PRINTING ELECTRONICS REPORT

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NEWS

Printed Electronics Update - What are the future applications for organic electronics, which processes and materials are needed, what are the major hurdles? The second version of the OE-A Roadmap for Organic Electronics will try to answer these questions. The Organic Electronics Association (OE-A) presented live demonstrations of flexible organic electronic systems and provided giveaways with a set of printed electronics samples and interactive electronic paper cards at the Organic Electronics Conference & Exhibition (OEC-07) in Frankfurt, Germany last week (shown later). Organic electronics were touted as thin, lightweight, and flexible and produced at low cost, now ready for commercialization. The OE-A claims to be the key industry association for organic and printed electronics. A set of organic electronics devices was distributed as an inlay in the OE-A brochure, including printed batteries, displays, radio-frequency-tags, sensors, switches, transistors (see below). The flexible demonstrators combined multiple organic electronic devices. Acreo, Agfa, BASF, COPACO, Fraunhofer IAP, H.C. Starck, HDM-Stuttgart, MAN Roland, Mitsubishi Polyester, Plastic Electronic, PolyIC, Thin Film Electronics and VARTA Microbattery all worked together on these projects. Interactive electronic paper cards by Printed Systems were also included in the brochure. They enable easy access to a number of websites, cross-linking the paper and the digital world. OE-A members updated and expanded the roadmap for organic electronics. This second version gives an overview of future product generations, material and technology requirements, and identifies "red brick walls" – principle challenges on the way towards mass production. The roadmap and technical projects are key activities of the OE-A. Meetings in Europe, North America and Asia are planned for a global network for organic electronics, according to the chairman of the OE-A. The Organic Electronics Association (OE-A) is a working group within the German Engineering Federation (VDMA) founded in December 2004. More than 80 companies from Europe, the US and Asia work together to promote the establishment of a competitive production infrastructure for organic electronics. Source: www.oe-a.org.

Organic Electronics Association Roadmap Summary - The new roadmap covers printed electronics through 2015 and beyond. Seven applications ranging from sensors over radio frequency tags to photovoltaics are covered in this publication. Additionally, manufacturing technologies and materials along with their corresponding technical barriers are also identified and assessed. Organic electronics is a platform technology that enables multiple applications that vary widely in terms of product specifications. Since the technology is still in its early stage, and is in the transition from lab-scale and prototype activities to production and commercialization, it is important to develop a common opinion about what kind of products, processes and materials will be available and when. The OE-A roadmap is a key activity of the Organic Electronics Association. This second edition of the roadmap the OE-A helps the industry, government agencies and scientists plan and align their R&D activities and product plans. We will frequently update and expand the roadmap with the international experts along the value chain. Organic electronics is based on the combination of new materials, organic and inorganic, and cost-effective, large area production processes that open up new fields of application. They are thin, lightweight, flexible and environmentally friendly. Organic electronics also enable a wide range of electrical components that can be produced and directly integrated in low cost reel-to-reel processes. Intelligent packaging, low cost RFID transponders, rollable displays, flexible solar cells, disposable diagnostic devices or games, and printed batteries are just a few examples of promising fields of application for organic and printed electronics. A number of key applications have been chosen to demonstrate the needs from the application side, identify major challenges, crosschecked with the possibilities of the technology and to forecast a time frame for the market entry in large volumes. Key results are summarized in Figure 1 that illustrates the expected market entry in large volumes for seven application fields. First organic electronics products have already reached the market, including passive ID cards, flexible lithium polymer batteries and sensor devices. Additional products, such as displays with organic TFT backplanes, printed radio frequency tags, organic photovoltaic cells and printed memories, are likely to reach the market later this year or early in 2008. Within the next several years, it is expected that mass markets will be reached and that all the above-mentioned applications will be available in large volumes. There are many approaches on the material and process side. The resulting questions, organic or inorganic, printed or not, are still under discussion. But further improvement of material, patterning processes and device design are necessary in order to meet the demands of future product generations. In Figure 2, a forecast for the charge mobility of semiconductor materials for devices that are manufactured in high throughput processes is given. New material classes and optimized materials are necessary. Source: OEA.

