PRINTED ELECTRONICS PRIMER: AN INTRODUCTION TO THE BASICS OF PRINTED ELECTRONICS

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This white paper provides an overview to printed electronics (PE) and explains basic terminology used in the field. It provides a basic description of the PE industry today, including prevalent technologies, materials and manufacturing processes. This paper is intended for the general audience that wants to understand and learn about the fundamentals of printed electronics.

Printed electronics, as the name suggests, combines two different fields into one. Traditional printing that creates a product by application of ink onto a substrate and electronics, the technology that creates variety of devices, circuits or systems. Printed electronics (PE) in its basic form was around for many years in the form of simple membrane switches, electronic circuitry or as a complementary technology to the conventional copper circuit technology during the manufacturing of printed circuit boards (PCB). However, one should not confuse the word "printed" in PCB. This does not mean that a traditional printing process was a part of PCB manufacturing.

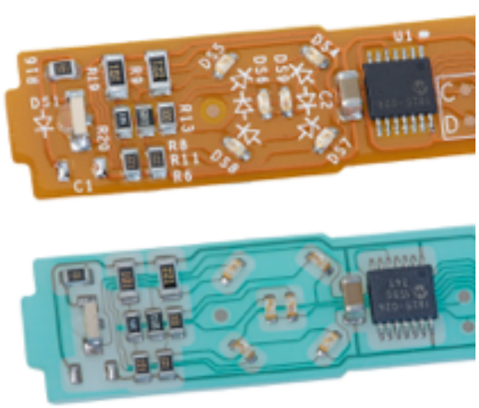

Figure 1. PCB product made with traditional technology (A) and with PE technology (B)

PCBs and other electronics are traditionally manufactured using subtractive processes. Throughout such manufacturing processes, raw materials are removed in order to create the final product (Fig. 2). In many cases, these removed materials cannot be reused, so are therefore wasted. For example, during the manufacturing of traditional PCBs, conductive traces are created by removing the copper from dielectric material. This means, in most cases, that at the end of the PCB manufacturing process, more copper material is removed (etched away) than remains on the substrate. In addition to this subtractive nature of traditional electronics manufacturing, the process also includes multiple different steps to finish the product. These steps include for instance masking, etching, plating, chemical vapor deposition, etc. Typically, the manufacturing is carried out as a relatively slow batch process. Furthermore, certain steps must be completed in highly controlled environments (clean rooms). All this can make traditional manufacturing a lengthy and expensive process.

