PRINTING-DEPOSITION REPORT
(including Printed Electronics)
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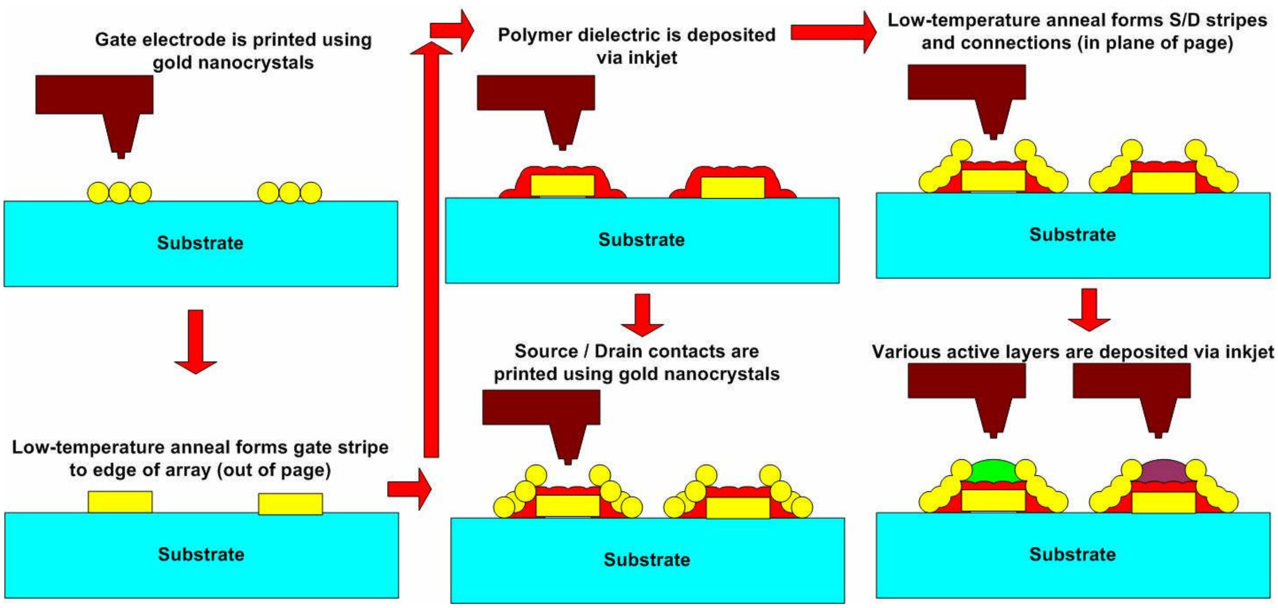
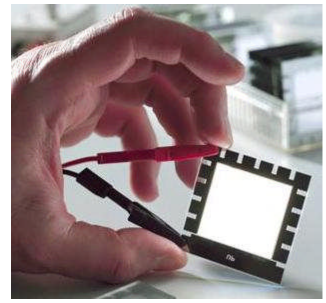
ET TRENDS

BUSINESS & MARKET NEWS

Overview of Printed Electronics (PE) - Printed electronics has focused on simple processes, especially conductive patterns. Some printed conductor products include wallpaper that generates power and anti-counterfeiting on 100-billion cigarette packets yearly to provide traceability at a cost of only 0.1 cents per package. And in the future, the US Army plans to use printed electronics to reduce the weight of the Warfighter pack by two-thirds and give the soldier *smart clothing* that generates electricity, heats him, cools him, monitors vital signs, acts as a long range antenna and so on. Printed electronics has been mostly about reducing cost, but it can also be applied to printed lasers, photodiode arrays and many other complex structures. But, the biggest potential of printed electronics lies in organic, or combined organic/inorganic structures, that have the lowest costs, combined with the fastest printing technology. **Inkjet** is a popular choice because of its tolerance of uneven substrates and its "tooless" capabilities. **Silicon-Printed Electronics** hybrids also make sense. Co-deposition of different devices using printed electronics could add functionality not easily obtained with silicon alone; for example, actuators, batteries, powerful capacitors and resistors, photovoltaics and a considerable choice of wide area sensors. This co-deposition of many large area components saves cost and increases reliability, something the silicon chip cannot achieve because it is only economical when very small.



