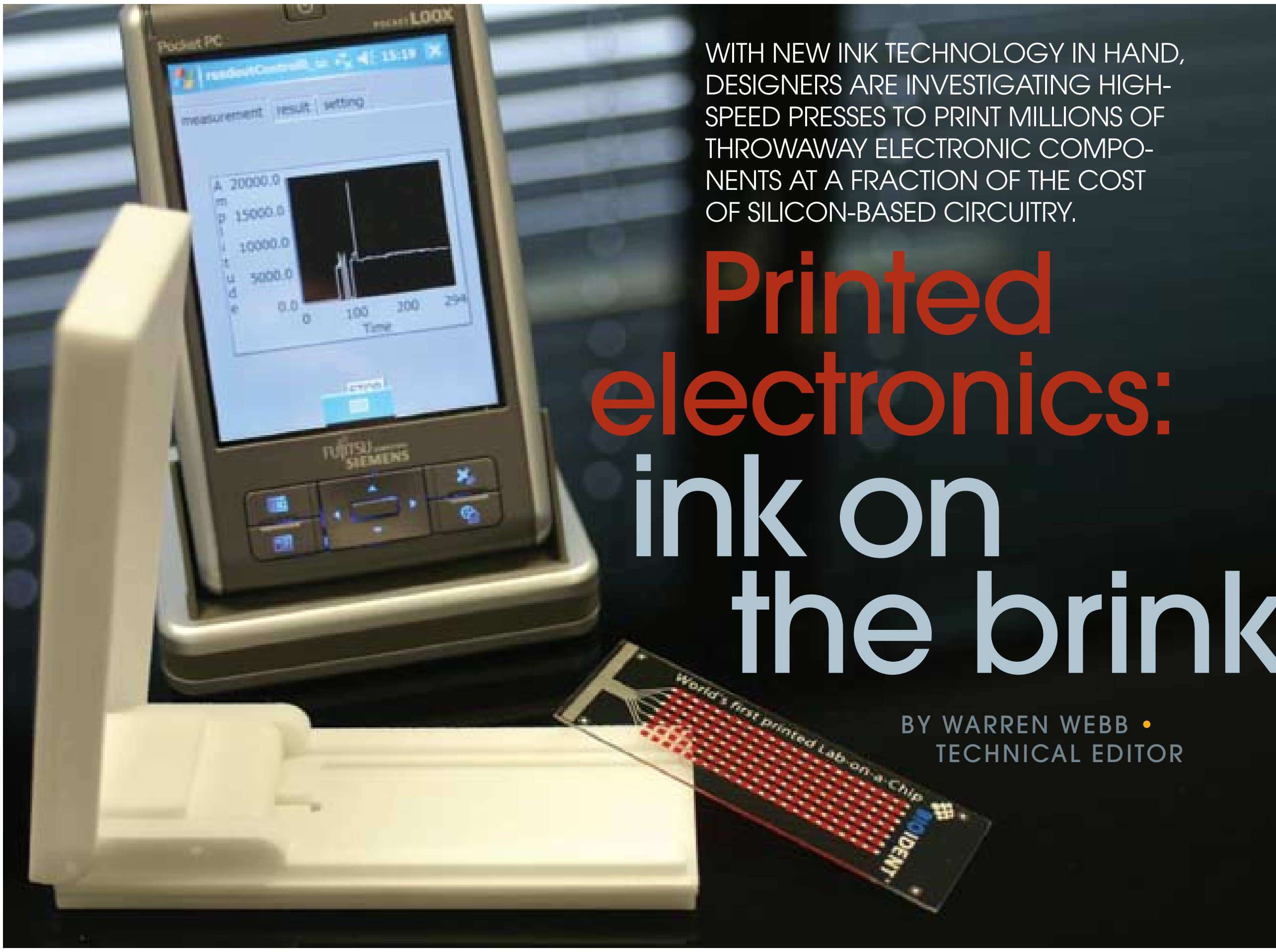
WITH NEW INK TECHNOLOGY IN HAND, DESIGNERS ARE INVESTIGATING HIGH-SPEED PRESSES TO PRINT MILLIONS OF THROWAWAY ELECTRONIC COMPONENTS AT A FRACTION OF THE COST OF SILICON-BASED CIRCUITRY.

