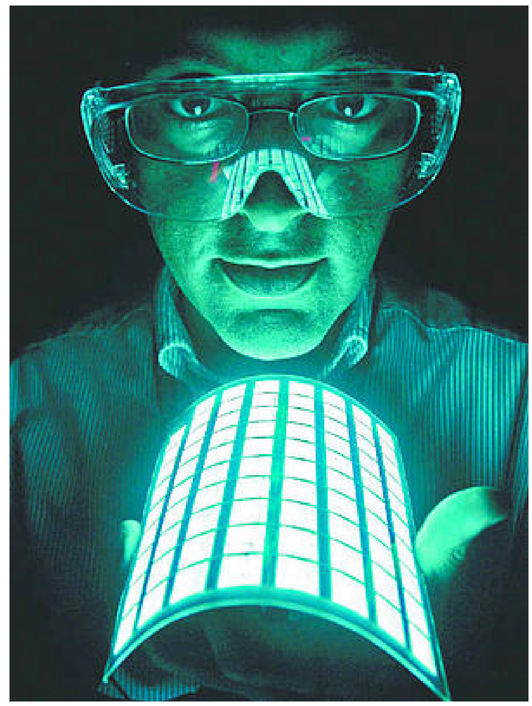
The promise of organic electronics – previously-unimaginable innovative products

The productronica trade show (Nov 10-13, 2009, Munich) will provide additional information about the worldwide organic electronics market

Introduction

From "electronic newspapers and magazines" to smart windows, flexible film solar cell sheets to luminescent wallpaper, organic electronics has the potential to change the way we use computers and other electronic devices. Organic electronics may be printed on a flexible substrate at room temperature, rather than diffused into a pure silicon die at around 1000ºC which is typical of most of today's semiconductors.



Anil Duggal, who heads up GE Global Research's Organic Electronics Project, says sheets of organic light-emitting diodes, such as the one above, might be the future of lighting.

Organic Electronics (OE), plastic electronics or polymer electronics technology uses conductive polymers, plastics, or small molecules. It is called "organic" because the polymers and small molecules are carbon-based, much like living organisms. Traditional electronics rely on inorganic conductors such as copper and doped silicon.

Most electrically conductive polymers are derivatives of Polyacetylene black (PA), sometimes called "the simplest melanin". Examples include PA (more specifically iodine-doped trans-polyacetylene); polyaniline: PANI, when doped with a protonic acid; and poly(dioctyl-bithiophene): PDOT.

Conductive polymers are also expected to play an important role in the emerging science of molecular computers.

Identified organic applications and expected market values [1]

The ability to apply low temperature, low cost transistors and LEDs to flexible substrates using a process that could be as simple as painting can enable new products that, until now, were unfeasible.

While the OE industry is still developing, there are promising signs that some of these new, innovative products will soon be available. Here are some examples.

RFID tags

Inexpensive printed Radio Frequency IDentification (RFID) tags will replace barcodes in some applications, giving packaging and low cost products a great deal of self-information. RFID tags can revolutionize retail management with improved inventory tracking and enhanced brand management. This market is expected to generate US $12.4B by 2015.

Industry insiders say that RFID is the front running technology for automatic identification and data collection

e-paper

e-paper technology will replace ordinary paper as an information medium in applications where updateability is crucial. For example, by 2015 a significant number of paper pricing labels will be replaced by e-paper Point-Of-Purchase (POP) displays. e-paper is also expected to significantly impact smartcards (especially for one-time security pass codes) and smart packaging. This market could reach US $1.6B for POP e-paper displays by 2015.

Organic transistors and memory

Organic transistors and memories will create new classes of products ranging from multifunction smartcards to pharmaceutical packaging and could also create new opportunities for the game, toy and greeting cards businesses. Printed electronic technology can enable games, toys and other novelties to interface directly with the Internet, expanding the boundaries of the gaming business. By 2015, the value of "games, gadgets and gizmos" using printed or organic electronics will be US $1.2B.

Disposable electronics

Materials suppliers will supply more than US $17.5B in materials into the disposable electronics sector in 2015. A large market is expected to emerge for inexpensive conductive inks for disposable applications that are far less demanding than larger displays, solar panels, etc.

Paper substrates

There has been a lot of specialized work at both universities and in commercial firms to create electronics on coated papers or even corrugated cardboard. This work will lead to a market for paper and board substrates for disposable electronics that are expected to reach sales of US $1.8B by 2015.

