deal of accuracy.

Building a screen for printing requires the following items: emulsion, frame and screen. Screens come in a variety of sizes and are sized according to the number of threads per inch (or centimeter) and the diameter of the threads in the mesh. Screens are then given a number based on the thread count and diameter. For example, a typical screen size for printing conductive silver inks is 230/40. The first number (230) is the number of threads per inch and the second number (40) is the thread diameter of the thread in the screen. Using these numbers, the amount of "open area" a given screen has can be determined. In the case of the 230/40 screen, the open area is 41%.

This enables determination of the coating thickness and provides data for consistent lay down in regards to the maximum particle size that can effectively pass through the mesh while printing. A good rule the largest particle size be no more than 30% of the opening diameter.

The emulsion is a photosensitive polymer that is applied to the screen. There are two types of emulsion. Capillary and Direct. Capillary emulsion is a film that is applied directly to the screen. It comes in sheets that are different thicknesses depending on the mesh size of your screen and the deposit thickness desired. The screen is moistened then the film is applied. The screen is then allowed to dry before the image is "shot". The image for the screen is first digitally printed onto a clear polyester sheet. The polyester image is then placed on a light table with the screen over it. The light table is turned on to expose the emulsion. After the emulsion is fully polymerized it is taken to a high pressure wash out to remove the undeveloped emulsion. This leaves the open image on the screen ready for printing.

Direct emulsion is a photo sensitive liquid that is applied in several layers to achieve the same effect as the capillary emulsion. Once the direct emulsion dries it can then be exposed using the same process.

The application-specific screen is then placed inside the printer. The printer consists of a vacuum table, flood bar and squeegee. The screen is set so there is no contact with the substrate with a gap of approximately two millimeters. Ink is placed onto the screen and the printer cycles, first flooding the screen with the flood bar following which the flood bar lifts and the squeegee comes down pressing down on the screen, deflecting it to make contact with the substrate. The squeegee then moves down the screen transferring the image to the substrate.

There are many factors that determine the coating thickness applied by flatbed printing. These main factors are screen size, emulsion thickness, squeegee hardness and sharpness. Also, the volume solids of the material being applied can vary impacting the dry film thickness.

A courser mesh screen will apply more material giving a thicker deposit but looses some line definition. A 156 mesh screen will deposit more material than a 330 mesh but will not be able to print a line finer than 150 microns in width. A 330 mesh will be able to print lines as fine as 100 microns but will be limited to the deposit thickness that can be applied.

Deposit thickness can also be manipulated with emulsion thickness. A thin emulsion can give very fine features to a print but will lack the necessary film build to get the functionality needed out of the ink. A thicker emulsion will give more gasketing ability to the screen, but can cause scooping effects if the lines are too wide.

There is definitely a balance that has to be achieved when determining screen sizes and emulsion thicknesses. One should try to use the largest screen possible to accurately maintain the proper coating thickness along with the line definition need for the given part.

Squeegee hardness and roundness play a smaller part in coating thickness. These factors do, however largely impact line definition. A soft squeegee (60 durometer) will flex more causing more hydraulics to be applied. This will force more ink to be pushed through the screen, which improves coating thickness but also tends to cause more bleeding of the line resulting in some line definition sacrifice. A hard squeegee (90 durometer) will not have the same hydraulic properties as a softer squeegee but is capable of printing finer features with less chance of bleed.

The angle at which the squeegee is placed into the print head when placed against the screen is called the "attack angle". The attack angle also has an impact on the amount of material applied and suggested attack angles are from 60 to 45 degrees. Slight adjustments can have subtle changes in the coating thickness and print quality.

There are other parameters that can affect print quality such as off-contact, flood bar pressure and print speed but these have a lesser degree of influence on the overall print.

FLEXOGRAPHIC PRINTING

Flexographic or flexo printing is a type of letterpress printing that uses a flexible polymer plate that is attached to a cylinder. Ink is placed into a reservoir then transferred to a cylinder that goes into the ink pan. This cylinder is called a pick-up roll or fountain roll. The fountain roll then transfers the ink to a second roll, which is called an anilox roll. The anilox roll has grooves in it that meter a precise amount ink. The ink fills the grooves in the anilox and then a sharp metal blade called a "doctor blade" wipes off the excess ink. The remaining ink is then transferred to the plate cylinder which holds the flexo plate. This cylinder rotates and then comes into contact with the substrate transferring the ink from the plate to the substrate forming the printed image. *(See Figure 2*)

Flexo printing is a continuous process that is made up of different stations. Each station has the capability to print and cure a layer of ink. Typical flexo lines for graphic printing have four stations. These in-line stations are made up of a print head and some sort of drying or curing capability. Which may be forced air, UV or IR dryers.