Printed electronics: ink on the brink

BY WARREN WEBB • TECHNICAL EDITOR



Bioident Technologies' PhotonicLab Platform analyzes multiple samples in real time with a printed semiconductor photodetector under each well.

Printed electronics may be the next big thing in our technological future and promises extremely low-cost, flexible, and disposable circuitry that you can manufacture with custom ink-jet printers or high-speed presses. Leading-edge companies are using specialized ink technology to transform basic circuit elements, such as thin-film transistors, resistors, inductors, and capacitors into printed batteries, displays, sensors, RFID tags, interactive packaging, solar panels, and even speakers. Although the printed-electronics concept has been around for years, recent advances in conductive-ink chemistry and flexible substrates promise to deliver a flood of new markets and application areas.

Unlike traditional silicon-based circuitry, you manufacture printed electronics using an additive process that deposits multiple layers of conductive, semiconductive, and dielectric materials onto a flexible medium, such as plastic film, foil, or paper. Most current printing processes—such as ink jet, roll-to-roll offset, flexography, rotogravure, or screen printing—can place individual layers. With a relatively small investment in capital equipment for manufacturing and the ease of producing millions of copies on demand, printed electronics will target high-volume, simple-function consumer applications previously impractical for silicon-based circuitry. Research organizations predict huge growth in printed-electronics products. For example, IDTechEx (www.idtechex.com) forecasts that the market for printed and thin-film electronics will exceed $1 billion in 2007 and grow to $5 billion by 2011 and $48 billion in 2017.

Disposable-battery testers integrated into the product or packaging were one of the first widely used printed-electronics applications. These low-cost, interactive testers rely on conductive inks to form a resistive-heating element and temperature-responsive inks to provide the display. In an example, Duracell prints a wedge-shaped resistor directly below the thermochromic-display area (**Figure 1**). When the user presses the conductive traces onto the terminals, current flows through the resistor and heats the display strip depending on the current the battery

AT A GLANCE

- Innovative designers are using conductive-ink technology to create low-density printed circuitry for user-interface applications.
- With thin-film transistors, resistors, capacitors, displays, batteries, and speakers available, the number of applications for printed electronics is enormous.
- You can simultaneously and directly apply many printed electronics applications with conventional graphics onto product packaging.
- New ink technologies and high-speed roll-to-roll presses enable sophisticated printed circuitry at much lower cost than silicon-based components.

Figure 1 Interactive battery testers use conductive inks to form a resistive-heating element and temperature-responsive inks to indicate the charge (courtesy Duracell).

provides. A fully charged battery offers enough current to heat the entire wedge and provide the "good" indication. Duracell prints the tester electronics as part of the battery packaging at little additional cost.

Although printed electronics will not approach the sophistication or performance of silicon-based circuitry, plenty of applications exist in which adding a few electrical components to the manufacturing process can create new markets. Many potential applications for printed electronics are in intelligent and mass-produced items at the human-interface level. For example, flexible paper or polymer substrates allow designers to create interactive signage, clothing, labels, wallpaper, books, newspapers, and product packaging. You can directly embed these applications into the environment, and they fit into the vision of pervasive computing. In many cases, printed electronics requires no additional setup or assembly, unlike conventional electronics—in which the installation costs may exceed the price of the device.

PRINTED TOYS

With a portfolio of patented conductive-ink technology, T-Ink is a pioneer in printed-electronics applications. The company's approach is to target consumer goods, packaging, and promotions applications that do not require extensive design and testing cycles. T-Ink technology replaces switches, wires, buttons, speakers, lights, and batteries with printed-ink, touch-activated applications. Successful products include an interactive tablecloth for Hallmark (www.hallmark.com), place mats for McDonald's (www.mcdonalds.com), pillow radios, and interactive games. The company also offers a series of educational toys to teach children spelling and math through the act of coloring onto printed conductive inks that trigger an appropriate audio response.