OLEDs

OLED displays are used in applications ranging from low-end MP3 players to cell phones to laptops. Wireless device manufacturers are attracted by OLED technology's low power consumption and video qualities. As a result, the OLED display market will grow to US $7.1B by 2016, from US $0.6B in 2008, with a CAGR of 36%.[2]

OLED unit costs will likely remain higher than older general lighting technologies, but the higher costs will be offset by improved OLED lifetimes and efficiencies. During 2008, OLED lifetimes improved from 24 kHrs to 100 kHrs. Meanwhile, the U.S. Department of Energy now expects OLED lighting to reach 150 lm/W efficiency in 2012 rather than 2014 as previously forecast.

Market Dynamics

The market for small Organic LED (OLED) displays is already hundreds of millions of dollars. Larger OLED displays will soon begin to appear in television sets. Companies are investing heavily in organic RFIDs, backplanes based on Organic Thin-Film Transistors (OTFTs) and organic solar cells. Organic electronics-based sensors, memory and lighting are not far behind.

Sony unveiled what it is calling the world's first flexible, full-color OLED display built on organic thin-film transistor (TFT) technology

As a result of these innovations, conductive polymers, organic photovoltaic materials and other organic materials could develop from a market measured in pounds to one measured in tons. Organic material research is yielding previously-unheard of products such as small molecule inks, hybrid organic/inorganic materials, and electrical-biological materials.

However, there are also challenges. Organic material conductivity is typically orders of magnitude lower than its inorganic silicon counterpart. In order to remain competitive, OE must make significant performance improvements.

One project that could advance OE performance is "Printed Organic Switches and Chips" project (Polytos) sponsored by the German Federal Ministry of Education and Research (BMBF). Polytos will develop new materials, concepts, components, manufacturing processes and software for printed organic circuits with integrated sensors for applications in the packaging industry. Polytos consortium partners are BASF SE (Ludwigshafen), Pepperl+Fuchs GmbH (Mannheim), PolyIC GmbH & Co. KG (Fuerth), Robert Bosch GmbH (Stuttgart), SAP AG (Walldorf) as well as the University of Heidelberg, the Technical University of Darmstadt and the University of Mannheim. Copaco GmbH & Co. KG (Mainz), Innovation Lab GmbH (Heidelberg) and Varta Microbattery GmbH (Ellwangen) are associate partners.

The Polytos project also plans to develop printed organic circuits with integrated sensors capable of recording data such as temperature, humidity or light exposure. Interfaces are used to read this information. These types of printed organic circuits could be used as printed smart labels that together with their antenna can transmit information.

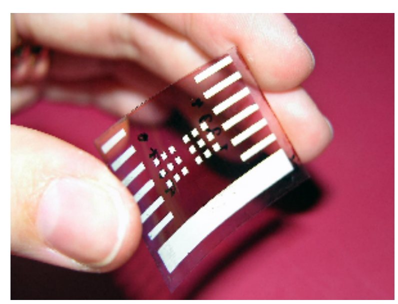
Another joint OE project will develop better ways to make OE displays and circuits. OLED specialist Novaled AG (Dresden, Germany) has teamed with Holst Centre in Eindhoven, Netherlands to develop and exploit Organic Thin Film Transistors (OTFT) using the Novaled PIN OLED technology and materials.[3] Their initial focus is to investigate the feasibility and benefits of Novaled's dopants in organic thin film transistors qualified for displays and circuits.

Novaled says its doping technology contributes to high power efficiencies and long lifetimes in OLEDs by improving charge carrier injection and transport in the organic layers, and that its researchers have shown that these effects are also relevant for organic TFT as the carrier injection from drain and source into the organic material has a major influence on the device performance.

OTFTs use organic materials to conduct charges between source and drain electrodes which are controlled by a gate electrode. OTFT production costs for large areas are expected to be low enough to address numerous applications such as flexible displays, intelligent food packaging and paper identification (ID) documents.

Room temperature TFT fabrication

A new class of OTFT can be fabricated on polymer substrates at room temperature, resulting in a unique operation at very low voltage. This technology enables production of large-area, light-weight, low-cost flexible electronics with high impact resistance.



A Korean research team demonstrated a sub-3V OTFT fabricated at room temperature on a flexible substrate.