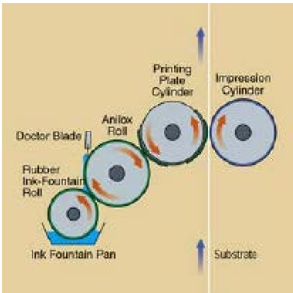

Figure 2 show typical flexographic press design.

There are two types of flexo presses: sheet fed, used primarily for printing on cardboard, and web fed. Web fed is the primary press type for the printed electronics industry and will be discussed here.

Flexo presses have seen more advances in ink development, process changes and press designs in the last ten years than flat bed and Rotogravure combined. Developments range from changes in flexo plate designs and materials to improved anilox designs and drying capabilities to the presses themselves. With the continuous roll to roll processing, newer flexo machines are capable of running at speeds that can process upwards of 2000 feet per minute. Because of the deposit thicknesses and drying capabilities needed for today's functional inks typical processing capability for the PE industry are closer to 100 feet per minute.

Fountain roll

Flexo presses are comprised of four rolls: three that carry ink to the given substrate and the impression roll, which runs on the backside of the substrate to support it for the contact being made with the plate cylinder. The three rolls that carry the ink are the fountain roll, anilox roll and plate cylinder roll.

The fountain roll typically made of a polymer or rubber coated material, picks up ink from the tray or "fountain". The distance between the fountain roll and the anilox roll dictates how much ink is transferred to the anilox.

Anilox roll

The anilox roll is one of the key components in flexographic printing. It is the primary component responsible for controlling the film deposit thickness onto the substrate and is made up of either a metal that is soft enough to be engraved or a ceramic-coated roll. The roll is engraved or etched by a steel milling or a laser etching process. Laser-etched rolls are becoming more popular due to the different types of cell designs that can be created on the roll. This system is better suited for PE types of printing with the newer cell designs. Anilox roll are made in many different size and cell configurations. *(See figure 3)*

Anilox are measured by line screen which correlates to the cell volume in the roll and are characterized by a line count designation and a volume specification (220/25). The line count reflects the number of cells per inch. The volume is measured in billion cubic microns (bcm) and is calculated by a direct measurement from the etched roll.

Anilox rolls can also be etched with several bands on one roll. Each band is etched with different cell volumes to allow for comparing line definition and coating thicknesses on-line without changing rolls out completely. Banded rolls allow research to determine the best line count per cell volume at a lower cost through reduced printing time and ink consumption. Anilox rolls have traditionally been etched for graphic ink applications that incorporate much smaller size pigments. Conductive inks present a challenge with large size highly pigmented dense systems. In typical cell designs silver pigment "packs in" or fill the cells without completely transferring to the substrate. This limits the amount of silver ink that enters the cells and renders the anilox roll ineffective within minutes of printing.

Cross section of typical cell Structure

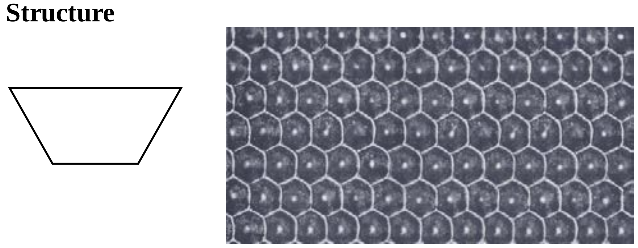

Figure 3 shows the structure of a typical Anilox cell

Due to the deposit thicknesses required for maximum functionality, many anilox manufactures have developed rolls with different types of etching designs in an attempt to transfer more ink than what is typically achievable with traditional graphic ink designs. One such roll has been developed by Praxair. It is different from traditional cell structure by using an offset approach. The new method [1]ART (Anilox Reverse Technology) uses an engraving that has an open cell design as opposed to traditional single cell designs. *(See figure 4)*

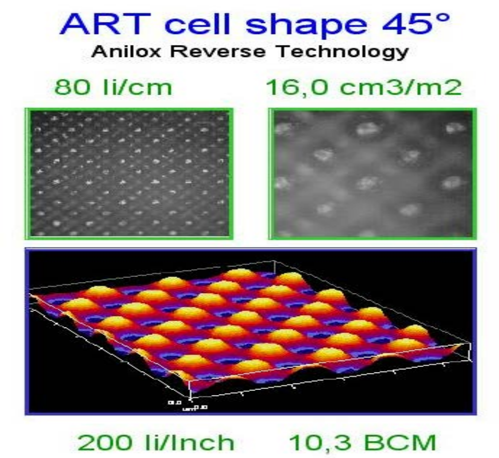

Figure 4 shows the Praxair ART anilox design

By using these new anilox designs printers are able to deposit ink thicknesses up to three times higher than with conventional anilox designs. The open pattern also helps to improve transfer the much larger silver particle sizes to the substrate without packing the cell walls.