Manufacturers also employ printed electronics in the creation of OLED (organic-light-emitting-diode) displays. These displays rely on organic compounds that a multilayer-printing process deposits in rows and columns onto a flat carrier. Unlike the traditional liquid-crystal type, OLED displays require no backlight, have a faster response, and consume less power. You can print organic materials onto many substrates, including flexible or even fabric materials, creating roll-up or wearable displays. A possible drawback of OLED displays is the reduced lifetime of certain colors of organic materials. At this year's Consumer Electronics Show (www.cesweb.

Figure 2 Electronic-paper displays employ an active-matrix backplane of printed transistors and conductors to produce portable electronic-reader products.

Figure 3 The Cypak intelligent-pharmaceutical-packaging system records medication use and is programmable to deliver patient reminders.

org), Sony demonstrated a prototype high-definition television with a 27-in. OLED display and a contrast ratio of greater than 1 million-to-one.

Electronic paper is another display variation that benefits from printed electronics. The migration of colored microparticles, which an active-matrix backplane of printed transistors and conductors charges, forms images on electronic paper. Also known as an electrophoretic display, electronic paper reflects light like ordinary paper and is bistable, thus indefinitely storing text and images without power. Plastic Logic recently opened a factory in Dresden, Germany, to make flexible displays based on the electrophoretic films from E Ink Corp. The facility will produce flexible active-matrix-display modules for "take-anywhere, read-anywhere" electronic-reader products (**Figure 2**).

It is not surprising that printed-electronics applications abound in the medical market in which almost half of all patients incorrectly take their medications. Manufacturers are producing smart packaging with printed sensors and, sometimes, printed batteries to improve drug delivery. Cypak produces a medical-delivery system for carded-blister packs known as IPP (intelligent pharmaceutical packaging). The system records the number of pills removed and each time you remove a pill from the blister pack for later read-back by placing the IPP on a Cypak reader (**Figure 3**). You can program the package to remind the patient that it is time to take more medication, and the application can ask the patient to answer simple questions regarding his physical or mental state by pressing an answer key printed on the paperboard.

LAB ON A CHIP

Bioident Technologies, a leader in optoelectronic-test equipment for life sciences, recently announced a multiwell

Figure 4 Essential in printed-electronics-prototype development, the Dimatix DMP-2800 printer deposits layers of fluidic materials using a disposable piezoelectric cartridge.

Figure 5 With layers of zinc and manganese dioxide to create the anode and cathode, Power Paper creates flexible and disposable printed batteries.

lab-on-a-chip prototype that it bases on printed semiconductors. The PhotonicLab Platform prototype includes a 1×3-in. nanotiter plate—a type of lab-on-chip device with multiple wells that can hold testing agents to perform laboratory functions. The nanotiter plate includes a photodetector array that Bioident bases on printed-semiconductor technology, with one pixel under each well. This array converts light into electrical signals, enabling simultaneous, real-time analysis on multiple agents. The system eliminates the need for high-precision translational stages, which are common among microplate and biochip readers. Placing the detector directly beneath the sample makes precision motion of the sample and detector unnecessary. Bioident's PhotonicLab Platform uses technology the company bases on organic semiconductors to print light-emitting and -detecting capabilities directly onto any surface, including glass, enabling on-chip analysis and diagnostics.

Audio speakers are one of the more unlikely applications for printed electronics, because they require mechanical movement. Yet, researchers involved in Mid Sweden University's (Sundsvall, Sweden, www.miun.se) Paper Four project have created an interactive paper billboard that emits recorded sound in response to a user's touch. They make printed speakers by printing electromagnets from conductive ink and stretching the paper over cavities in the poster board. Recent progress in rare-earth, metal-based magnetic materials allows the high-speed printing of low-cost permanent magnets. The printed electromagnets vibrate with induced current to create sound. When you produce the interactive billboards in sufficient quantities, they can be inexpensive and disposable. The researchers have produced a video showing the features of the printed paper billboard (**Reference 1**).