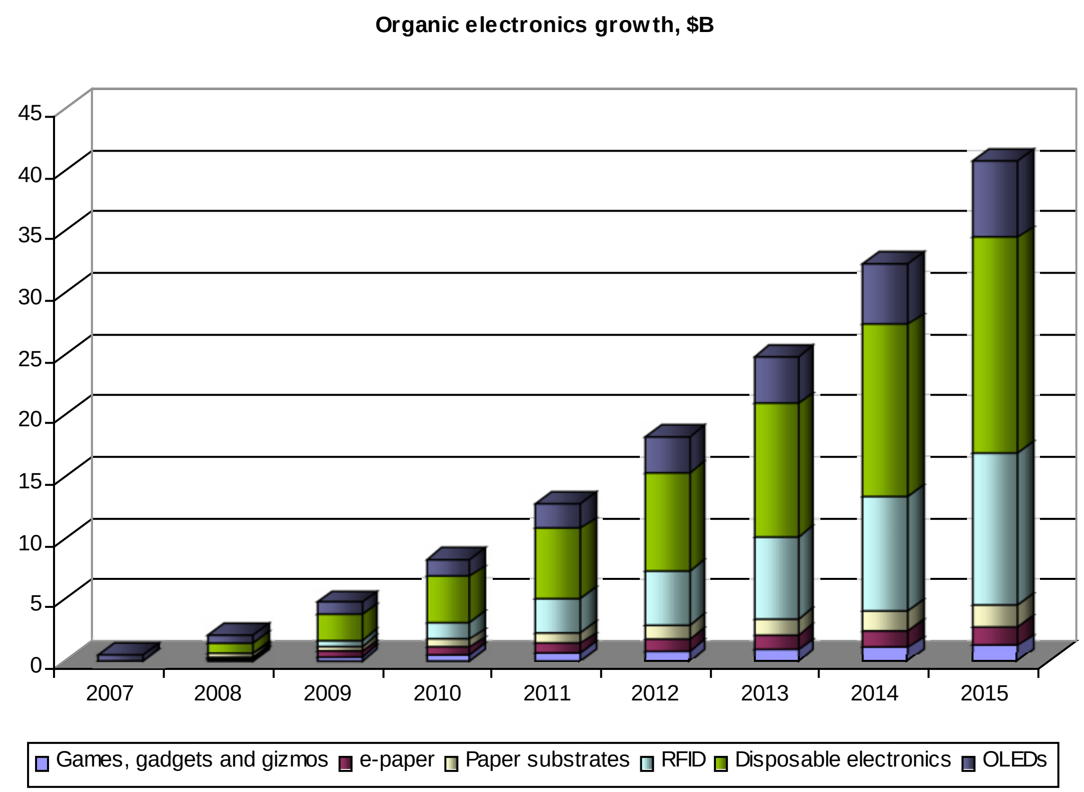
A Korean scientific team [4] developed the flexible transistor board which will operate at under 3V at room temperature using a BZN(Bi, Zn, Nb)-Oxide based gate insulator (ZnO-TFT) . The flexible transistor is capable of operating at even less than 3V operating voltage, compared to existing transistors which operate at 10V+.

This technology could have a huge impact on the display industry by reducing fabrication cost.

Market size [5]

The market for OLEDs, organic thin-film transistors and other organic electronics will grow from US $1.4B in 2007 to US $19.7B in 2012, a Compound Annual Growth Rate (CAGR) of 70%.

- By 2015, 80% of organic electronics materials will be sold into three applications: RFID, display backplanes and OLED lighting and displays. RFID will be the largest application accounting for US $6.9B, with OLEDs accounting for US $5.6B. RFID will likely overtake OLEDs as the largest consumer of organic electronics materials by 2012.
- Organic material improvements in electron mobilities, switching speeds and environmental stability will expand the market to US $4.9B by 2015.
- The substrate business will grow to US $6.9B by 2015 with the majority of these substrates being flexible and specially prepared for organic electronics through novel forms of barrier coatings and reduced surface roughness.



Organic electronics market actual and forecast growth rate by segment. The OE technology yields inexpensive transistors which can be deposited on a flexible substrate, enabling a broad range of new, low cost products.

Organic cell technology: improvements needed

Today's organic semiconductor materials are inadequate for future applications because of their limited performance and availability.

- The anticipated use of printing to fabricate circuits is considered the primary way to make cheap products. However, organic materials based on small molecules do not lend themselves to solution processing of any kind. More than 90% of the OLED market is fabricated using vapor deposition of small molecules. There is a need for new inks that can be used in the process of printing organic electronics.

- Organic device performance is inferior to silicon-based device performance. While organic devices can now compete with thin-film amorphous silicon devices, there are now higher performance thin-film silicon solutions. The latest silicon innovation - printed silicon - promises all the cost advantages of printing-based fabrication with orders-of-magnitude better performance than today's organic electronic materials. Consequently, organic materials need improvements in mobilities, switching speeds and other characteristics in order to compete with silicon.