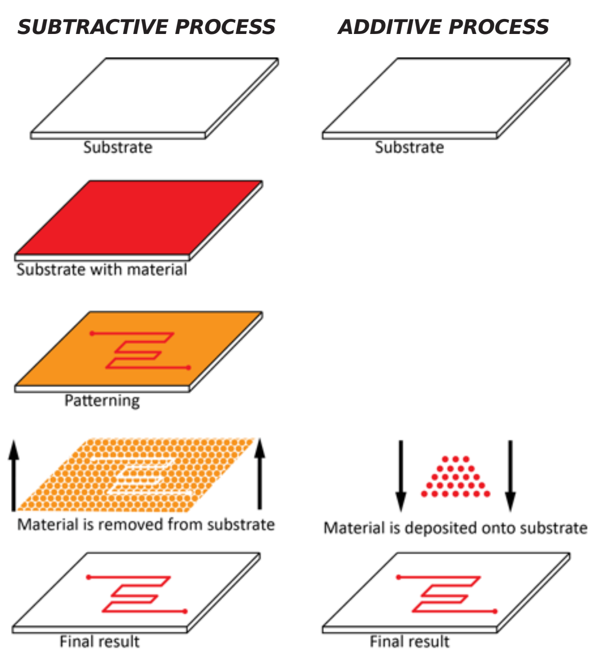

Figure 2. Processing steps for subtractive and additive processes

On the contrary, printing is an additive process. During such manufacturing processes, materials are only deposited where they are needed (Fig. 2). Another very important advantage of a printing process is production speed. Some printing processes can reach speeds up to 1000 feet of printed material per minute. However, printing speeds vary depending on the complexity of the final product and materials used. The main reasons for adjusting the speeds are registration capabilities, drying requirements and deposition of uniform, in some cases thick layers of the material. For many PE products the precise placement (registration) of multiple layers is critical to ensure proper functionality and performance of the final product. In general, the slower the printing speeds the better the registration tolerances. As for the drying, many functional materials (especially conductive inks) require excessive and prolonged application of heat to achieve proper adhesion (between the substrate or other functional layers) and electrical properties. Insufficient drying may result in higher electrical resistance or interlayer adhesion failure.

There are different deposition methods/technologies used by the printing industry. The most commonly used processes for manufacturing of printed electronics are screen printing, flexography, inkjet and in some cases rotogravure. The substrate can be processed in two forms, as rolls (roll-to-roll process) or as sheets (sheet-fed process). The true continuous roll-to-roll (RTR) process can be employed by flexography, gravure or rotary screen. Traditional screen printing is mainly a sheet-fed system. Even though screen printing can process substrate in the roll form, it is not a continuous process because the web of the material stops for every printing cycle. An advantage of a RTR system is also the ability of having multiple printing stations in parallel configuration, so the product can be completed in one pass through the printing press. However, as mentioned before, some layers may require post curing. This requirement cannot be always met by employing RTR systems. Another factor to consider is extended set-up time and higher consumption of materials (inks and substrates) for a RTR process, especially for high-speed production. Due to this fact, the RTR process is most attractive only for production where very high throughput is required.

Each printing method has its advantages and disadvantages. Screen printing can print thick uniform layers (which is directly related to the overall performance of printed circuits) at high resolution (small feature sizes, Fig. 3). However, even though there has been some development made in this area, screen printing technology is not a high throughput system. Flexo printing can provide high resolution printing but the ink layers are thinner compared to screen printing. As for the gravure printing, even though this technology provides many advantages, it is a more costly process overall. Inkjet printing is mostly used in the R&D stage since it requires very small quantities of often expensive materials.

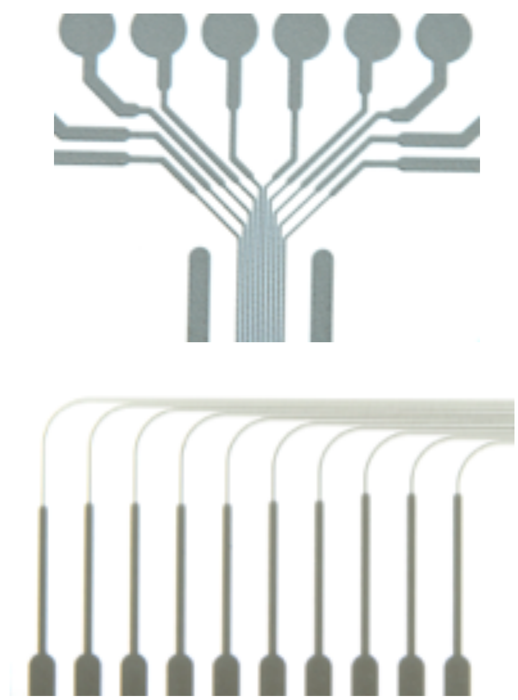

Figure 3. Silver conductive traces (0.004”) printed with screen technology

Some RTR printing systems offer hybrid solutions where one printing press can combine multiple deposition methods such as rotary screen, flexo, gravure and even inkjet station. This allows taking advantage of multiple deposition methods. Choice of the printing methods depends on the material and resolution requirements for the application. For example, printed batteries or organic photovoltaic require different deposition requirements than integrated circuitry or OLED displays. Another unique feature of PE manufacturing is the ability to use a variety of substrates. The substrates used in traditional electronics manufacturing have to meet certain requirements; they have to withstand high temperatures or be resistant to harsh chemicals of etching and plating baths. The substrates used for PE do not need to meet these requirements and therefore the selection of the substrate is broader and offers additional cost savings during PE manufacturing. Relatively economical materials like plastic films, papers, fabric or glass can be used.