You can produce, or at least prototype, many printed-electronics products on relatively inexpensive desktop printers using specialized ink cartridges. The Dimatix DMP-2800 series printer from Fujifilm deposits layers of fluidic materials on any 8×11-in. substrate, using a disposable piezoelectric cartridge (**Figure 4**). The machine has a printing area of approximately 200×300 mm with an adjustable height and can print with resolutions as high as 5080 dpi. Unlike thermal ink jets, piezoelectric print heads are compatible with a variety of materials, including solvents, aqueous solutions, and ultraviolet curing fluids. Additionally, a system waveform editor allows the user to manipulate the electronic pulses to the print head to optimize the shape of the fluid drops that the nozzle ejects. The 16-nozzle drop-on-demand ink-jet cartridge is adjustable for a 1- to 10-pL nominal drop volume and is refillable. Prices for the DMP-2800 series printers start at less than $30,000. Each system includes the

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printer, a supply of print cartridges, and driver and application software.

PRINTING WIRES

Although all printed-electronics applications use a variety of conductive liquid to create component-to-component wiring, most inks have relatively high resistivity. These circuit paths work for many applications, but some designs call for extremely low resistance. In the past, designers have used liquids with suspended silver-metallic flakes to increase conductivity. But this approach requires pressure or heat to fuse the particles. To overcome this problem, NovaCentrix has developed a new line of inks and formulations for high-speed printing of electronic devices. The company's Metalon process uses nanoparticles of silver and copper to allow direct printing of electronic circuits on low-temperature substrates. Potential applications include RFID antennas, transistors, solar-cell contacts, display backplanes, and electrostatic discharge/electromagnetic-interference films. NovaCentrix has a novel technique for curing or sintering metal-nanoparticle-based films by exposing them to a brief, intense pulse of light from a xenon flash lamp. This photonic-curing technology rapidly and selectively heats and fuses nanoscale metallic-ink particles, forming highly conductive paths.

Nonvolatile memory is an essential element in the growth of the printable-electronics industry. Product applications employing flexible memory could include intelligent packaging, game cards, and medical devices to store information for later display to the customer. Another application is printed antifraud and anticounterfeit security tags that store product identification and security information in rewritable memory. Thin Film Electronics is working to develop low-cost volume-production processes for its nonvolatile-printed-polymer-memory technology. Thin-film memories include a printed bottom and top electrode with a ferroelectric, nonvolatile, rewritable polymer sandwiched between. The Thin Film system eliminates the need for transistors in memory cells, a substantial simplification over alternative memory designs.

The key to many printed-electronics applications is a reliable source of power integral to the product. The obvious example is a printed battery that sits idle until you activate the application. Power Paper has developed such a power source. It requires no metal case, and you can print it onto most flexible materials (**Figure 5**). The batteries, which have a shelf life of about three years, comprise proprietary printed layers of zinc and manganese dioxide to create the anode and the cathode. In addition to outside licensing, Power Paper uses its batteries to power microelectrical pharmaceutical and cosmetic patches to enhance the delivery of active ingredients to the skin. The patches target conditions such as skin damage, aging, wrinkles, hyperpigmentation, and photo damage.

Printed electronics has the potential to greatly expand the role of the circuit-design engineer. Designers may find themselves working in a traditionally nonelectronic industry to add new functions to product packaging or signage. With the lowest cost silicon still orders of magnitude more expensive than printing and a constant flow of new ink technologies, you can expect explosive growth in disposable electronic products. In addition, electronic applications are ideal for the multitude of printing presses that will sit idle when society completely switches to virtual books, newspapers, and magazines.**EDN**

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