- Today’s organic materials can be damaged by water vapor and extreme temperatures and require expensive encapsulation or barrier treatments. The industry needs low cost protective materials.

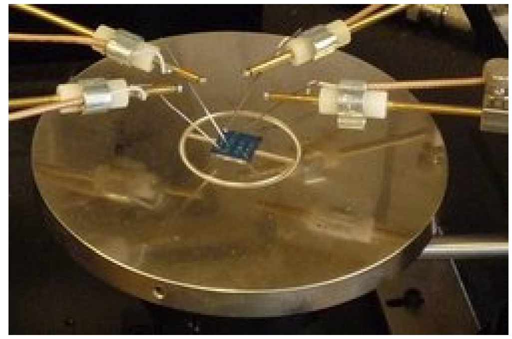
- The industry needs an organic version of venerable CMOS with its own stable materials sets, including commercially-available n-type semiconductors and organic dielectrics. [6]

There is hope on the horizon. New kinds of organic semiconductor materials such as rubrene and hybrid materials including formulations with carbon nanotubes will deliver the needed improvements in electron mobilities, switching speeds and environmental stability. Whether or not they will be able to compete with silicon-based devices remains to be seen.

Despite making remarkable technical progress over the last five years, lack of funding could stall some OE company’s efforts to transition from research to production. To date, the majority of external funding in the organic electronics market in Europe and the US has come from government sources rather than private equity. This balance needs to shift in order to meet investment for production capacity during the next three years. [7]

Technology: bi-lateral charge transport

Until now, organic material circuits have allowed only one type of charge to move through them. Researchers at the University of Washington have recently developed an organic material that allows charge to flow in both directions.



Organic circuit developed at the University of Washington will conduct positive and negative charges.

Technically, predecessor materials would only move positive charge or "holes" where electrons are missing. By carefully layering two complicated patterns on top of one another, one that transports electrons and another one that transports holes, the new material will conduct either positive or negative charge. Consequently, a single new substrate material can host a transistor, as demonstrated by the UW research team.

This is expected to lead to more complex circuits as the new material's electrical qualities are exploited.

Technology: AM and PM OLEDs

OLEDs fall into two general categories: Active Matrix (AM) and Passive Matrix (PM).

PM OLEDs are formed by creating an array of OLED pixels connected by intersecting anode and cathode conductors arranged in rows and columns. Electrical power is passed through selected pixels by applying a voltage to the corresponding rows and columns from the drivers attached to each. An external controller circuit provides the necessary input power, video data signal, and multiplex switches.

AM OLEDs have an integrated electronic backplane as its substrate that use at least two thin-film transistors (TFTs) to control the on-current at each OLED cell or pixel. The transistor circuits retain the state (on/off) and level (intensity) information programmed by the display electronics. Therefore, the light output of every pixel is controlled continuously, rather than PM OLED displays which are pulsed with high currents just once per refresh cycle.

Compared to PM OLEDs, AM OLEDs fabricated on flexible plastic substrates have these advantages:

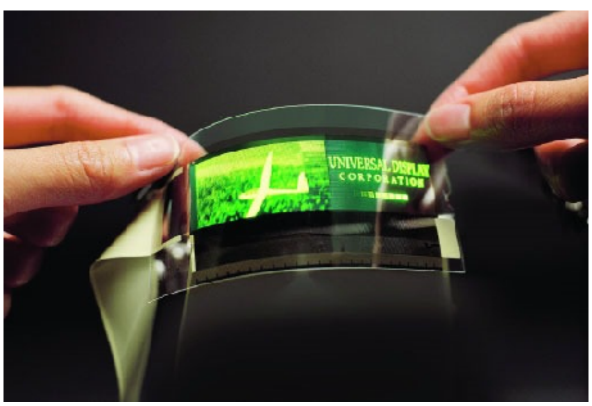
- Thinner and lighter weight
- Less susceptible to breakage, which allows the arrays to be rolled for transportation and storage and formed in unusual ways for use.
- Lower-power, highly rugged with superior image quality, and low cost compared to the current LCD displays

Active-matrix OLED displays provide the same video-rate performance as their passive-matrix OLED counterparts, but they consume significantly less power. This advantage makes active-matrix OLEDs well suited for portable electronics, where power consumption is critical to battery life.

OLED manufacturing processes are improving. GE and the Fraunhofer Institute have both demonstrated OLED array lighting roll-to-roll manufacturing which will ultimately lead to significant fabrication cost reductions. Low cost printing approaches and new small molecule inks will also help propel OLEDs into the backlighting market.