But where is the market? Printed electronics has more to do with new products; patches, tapes, electronic wall coverings and totally new products. Eventually it will involve applying electronics to almost anything. And it may eventually impact conventional lighting, when the up front cost, installation cost and running cost of Organic Light Emitting Diodes OLEDs become superior and they use flexible plastic film. Applications of printed electronics and electrics could be huge because they do new things to create new markets. In other words, PE does not even need to replace existing technology for success. Indeed, even with lighting it will often mean creating light in new ways and new locations. The biggest opportunity for most forms of printed electronics is on flexible substrates because these will become lowest in cost and most suitable physically for the largest volume applications in future such as smart labels, smart packaging, books, newspapers, signage, posters and billboards. While paper can be used as substrate, plastic film is more versatile, and is especially suitable for displays.



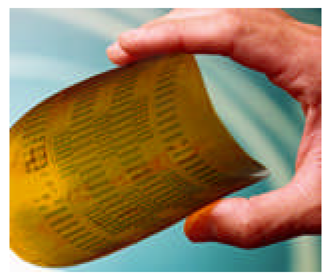
The business models for PE are very different from those for the silicon chip or other conventional forms of electronics or electrics. In this new field, electronics and electrics merge. The fundamental drivers of printed electronics are (a) build new things, (b) replace silicon chips and conventional components where they are uneconomic for certain applications, or are constraining a mass market to a tiny niche as with talking gift cards or blister packs that record when you took your pills. These blister packs, despite having printed sensors and interconnects, cost $15 to $30 so they will never be used beyond drug trials. Fully printed versions could be a few cents each and sell in tens of billions yearly. Today, the main applications of printed electronics in combination with conventional components such as silicon chips and button batteries etc. These applications are usually chosen to be relatively undemanding in technical parameters such as definition, color quality (of printed electronic displays) and conductance (of antennas and interconnects). Examples are the screen printed electrochromic displays on Valentines cards in 2003, billions of printed Ultra High Frequency (UHF) antennas on Radio Frequency Identification (RFID) tags in 2005 and, in recent years, vast areas of electroluminescent flexible billboard albeit based on a limited range of emitted colors. Eastman Kodak is now developing full color electroluminescent displays [licensing to Rohm & Hass]. Electrophoretic displays are usually only black and white. They are non-emissive, but they need no electricity other than when the message is changed so they are ideal for signage in supermarkets, airports etc and for electronic newspapers and magazines. Toshiba and others are learning how to do color versions. Plastic Logic, with Intel, Seiko Epson, BASF and other giant backers, has the printed transistor backplanes that are key to increasing their market tenfold because they and the display can now be flexible, avoiding the dead end of thin film silicon. This company is setting up a factory in Dresden Germany to make complete flexible displays and Sony has been developing similar flexible back plane and front plane technology. The only disappointment has been the recently revised view of some participants that cost-effective, flexible OLED displays of adequate life may have slipped to as much as ten years away.