Despite all the mentioned advantages of the printing technology, it has to be noted that printing itself cannot fully replace current processes used for manufacturing electronics. The performance of traditionally made silicon-based electronics is still much higher than what can be achieved with printed electronics. However, there are some applications that do not require high overall performance and can benefit from advantages that printing can offer. In general, the primary goal of PE is to simplify and speed up electronics manufacturing processes at lower costs compared to traditional manufacturing. Most of the current production that involves printing as a manufacturing step can be considered as hybrid manufacturing. Meaning that only certain portions of the circuit is printed and the rest of functional components are traditionally made, Fig. 4. (resistors, capacitors, IC chips, LED, etc.).

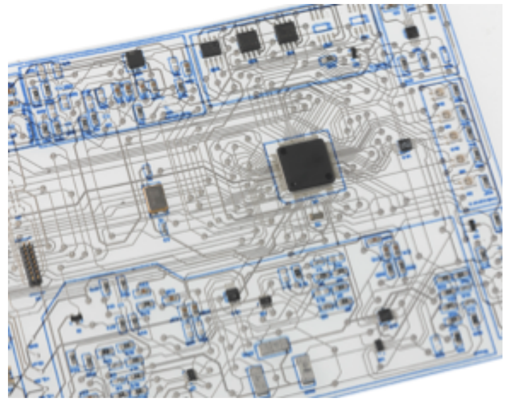

Figure 4. Hybrid electronics (printed circuit with functional components)

Even though PE has been used for many years, only recent developments of new functional materials and improvements in printing technologies have allowed for the expansion of PE and creation of new products. Functional materials are generally divided into three categories; conductors, isolators (dielectrics) and semiconductors. These materials (inks) contain substances (inorganic or organic) that give the inks their functionality. For example, conductive inks can contain silver, carbon or copper particles. Furthermore, inks contain other components (polymer binders, solvents and various additives) that influence the functional properties of the inks as well. Conductive particles (fillers) can be different sizes (micro or nano scale) or chemical structures (for example, carbon can be used as graphite or graphene structure) that directly influence the properties of the ink and dry printed layer itself. Traditional fillers are larger in size and therefore are a limiting factor during the printing of small features (less than 200 microns). Over the years, ink manufactures have been able to lower the size of the fillers and make it possible to reliably print these features below 50 microns.

Printed conductive inks require heat to cure and the dried films increase their conductivity with additional application of the heat. Dielectric inks are used to separate conductive layers between each other or protect the final printed circuit. They are mostly UV light curable materials that do not require heat curing. Printable semiconductive inks are less available, and typically organic solutions that require processing in highly controlled environmental conditions. As of today they are rarely used for commercial production.

Developments in materials and printing technology have allowed for the creation of new PE products. From printing of membrane switches and simple electronic circuitry years ago, the industry has made significant strides—yielding new more sophisticated electronics made using printing technologies—from smart sensors and RF identification to fully printed batteries and photovoltaics. The most promising applications with the potential for PE are disposable electronics and wearable devices. These applications take advantage of the low-cost, flexibility and lightweight nature of PE. Disposable electronics are very attractive to the health care sector whether they are smart packaging for pharmaceuticals, various sensors monitoring patient condition or drug delivery systems. Wearables can include different activity sensors, smart patches that can control other devices. Another area with big potential for PE is lighting, in mold electronics, touch sensing, and the Internet of things.

Manufacturers have proven that the new generation of PE products is reliable and that for certain applications it can compete with traditional electronics. In addition, technology integrators are showing willingness to adapt PE as a valid alternative to traditional electronics and have already started to implement these products. Further developments in the materials and technologies used to manufacture printed electronics will in the future open even more opportunities for this field.