Plate cylinder roll
The plate cylinder roll, which is a chromed metal cylinder to which the flexo plate is attached, holds the image that is transferred to the substrate. The flexographic plates are sheets of polymer that are not completely polymerized but can be polymerized or developed using analog or digital processing. Analog processes require a mask similar to the methods used for developing screens in a screen printing process. Digital development incorporates a carbon film on the flexographic plate that is thermally imaged with a digital print head. The developed plate is then exposed to either a solvent or dry thermal process to remove the unexposed material forming the image. The polymer plates come in different hardness levels and surface textures, which help transfer material more precisely onto the substrate. The plate is attached to the cylinder with a double sided tape referred to as "sticky-back" which is an adhesive that is coated to both sides of a spacer material. The spacer material comes in many different thicknesses and hardness levels, which helps determine line definition in the finished print.

Some of the other benefits of flexographic printing are the versatility to change head designs. Flexographic presses have the ability to incorporate rotary screen heads in their stations. These screen heads give a flexo line the ability to provide screen printing characteristics for an inline application. Other flexo line alterations may include laminating systems, inline surface treatments, inline converting and die cutting. These adaptive abilities are some of the reasons for the rapid advancement in today's flexographic lines.

ROTOGRUVURE PRINTING
Rotogravure printing incorporates an etched copper roll that goes directly into an ink well and picks up the ink. The recesses in the etched roll fill with ink when in the well. A metal blade called a doctor blade removes the excess ink from the roll and the remaining ink that is in the etched cylinder then transfers to the substrate. (*See figure 5)*.

Rotogravure is currently capable of providing the fastest speeds in PE printing. With proper drying rotogravure can reach speeds capable of processing 3000 fpm. Due to the heavier volumes of ink that can be deposited, rotogravure is typically used for high end magazines where color and photographic type quality is important. The process is also used in the production of low-cost, high-volume parts such as EKG and tens pads for the medical industry, as well as for RFID applications. The cost of setting up a rotogravure line is much higher than that of a flexo line, and therefore tend to be cost-effective only when looking at programs where parts needed are in the millions.

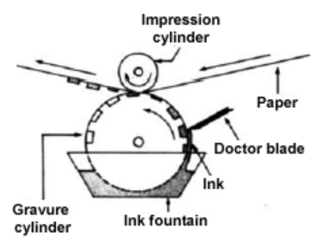

Figure 5 shows a typical rotogravure type system

Rotogravure is a web-fed process with multiple print and curing stations much like flexo but on a larger scale. Web widths for typical flexo lines are from 12 to 36 inches wide. Average rotogravure web widths are 60+ inches wide. Due to the extreme speed requirements and the need for quick drying materials, rotogravure systems require inks with solvent systems having a very low flash point. Because of this systems are built to be explosion proof.

Ink fountain
The ink fountain consists of an enclosed reservoir and a reticulating pump. The pump pushes ink into the pan to be picked up on the cylinder. Many recirculation systems have viscosity control in-line to monitor changes in the ink and automatically add more solvent to the system as needed.

Gravure roll
The gravure roll is made up of a metal roll electroplated with a film of copper. The copper is etched with a mirror image of the print design. The rolls are often then chrome plated to extend their life on press. Thickness and depth of the etching determines the amount of material deposited onto the substrate.

Impression roll
The impression roll is comprised of a steel cylinder with a rubber coating. It is used to push the substrate into the

gravure roll to enhance the capillary action, transferring the ink from the cell walls to the substrate.

To further enable the complete transfer of ink from etched cells to the substrate, many presses are equipped with electrostatic assist (ESA).   ESA works by adding an electric current to the impression roll. When the voltage is applied the ink is transferred not only by capillary action but by electrostatic action as well. With some ink chemistries, a 30% improvement is seen in the amount of ink being transferred from cell to substrate. This further enables deposit thicknesses needed for proper functionality out of a given part.

INK REHOLIGIES FOR DIFFERENT PRINTING TYPES

Because of the variety of print methods used in the PE industry, ink requirements vary greatly. Material viscosity, shear rate and film deposit are dependent upon the type of printing being performed.