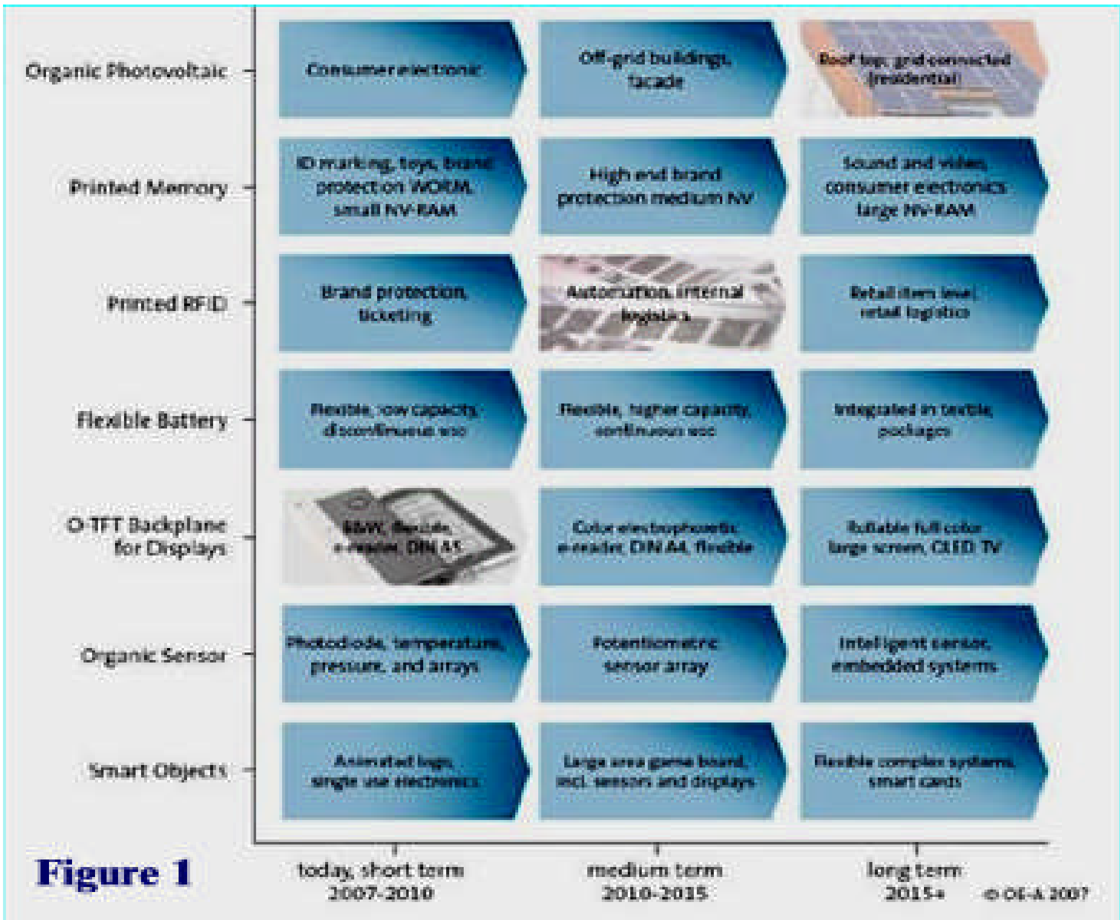


Figure 1

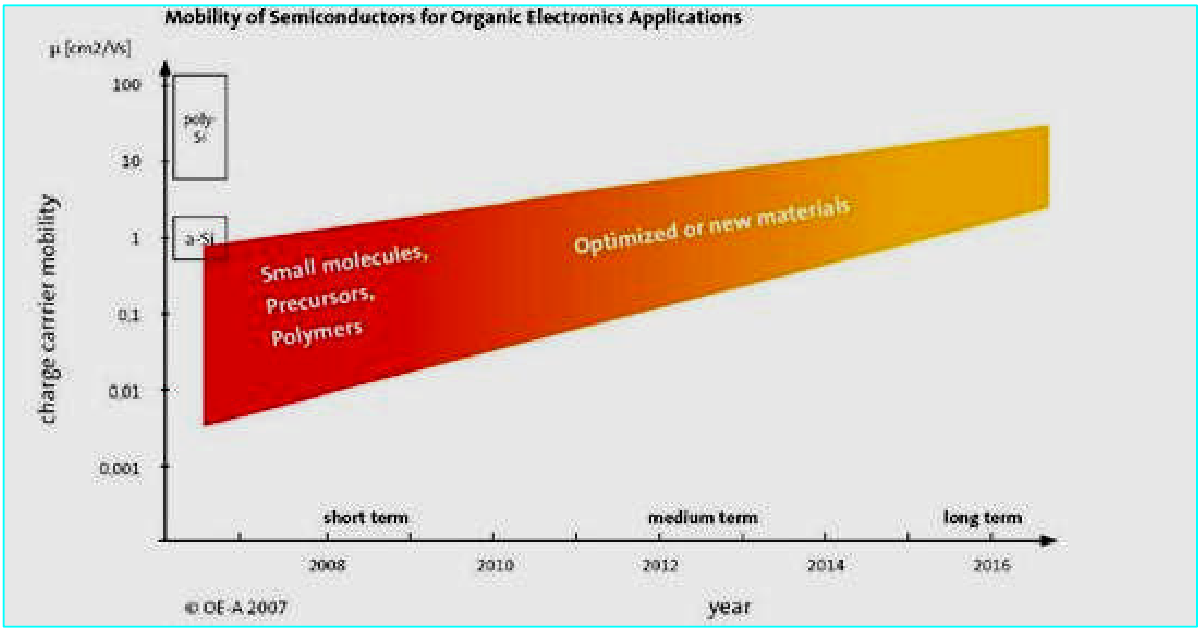


Figure 2

Kovio Secures $19.5M for Printed Electronics - Privately-held semiconductor startup Kovio Inc. announced that it has raised $19.5 million in the first closing of its Series D funding round. Kovio (Sunnyvale, CA) said it would use the funding to design, develop and commercialize printed electronic products using its proprietary printed silicon electronics technology. Led by Pinnacle Ventures, the round also includes investments from Bessemer Venture Partners, Duff Ackerman & Goodrich Ventures, DEA Capital, Flagship Ventures, Harris & Harris Group, Jerusalem Venture Partners, Kleiner Perkins Caufield & Byers, NCD Investors and Yasuda Enterprise Development. The chairman of Kovio said the funding validates their vision for the printed electronics industry. The new funds we will used to introduce a new semiconductor manufacturing technology that conventional silicon cannot match. Kovio has not disclosed further details about its technology. Source: Electronic News

kovio

Plextronics Investment - Solvay announced today that it has decided to participate, as lead investor, in the recent capital increase of Plextronics, Inc., an innovator of technology for the printed electronics market. Based in Pittsburgh, Pennsylvania, Plextronics specializes in the development and commercialization of polymer-based technologies for printed electronics such as displays, solar cells and RFID Smart tags. The $10-million investment grants Solvay a minority interest in Plextronics. It complements the recent R&D agreement between the Group’s 100% subsidiary Solvay Solexis and Thin Film Electronics ASA of Oslo, Norway, to develop polymeric inks for the manufacturing of printed electronic circuits, as well as Solvay’s research collaboration with the Georgia Institute of Technology's Center for Organic Photonics and Electronics. Plextronics has won a number of prestigious awards since it was founded in 2002, and is considered one of North America’s most impressive emerging companies among high technology innovators. Their expertise, which capitalizes on extensive research efforts at Carnegie Mellon University, and their market-driven activities are a perfect match for one of Solvay’s most promising innovation platforms. Solvay has a vision of building long-term platforms in solar