Technology: electroluminescence

Light emitting polymers are the raw materials used in Cambridge Display Technology color displays shown below.



Cutting-edge research at Cornell has yielded an organic semiconductor which exhibits electroluminescence and acts as a photovoltaic cell. [8] The device is the first to use an "ionic junction," which researchers say could lead to improved performance.

Since organic semiconductors can be made in thin, flexible sheets, they could create displays on cloth or paper. This could lead to window film that generated their own light at night.

Semiconductors - organic or otherwise - are materials that contain either an excess of free electrons (N-type) or "holes" (P-type). Holes are spaces where an atom ought to have an electron but doesn't, representing a positive charge. N- and P-type materials can be joined to form diodes and transistors. The Cornell researchers went a step further by making a diode out of organic semiconductors that also contain free ions (molecules with an electrical charge). They laminated together two organic layers, one that contained free positive ions and the other negative ions. They then added thin conducting films on the top and bottom; the top conductor is transparent to allow light in and out.

Where the two films meet, negative ions migrate across the junction to the positive side and vice versa, until an equilibrium is reached. This is analogous, the researchers said, to what happens in a silicon diode, where electrons and holes migrate across the junction.

When a voltage is applied across the top and bottom electrodes, a current flows through the junction. The ionic charge migration across the junction raises the energy of the molecules, which quickly release the energy as photons of light.

On the other hand, when a bright light is applied, photons are absorbed by the molecules, causing them to emit electrons. The ionic charges create a "preferential direction" for the electrons to move, creating DC current.

The collection of charges also allows electrons and holes to move across the junction easily in one direction but only weakly in the other, making the device a rectifier. It may be possible to change the configuration of the ionic charge by applying a voltage to the device, telling it whether to conduct or not, so organic diodes might be used as components for computer memory.

To learn more about organic electronics and the OE market

productronica 2009 (November 10-13, 2009, Munich) will feature an innovation forum entitled "Organic Electronics – Enabling Electronics Everywhere" organized by oe-a, the Organic Electronics Association (www.oe-a.org), part of VDMA, a network of about 3,000 engineering industry companies in Europe. See the productronica program (www.productronica.com) for more information.

About the author

Forrest Sass is Principal of Theorem (www.theoremservices.com), a public relations and marketing firm based in the San Francisco Bay Area.

About productronica

productronica is the leading world trade fair for innovative electronics production. It has taken place in Munich every two years since 1975 and is a core element of the electronics trade fair network of Munich International Trade Fair. This network includes the leading global trade fairs, electronica, and Productronica, held in Munich, as well as leading regional trade fairs in Brazil, Hong Kong, China, and India. With over 8,000 exhibitors and more than 280,000 visitors, the Munich International Trade Fair is one of the internationally leading trade fair organizer in this segment.

Appendix

Acronyms and terms used in this report

AM OLED	Active Matrix Organic Light Emitting Diode
BMBF	German Federal Ministry of Education and Research
CMOS	Complimentary Metal Oxide Semiconductor
DC	Direct Current
LED	Light Emitting Diode
OE	Organic Electronics
OLED	Organic Light Emitting Diode
OTFT	Organic Thin-Film Transistor
PA	Polyacetylene black
PANI	Polyaniline
PDOT	Poly (dioctyl-bithiophene)
PM OLED	Passive Matrix Organic Light Emitting Diode
Polytos	Printed Organic Switches and Chips project sponsored by the German Federal Ministry of Education and Research
POP	Point-Of-Purchase
RFID	Radio Frequency IDentification
TFT	Thin-Film Transistor
UW	University of Washington
VDMA	Verband Deutscher Maschinen- und Anlagenbau - German Engineering Federation
ZnO-TFT	Bi, Zn, Nb-Oxide Thin-Film Transistor

[1] NanoMarkets projection
[2] DisplaySearch forecast, July 2009
[3] August 22, 2008 EETimes Europe
[4] Center for Energy Materials Research of Korea Institute of Science & Technology (KIST) team led by Dr II-Doo Kim and Dr Jae-Min Hong, Nov 27, 2007 Nikkei Electronics Asia
[5] NanoMarkets estimates
[6] NanoMarkets estimates
[7] Craig Cruickshank, CEO, cintelliq, presentation at OEC-07, Organic Electronics Conference and Exhibition, Frankfurt, Germany, September 2007
[8] September 7, 2006, www.physorg.com/news76865681.html