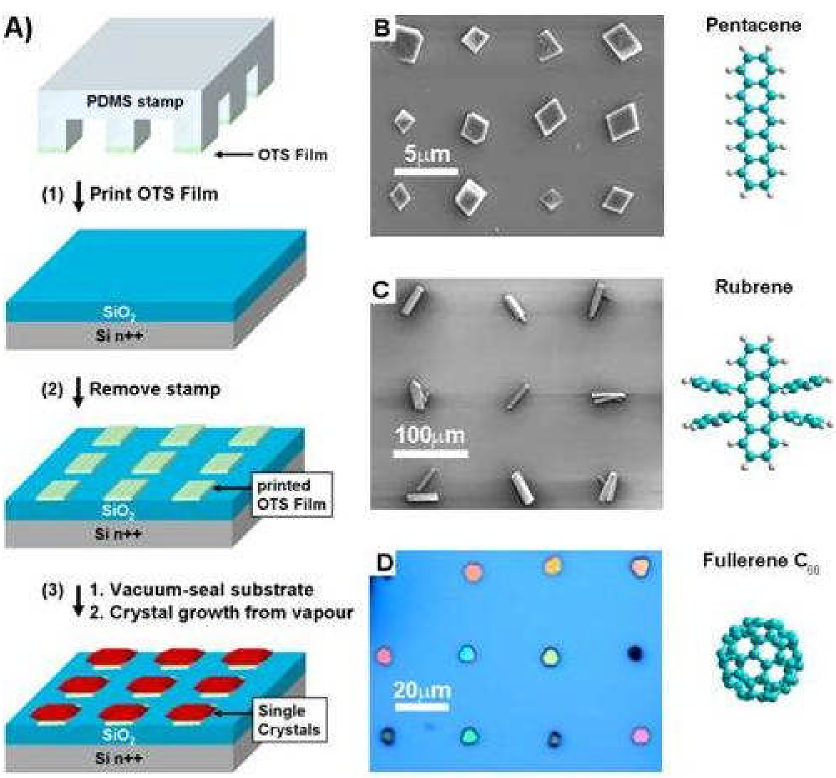
Printed electronics calls for a new marketing paradigm, where we go back to basics in looking at needs, we create new markets most of the time and our solutions most commonly take the form of an enabling technology such as a way of printing electronics on to things or a reel of electronic tape rather than a stand alone product. This is more the world of 3M, DaiNippon Printing and Toppan Printing than the world of many electronics giants though the latter seek to enter it. Indeed, Matsushita, Canon, Konica Minolta, Hitachi, Pioneer, IBM, Xerox, Samsung and many other giants are now investing heavily in printed and potentially printed electronics. Some are already trading at the conjunction of paper, plastic film, printing and electronics. They are backed by the might of the chemical giants developing the sophisticated materials and inks that are needed, such as Sumitomo Chemical, Mitsubishi Chemical and Nissan Chemical in Japan and Merck Chemical and BASF in

Germany. Eastman Kodak, BASF, the University of Tokyo, NanoMas Technologies USA, University of California, Paru Corporation Korea, Trinity College Dublin, Cambridge Display Technology, Plastic Logic and many other global leaders in printed electronics were present at Printed Electronics Europe 2007 in the UK on April 17-18.

TECHNOLOGY

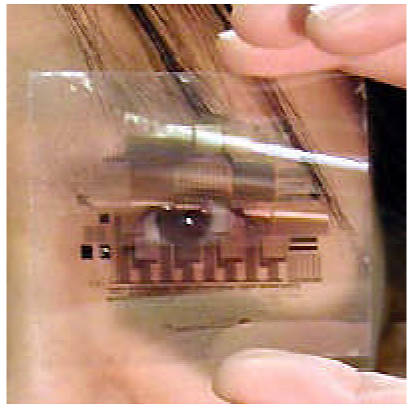
Nearly all of today's microelectronic devices are made from inorganic materials; primarily silicon. However, some organic materials can be made into semiconductors or full conductors of electricity. Recently, even superconductivity has been observed in a conjugated polymer demonstrating that a full spectrum of electrical properties. It is unlikely that organic electronics will ever be able to compete with silicon CMOS in terms of speed. While silicon chips have superior switching speeds and durability, plastic chips might have the edge on one crucial point - the price. This derives from their ease of handling. They do not require high vacuum equipment. They can be deposited at room temperature from solution, giving hope for low-cost, lightweight, rugged, flexible electronics: plastic electronics. Organic semiconductors should therefore tap a new market, involving applications that demand little from the speed of the circuits, but require that they can be produced in large quantities over large areas and at a low price. Organic, carbon-based materials combine their good semiconducting properties with mechanical properties that permit flexible, lightweight, and distributed electronic and optoelectronic applications ranging from low-end data storage, electronic tags and labels ('electronic barcodes') to smart cards, displays, and toys. Even wearable or disposable computing might be possible. Such low-cost applications represent a formidable challenge for single crystal, polycrystalline, or even low-temperature amorphous silicon technology. Consequently, organic electronics might be able to go where silicon can't follow.