PLEXTRONICS

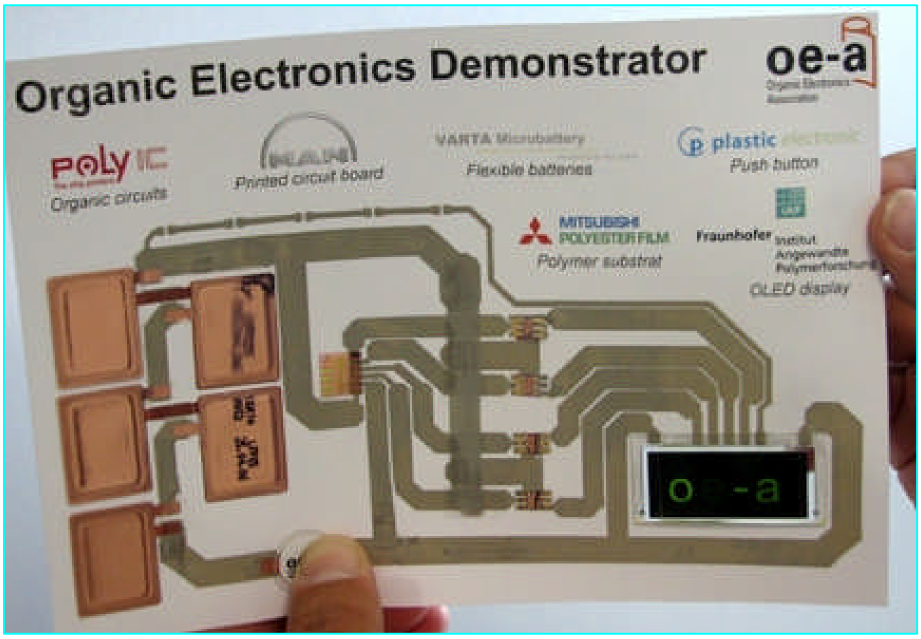
technology and printed electronics as demonstrated in its recent commitments to Georgia Tech and its joint development agreement with Thin Film Electronics ASA. Plextronics' technology has the potential to significantly reduce the cost of solar cells, compared with the cost of crystalline silicon-based solar energy systems, down to a commercially viable threshold of $1 / watt. Likewise, printed Organic Light Emitting Diodes (OLED) displays are intended to challenge today's Plasma technology and Liquid Crystal Displays (LCD) with considerably lower production costs and immense possibilities in terms of shapes and size. In the same way, printed OLED could be used for new energy efficient diffuse lighting. Other potential applications of Plextronics' products include 'smart labels' such as RFID tags, whose development is currently hampered by the excessive cost of current technologies. Source: http://www.solvaypress.com/

<u>TECHNOLOGY</u>

Printed Electronics Overview - by Ken Gilleo

Definitions should always come first and we need clarification for PE. There seems to a commingling of the old and new. Polymer Thick Film (PTF) is many decades old and not much has change.

Membrane switches (see figure, left) and simple circuits are still made by printing conductive ink and dielectrics. Conductive plastics and organic semiconductors have also been around for some time and the technology continues to improve. Earlier materials were difficult to handle and were typically unstable in air. PE attempts to use improved organic semiconductors to build complete electronic systems, albeit, simple and low-density products, like RFID tags. While PTF inks are the obvious choice for creating the printed circuit portion of the assembly, PE advancements must focus on the semiconductor materials and processes that will produce active devices. While materials and methods for printing circuitry (additive process) are well established, this is not true for active devices. Some writers have assumed that printed semiconductors will catch up with conductors, but this is unlikely since the degree of difficulty between depositing a conductor and crafting a transistors are orders of magnitude apart. Furthermore, conductive inks are not all that different from etch metal traces; both start with conductive metal. But the difference between traditional inorganic and newer organic transistors is extreme. The technology for printing conductors is mature while that for printed transistors is embryonic.



← OE-A demo from recent conference.