Flat bed printing requires a relatively thick ink that quickly shear thins to a much lower viscosity. Shear thinning is required for good transfer of the ink from the screen mesh to the substrate. The ink also needs to recover quickly after shear to enable finer lines without much slumping or bleed. This is especially important when printing high film thicknesses.

Flexographic inks need to be much thinner to be able to flow into the anilox, transfer to the cylinder plate and again to substrate. The use of polar solvents in ink formulation helps in the transfer.

Rotogravure inks need to be even thinner. The viscosity of the inks must be low enough to quickly and completely flow into the cell at high speeds. Surface energy is also important, as optimized surface tension is required to hold the ink in the cell until it comes into contact with the substrate without running and causing fuzzing of the lines. If there is too much surface tension and the ink tends to bubble when running at high speeds. The use of polar solvents help ink transfer in gravure printing as well, especially when using a press equipped with ESA.

INK FUNCTION AND MARKETS

The PE industry has developed many different types of inks to suit the needs of various markets. While many are market/application-specific, there are some inks which are cross-functional and can be used for a variety of PE applications. Two such inks are high conductive and dielectric inks.

Conductive inks.

Inks developed for high conductivity are employed throughout the PE market and are used as the primary circuitry carrying the electrical current to all components on a given board or flexible part. Generally speaking, most companies desire the highest conductivity printed lines they can achieve at a cost point they can absorb. *(See Figure 6)*

There are many different inks used in conductive printing and these materials are made from a wide variety of resins and solvents. These include water-based, UV curable and solvent-based systems. They are built to perform on many different substrates and under varying environmental conditions. While the resin and carrier systems differ greatly, the types of conductive pigments used in the systems do not. There are only two types of conductive pigments widely used. These are silver and carbon.

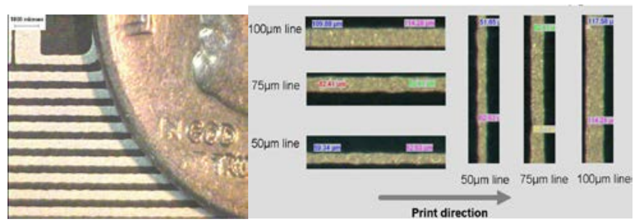

Figure 6 shows typical conductive traces for RFID and fine line printing capabilities.

Silver inks

Silver is the most electrically and thermally conductive material of all the metals. One of the key properties of silver is also the ability to remain conductive after oxidation has occurred and the oxides that are produced on silver are as conductive as the silver itself. This makes silver a perfect material where fine inner particle contact is important.

There is a great deal of development effort underway to develop other metal pigments such as copper and nickel as a replacement for silver. Of course the primary driver for these developments is the reduced cost of the inks. The primary drawback of other pigment systems is that the oxides formed on other metals are not conductive. Over time, these oxides reduce the conductivity of a given trace to the point at which they are no longer conductive. While there has been some advancement in development of these pigments, there are currently no commercial inks that use alternative pigments with the effectiveness of silver.

Carbon inks

Carbon inks (or carbon graphite blends) are also used across the entire field of PE. Carbons are typically three orders of magnitude more resistive than silver, but are typically a much lower cost ink system. Often if a manufacture can change the electrical needs of a given part, carbon alternatives can be used. Carbon systems are incorporated in applications where resistance is a requirement and used as a component of the functional part. Some of these applications include printed resistors, heaters and potentiometers.

Dielectric inks

Dielectric inks also play a very important role in the structure of PE circuitry. They provide environmental protection to the printed conductive trace, stop shorting and make it possible for multi-layered printing to take place. This allows for building more complex circuitry in a smaller area. (*See Figure 7)*

Dielectrics are also used to help minimize silver migration which is important especially where there is current draw and moisture present in a printed circuit.

Dielectric formulations are made for thermal cure and UV cure systems, with the vast majority of systems being the latter. The 100% solids formulations and crosslinking properties make UV systems the preferred chemistry choice for most applications. The processing speed combined with the chemical and environmental resistance benefits make UV systems ideal.

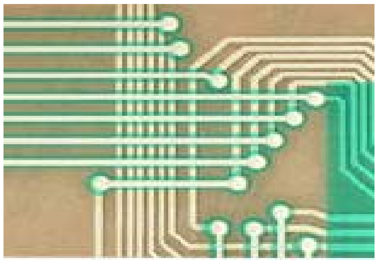

Figure 7 shows multi layered printing with dielectric crossover.

SPECIALTY INKS FOR DIFFERENT MARKETS

There are also inks sets that have been developed for specific markets. Here, the author will touch on inks for the medical, lighting and sensor markets.