The most common plastic electronic device is the organic thin film transistor (OTFT), which is very similar to the metal oxide semiconductor field-effect transistor-based (MOSFET) silicon technology. The nominally undoped organic semiconductor film is insulating. A negative voltage on the gate electrode attracts electrons to its surface and positive charge carriers (holes) to the interface between the semiconductor and insulator to form an 'accumulation layer'. If a voltage is applied across the source and drain electrodes, a current will flow between them. In this way, a small voltage change at the gate electrode can result in a large current change between the source and drain. Consequently, OTFTs can switch and amplify electrical signals as needed for logic operations.

Most of the early organic materials allowed only for p-channel devices, where holes are the major charge carriers, but careful synthetic, organic chemistry and molecular engineering successfully demonstrated n-type transistor materials of similar performance. More recent studies of devices made of high quality single crystals revealed that unintentional dopants and defects were mainly responsible for limiting OTFTs to one type of charge carrier and today several molecular materials have been shown to be capable of p- as well as n channel activity. This could be useful for the development of complementary logic circuits, similar to CMOS technology in silicon devices. The morphology of the organic semiconductor film also has an important impact on the overall device performance, mainly by limiting the charge carrier mobility. However, by optimizing deposition techniques and making use of alignment layers and the self-organizing properties of molecular solids, mobilities in the range of 0.1- 1cm2/Vs have been obtained in various materials. This is already in the right ballpark for the targeted applications but more progress might be expected from advances in materials processing or synthesis of new molecularly engineered materials. [TFT test chips at right].



Besides the performance of the semiconductor materials, the right choice of the gate insulator can also play a crucial role for OTFT performance. Both inorganic and organic materials have been used. Organic-based insulators, such as spin-on glass or polyimides, are especially attractive because they are compatible with solution processing on flexible, plastic substrates and their use has led to the demonstration of all-organic transistors.

In order to define the critical device dimension of the OTFT, the channel length or distance between the source and drain electrodes, several low-cost patterning techniques can be used. Some examples are **screen-printing, photochemical patterning, micro-contact printing, and inkjet printing**. These printing techniques are much less sophisticated, and therefore much less expensive, than the optical lithography used in silicon technology. Though the pattern resolution achieved is not as high as with the photolithography employed in fabricating standard CMOS silicon devices, channel lengths of 5mm and even less have been achieved on plastic substrates. As most of these techniques allow reel-to-reel processing, high throughput is possible in production. But their versatility also allows for rapid prototyping and the possibility of customized flexible, electronic circuits.

While transistor performance sufficient for the envisioned applications can be achieved using these low-cost processing and patterning techniques, logic circuits based on individual OTFTs must be prepared in order to commercialize "plastic electronics". So far, various companies have demonstrated the integration of a few thousand transistors. In one prototypical application of OTFTs, electronic paper, plastic electronics are used to drive an electrophoretic display. This was first demonstrated through a collaboration of Bell Laboratories, Lucent Technologies, and E Ink and has now been reproduced by other companies. High voltages and rather low currents are needed to switch the electronic ink pixels, requirements

that nicely match the characteristics of the organic transistors. That the display is also only several millimeters thick and bendable reveals the unique capabilities of plastic electronics. With continued progress in materials engineering, processing, and ultra-low cost fabrication techniques, commercial products may become possible and an evaluation of the full potential of plastic electronics would evolve.

The molecular nature of these carbon-based materials offers an intriguing final opportunity - molecular electronics in which logic circuits are based on single molecules or on a single layer of molecules! Recent results on carbon nanotube and self-assembled monolayer-based devices show that transistor action and voltage gain can be achieved in single molecular devices with channel lengths as short as 1 or 2-m. At these dimensions, the speed of the transistors and number of them per unit area might permit Moore's Law to extend beyond its limits for silicon CMOS technology. Of course, many issues must be addressed before this dream might become a reality. Nevertheless, the future for carbon-based electronics appears very bright indeed!

One of the most recent announcements was from Toshiba Matsushita Display (TMD) who has announced a 21 prototype organic EL (electroluminescence) display. This is the largest panel that uses polymer organic EL materials and poly-silicon (p-Si) TFT. TMD developed the prototype to examine feasibility of manufacturing process for large panels using polymer organic EL materials. Inkjet deposition methods are used for the organic materials.