One of the most appealing aspects of organic semiconductors is their potential for deposition in the

form of inks to allow the printing of electronic assemblies. A traditional inorganic semiconductor fabrication starts with extremely pure silicon wafers and then utilizes a myriad of processes, mostly in a vacuum, including deposition various additives, activation of surfaces to promote reactions, deposition of metal and insulator, and various etching methods; photolithography is used extensively. Organic semiconductors, at least in the ideal form, are made by printing inks that are then dried, polymerized, or otherwise “finished”. Organic polymers thus involve direct write deposition of any device, resulting in a paradigm shift in semiconductor device manufacturing. A number of printing technologies are available for printed electronic manufacturing, including gravure printing, flexography, screen printing, offset printing and ink-jet printing. However, screen printing and ink jetting are the most utilized and referenced. All printing technologies offer one clear advantage over traditional semiconductor manufacturing methods, extreme throughput. While many writers seem to focus on moving the printing methods from screen printing and jetting to common graphic press methods, like gravure, letter press and flexo, I don’t think that this is important. Both screen printing and fluid jetting, while slower than some of the more mainstream methods, offer much more versatility and control. All printing methods have orders of magnitude more throughput than modern semiconductor fabrication and equipment is a tiny fraction of the cost. So there is little value in moving from screen printing to gravure to gain more throughput, that will not likely be needed, at the expense of moving from etched gravure cylinders to photoimaged screens that can be made at low cost in less than 1-hour.

However, most printing presses have limited resolution. Screen printing is also unique in the ability to deposit thick layer and to control thickness. But all of these classical printing methods have the limitation of relatively low resolution. Traditional semiconductor manufacturing can achieve a device density level of about four orders of magnitude higher printing. That said, screen printing and fluid jetting almost certainly could be developed to achieve finer resolution. Perhaps the right mix is to screen print the circuit and ink jet some, or all of the semiconductors.

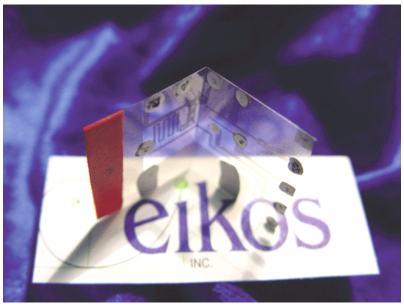
PE - Why Bother? - PE offers the clear advantage of very high throughput, but with limited resolution. Additionally, PE would provide much faster time to market, good economics at both high and low volume, and low capital investment. The direct write feature of jetting would be extremely valuable for R&D and prototyping. A complete PR factory might cost $10 to $15-million where as a semiconductor fab can exceed $3-billion. PE also eliminates packaging and component assembly; one more solderless idea. While the perfect PE transistor hasn’t yet been built, it’s likely that the technology will offer more than diodes and transistors. Batteries and sensors have already been made on a small scale and we can expect just about every type of component to be printed, including lighting and displays.

Timing - The roadmap for commercialization of printed electronics is still unclear. Some believe that the market will be worth tens billions of dollars by 2015, or even hundreds of billions by 2025. However, the sequence of products that will establish PE in the marketplace has yet to be more fully laid out. Many suggest that printed electronics will create and pursue new markets, rather than compete directly with silicon technology in its present application areas. The technologies for PE manufacturing do not offer the resolution required to fabricate computer CPUs and large-capacity memory chips. This is not to say that such obstacles could not be overcome using novel techniques (e.g., nanoimprint lithography). However, funding will more likely to be directed towards products for novel and uncontested markets rather than replicating silicon-like specifications.

Applications - Printed electronics will focus on addressing three major needs: 1) small, low-cost and disposable electronics (e.g.; RFID tags, smart packaging, disposable sensors); 2) large, rugged and inexpensive electronics (large signage displays, integrated photovoltaic panels, smart shelving, EMI/RF shields); 2) flexible optoelectronics (foldable e-papers, e-books, rollable displays). Some market analysts predict that we will have to wait until 2010 to observe a significant market penetration in any of these areas. By 2008 we can expect to see some interesting new products in the form of simple toys, keypads, greeting cards, the first printed displays for mobile phones, printed electronic backplanes for LCDs and printed OLED displays. However, big-volume sales of printed electronics are likely to come from the less glamorous retail and supply management sector. By 2008, smart packaging for food and medicines, low cost RFIDs for tracking and inventory, smart shelving with integrated display and wireless capability will be driving the demand for printed electronics. It will take at least until 2010 to see the rollout of printed organic batteries, super-capacitors, ultra-low cost RFID, photovoltaic panels, flexible and active displays, as well as some logic components. Products such as e-papers made of printed organic electronics have the potential for significant disruption in the market place. However, as their success will largely depend on the availability of complementors (e-content and e-content providers) and customer adoption, it is much harder to estimate accurate market forecasts. One requirement that technology has still to meet is the 44,000 hours (~5 years) lifetime required for OLED in automotive, military, signage and other applications. The 10,000 hours achievable in the short term should be sufficient for e-paper and other less-demanding applications. Some information is from: Future Fab Intl., "Plastic Revolution: The Rise of Printed Organic Electronics" (no date).