Medical inks

Silver/silver chloride inks systems are primarily used for medical applications, specifically for ECG/EKG pads. Functionality is achieved through the combination of silver inks and conductive gels. The inks are printed onto the ECG pad itself. The silver/silver chloride pad and conductive gel combine and when placed against the skin to form a conductive salt bridge that picks up the electrical pulses from your heart. These pulses are then transferred to a machine that records the information.

Another use for silver/silver chloride inks is for drug delivery systems or Iontophoresis.[2] Iontophoresis is a process using electrical current to deliver a medicine or other chemicals through the skin.
This process operates under the same principle as an ECG pad where silver/silver chloride inks combine with a conductive gel. I the case of Iontophoresis, the gel is also loaded with the drug to be delivered. A current is applied and the system ionizes the skin, which promotes drug delivery. By changing the amount of current applied delivery rate can be increased or decreased.

Lighting/Display

Functional lighting devices are also facilitated by modern ink materials. Electroluminescent (EL) lighting applications can also be facilitated through printing practices.

EL displays are constructed by printing a multi-layered construction that consists of a phosphor layer between two conductors. *(See Figure 9)* When power is supplied between the two conductors, a field effect causes the phosphor particles between them to excite. As they become excited, they emit photons that are given off as light. EL lamps need to be powered by an AC power source. The current switching between cycles is what causes the light to generate. By changing the frequency of the power supply, the brightness and color of the lamp can be changed. EL lamps are the primary source of light used in watch backlighting. It is also used in cells phones, point of purchase displays and automotive dash board backlighting.

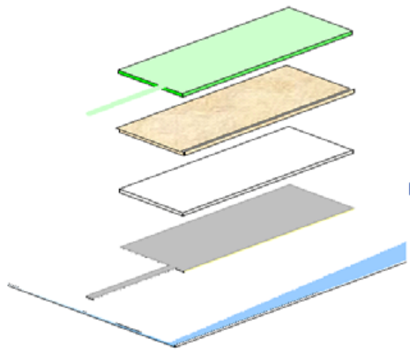

Figure 9 shows printing construction of EL lamp.

Other unique inks for the lighting market are clear conductives which are used for both EL lighting as well as capacitive touch screen assembly. There are different degrees of transparency found within different ink sets. Some of these systems are filled with material pigments such as indium tin oxide (ITO) and antimony tin oxide (ATO), while others use conductive polymers. Although these inks are conductive, many lack the degree of conductivity needed for certain display applications. Because of this sputtered transparent clear conductors are still the preferred method to achieving clear conductive layers. The uses of nano particles such as carbon nano tubes (CNT) are showing great promise for the development of next-generation clear conductives.

Sensors

Using inks to print sensors has been a standard method of electronics printing for some time. Inks for printing sensors and resistors vary widely in resistance values and compositions. In addition, these inks are used for a variety of other applications including seat sensors for airbag deployment, printed potentiometers for automotive and consumer markets as well as printed heaters. As stated previously, these inks have many different resistance values and can be blended to meet customer-specific values. Formulations of these inks also include extreme hardness ratings for wear resistance, which may be required for automotive foot peddle potentiometers for examples. Wear testing requirements for this type of application are in excess of eight million cycles with Dither testing.

Positive Thermal Coefficient (PTC) inks are also used in the sensor market. These inks are very unique: When used in a printed circuit, they act as a fusible link.

Functionality is achieved based on the ink's reaction to the current that passes through it. When current is introduced to these inks, they begin to heat and become less conductive as the temperature increases. When the inks reach a pre-determined temperature based on formulation requirements they go through a phase change at which point the ink resistance increases greatly. This prohibits electricity from passing through the circuit and effectively shuts down the unit until the ink cools below is phase change temperature. When the ink temperature drops low enough, current is reintroduced. Currently, this ink technology is most widely incorporated into heaters such as set heaters and mirror defrost heaters for the automotive market.

SUMMARY

It is hoped that this presentation will show you some of what is possible in the world of printed electronics. The possibilities for printed electronics are endless and this paper has only touched on a few examples of its current use. From presses and printing methods to ink sets shown. These are just samples of what inks can do in electronic assembly.

In many ways, printed electronics still very much in its infancy. The functionality delivered and throughput rates available with printing will no doubt ensure its viability for the foreseeable future. Increasing product diversity and the need for form factor modifications will drive printed electronics growth.

As new materials are produced for applications such as solar, energy storage, and interactive displays, PE in combination with surface mount technology, will deliver the low-cost, high-volume capability required to meet consumer demand.

REFERANCES

1 Praxair Anilox Technologies
2 Wikipedia, the free encyclopedia