Transparent transistors to bring future displays, 'e-paper'

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Researchers have used nanotechnology to create transparent transistors and circuits, a step that promises a broad range of applications, from e-paper and flexible color screens for consumer electronics to "smart cards" and "heads-up" displays in auto windshields.

The transistors are made of single "nanowires," or tiny cylindrical structures that were assembled on glass or thin films of flexible plastic.

"The nanowires themselves are transparent, the contacts we put on them are transparent and the glass or plastic substrate is transparent," said David Janes, a researcher at Purdue University's Birck Nanotechnology Center and a professor in the School of Electrical and Computer Engineering.

Other researchers had previously created nanowire transistors, but the metal electrodes in the transistors were non-transparent, which made the overall structure opaque, said Tobin J. Marks, the Vladimir N. Ipatieff Professor of Chemistry and a professor in the Department of Materials Science and Engineering at Northwestern University.

"Our study demonstrates that nanowire electronics can be fully transparent, as well as flexible, while maintaining high performance levels," Marks said. "This opens the door to entirely new technologies for high-performance transparent flexible displays."

Findings were detailed this month in a research paper in the journal

Nature Nanotechnology.

The advancement has three broad areas of potential applications:

-- Transparent displays for uses such as heads-up displays on windshields and information displays on eyeglasses and visors. The displays enable drivers to see information without looking down at the dashboard and could project information on visors for workers without obstructing their view. Potential applications also include sports goggles for spectators to follow a particular player while having relevant statistics displayed and real-time interactive information for soldiers and surgeons.

-- Flexible displays for future "e-paper," promising to allow full-motion video. E-paper is a technology designed to mimic regular ink on paper. Unlike conventional flat-panel displays, which use a backlight to illuminate pixels, e-paper reflects light like ordinary paper and is capable of holding text and images indefinitely without drawing electricity while allowing the image to be changed later. Potential uses of e-paper include low-cost, energy efficient ways of displaying information and video as a replacement for paper in magazines, newspapers, books, electronic signs and billboards.

-- Transparent and flexible electronics for radio frequency identification tags, electronic bar codes and smart credit cards, which resemble ordinary credit cards but contain an embedded microprocessor. This microprocessor replaces the usual magnetic strip on a credit or debit card, increasing the security of data stored on the card and enabling computers to "talk" to the microprocessor. Such a technology could be used to display balances on cards and could be used for the free flow of people through transportation systems, avoiding the need of ticketing machines or validation gates. The cards could contain encryption software, secure data for use in pay phones and banking, and to contain health-care data for patients and allow tamper-proof identification information for workers.

The nanowires were made of zinc oxide or indium oxide.

Unlike conventional computer chips - called CMOS, for complementary metal oxide semiconductor chips - the thin-film transistors could be produced less expensively under low temperatures, making them ideal to incorporate into plastic films, which melt under high-temperature processing.

Liquid crystal displays now used in applications such as color cell phone screens are made with thin-film electronics. This thin-film technology makes it possible to lay down electronic devices in large sheets containing individual pixels. Current thin-film electronics use technologies known as amorphous silicon and poly-silicon.

"These approaches work fine if you have a flat, rigid display that's going to be opaque," Janes said. "They require fairly high-temperature processing, so they are not good on plastic, although industry is working really hard to get them on plastic and make them lightweight, flexible and transparent."

An alternative, emerging technology uses so-called "organic" or "plastic" transistors to replace the conventional silicon that has been a mainstay of microelectronics for decades. While this technology enables transistors to be embedded in or printed on flexible plastic, it has lower performance, although major advances are being made, Marks said.

The new research represents the best of both worlds.

"You can get high performance because the nanowires themselves give you some unique performance advantages, and you could still think of dispersing them down over large areas for displays, smart credit cards and other applications," Janes said.

The nanowires are transparent because they are made of materials that do not absorb light in the visible range of the spectrum. In conventional electronics, transistors are connected to the rest of the circuitry by tiny lines of metal that act as wires. But in the new approach, the nanowires are the transistors.

"This is a different kind of wire," Janes said. "It is basically taking the place of the silicon in silicon electronics."

One reason for the higher performance realized in the new technology is that the devices have a better "on-off ratio" than previous thin-film technologies, Janes said.

Having a good on-off ratio helps conserve power, making the new thin-film transistors practical for portable battery-powered devices.

"In a transistor, you are trying to turn it off and on, like a switch," Janes said. "But unlike a wall switch in your house, a transistor never really turns completely off. There is always a little bit of leakage through it, sort of like crimping a garden hose."

The nanowire transistors help to reduce this leakage while also offering the possibility of precisely controlling the pixels in displays.

"We think of transistors as switches, but we don't just want them to be full on or full off," Janes said. "We'd like it to have gray scale, to be able to mix up many colors to get different subtle shades. And that's in part where this on-off ratio comes into play. We want to be able to turn it on, have the pixel light up really bright, but we also want to be able to controllably dim it down."

Television screens contain millions of pixels. Rows and columns of circuits crisscross in the large arrays, with each pixel located at the intersections. Control circuitry drives transistors and turns them on and off.

Researchers found that transistors using a single nanowire carry enough current to drive a single pixel.

"Ideally, we want to have circuitry where each pixel has a drive transistor and then some control transistors with it so that you can turn your pixels on and off," Janes said.

The new nanowire transistors could be used to create electronics based on another emerging technology called OLEDS, or organic light-emitting diodes. OLEDS are now used in cell phone and MP3 displays and the newest television sets, Marks said.

Unlike liquid crystal displays, the pixels in OLEDS directly emit light.

"In LCDs, the whole screen is backlit by a white light, and then each pixel is basically just a little filter that you can turn on and off," Janes said. "So the light you see is not directly being emitted by that pixel; it's being kind of screened by that pixel. In OLEDS, each pixel directly emits light, making the color richer and eliminating the need to backlight the display. Because OLEDS pixels are bright only when their part of the image is bright, they are more efficient, and they are ideal for use in transparent displays."

The technology also could be used to create new flexible antennas that unfurl like a sail and aim their signals more precisely than current antennas.

"What the military would really like is for the soldiers to be able to pull up to their destinations and unroll this large-area antenna array and be able to communicate with each other," Janes said "Most antennas don't work this way now. For example, you might notice that your cell phone sometimes gets a signal and sometimes doesn't. Part of the reason for this is that your antenna doesn't have any way to look just in one direction versus everywhere. You want this sort of omni-directional effect in commercial broadcast antennas for television or radio, but for certain military communications you'd like to go just from one soldier to another and transmit in a tight beam."

The new transparent technology has been shown to have "carrier mobilities" similar to those of conventional computer microprocessors, meaning electrons travel in the devices at nearly the same speed as current consumer electronics but in a low-cost, flexible package.

"The significantly higher mobilities than other thin-film transistor technologies offer the potential to operate at much higher speeds and to use much smaller transistors and other devices," Janes said.

Research has been funded by NASA through the Institute for Nanoelectronics and Computing, based at Purdue's Discovery Park, and at Northwestern University.

Nanotechnology is critical for the advancement because electricity flows differently on the scale of nanometers, or billionths of a meter, than it does in larger wires. The nanowires used in the research measure as small as 20 nanometers in diameter. A single nanometer is roughly the size of 20 hydrogen atoms strung together.

Future research is expected to include work to integrate the thin-film transistors into large circuits and to develop ways to interconnect numerous transistors.

Source: Purdue University

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