MATERIALS

Printed CNT Ink - Eikos Inc. (Franklin, MA) is demonstrating scalable production technologies for its transparent conductive films of CNT networks infused with binder that it said meet industry standards for electrical and optical performance and environmental stability. The company said that the printed CNT **films [more Printed Electronics?]** may be better suited to flexible applications rather than the more brittle indium tin oxide (ITO), and could likely used as a lower-cost alternative within the next year or two, particularly for applications such as touch screens and electronic paper that need patterning. Eikos purifies CNTs, disperses them in a variety of solvents, prints them with a variety of conventional printing technologies on a range of substrates, and then infuses them with a polymer binder. The material has a sheet resistance of 100 Ω/sq with ~90% light transmission for films 550 nm thick, roughly similar to ITO for less demanding applications. CNT films are beginning to be equal or lower cost for some transparent conductive applications, especially where value-added patterning is needed, according to Eikos. Although the single-walled carbon nanotubes (SWNTs) themselves are still expensive, only very small amounts are needed — the film can be as thin as 30-nm for 500 Ω/sq and the films can be applied and



patterned with low-cost printing processes. If the fragmented market for SWNTs consolidates as expected, and some big suppliers start producing in larger volumes, prices are likely to come down sharply over the next several years. When single-wall tubes get down to the current cost of multi-wall tubes, CNT conductive films will be the lowest-cost alternative, even for antistatic coatings. CNTs seem to be able to solve some real world problems, according to Nano Markets (Glen Allen, VA), noting the better performance on flexible substrates than ITO and better durability outdoors than OLEDs for displays, signage and lighting. **[All this is fine, but it will be difficult to replace incumbent technologies, that work fairly well, with new materials that do mostly the same thing. Using CNTs as conductive filler would not be my first choice for applications since the "nano properties" are not really being exploited. CNT sensors, on the hand, will likely succeed and created new markets.]**

EQUIPMENT

Nano-Micro-Ink Jet - A new type of inkjet printer has been developed that can precisely print dots of various materials just 250-nm in diameter. The inkjet printer could make it possible to rapidly synthesize complex nanoscale structures out of various materials according to University of Illinois- Urbana/Champaign ***[I thought that the nanoscale cut-off was 100-nm].*** The new printers is said to use a broad range of materials for manufacturing novel devices, from plastic electronics and flexible displays to photovoltaic cells and new biomedical sensors. The researchers have demonstrated that the new inkjets can print very precise patterns of electrically conducting polymers and carbon nanotubes. They go on to say that conventional inkjets are limited to resolutions of about 25-microns. U of I uses a different approach from other ink jets, called electrohydrodynamic inkjet (or e-jet) printing. They pull the fluids rather than push them. This involves using electric fields to create the droplets and relies upon there being a certain amount of electrically charged particles, or ions, within the fluid. Capillary forces pull the fluid from its reservoir to form a semispherical droplet hanging from its rim, like a drop of water on a faucet. By using electrodes to create an electric field between the nozzle tip and the substrate upon which one wants to print the material, it is possible to make the droplet conical. Ions accumulate at the surface of the fluid, at the apex of the cone. This concentration of ions allows the tip of the cone to break away and form a droplet that's just a fraction of the volume of the cone. You can generate droplets that are smaller than the nozzle diameter. Source: MIT Journal.