Move over, silicon

Semiconductors: Chip makers are looking for ways to make electronic devices out of cheap plastic instead of pricey silicon. Success could lead to a new market for flexible displays and memories that can be printed on anything—ushering in an age of disposable computing

TO MAKE computing power as seamlessly ubiquitous, and even, perhaps, disposable, as the consumer-electronics industry would like, something fundamental has to happen to the way chips are made. Despite a remarkable reduction in manufacturing costs over recent decades, silicon-based electronics remain too expensive—and will continue to be so for the foreseeable future—ever to be incorporated into items costing less than a couple of dollars. Costs aside, there are practical problems with today's chips. Being made of brittle silicon, they cannot easily be built into items as flexible as, say, clothing. This is where plastic (ie, organic polymer) chips might come in. These promise to be not only flexible but also cheap to make—and capable of working like silicon semiconductors.

Until recently, plastics were known more for being insulators than conductors or semiconductors. What changed this was the discovery in the late 1970s that, if the organic polymer was doped chemically, it could be made to act like a metal with dramatically greater electrical conductivity. That simple discovery kick-started research into a whole new technology, based on conducting and semiconducting plastics. The first fruits of this work are about to be harvested.

First to market will be light-emitting polymers (also known as polymer light-emitting diodes). Over the coming decade, LEPS are expected to become a multi-billion-dollar industry. Certain types of LEPS known as "small molecule organics" (which are not strictly polymers) are already appearing in car stereos and mobile telephones.

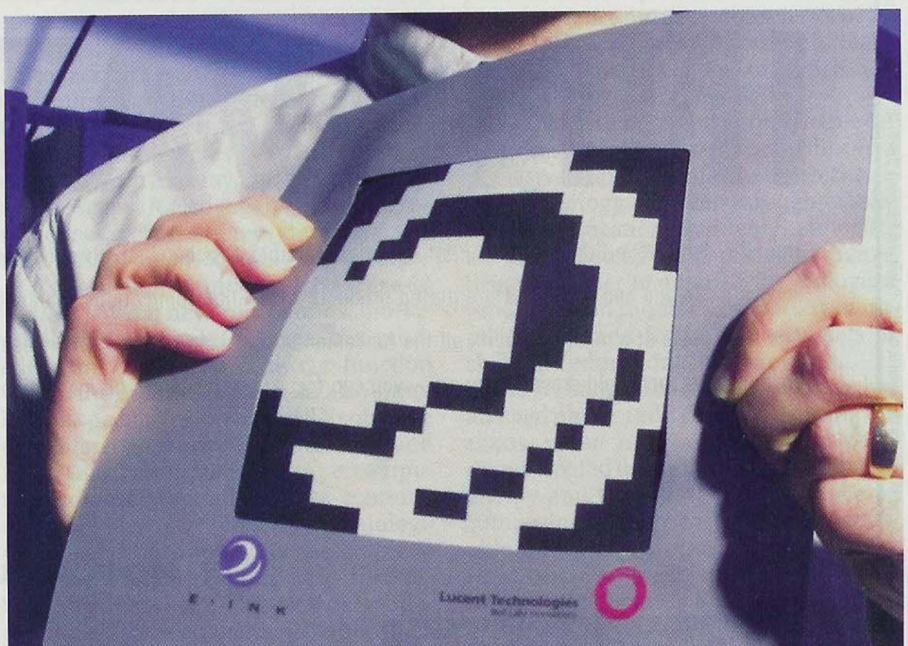
Unlike the liquid crystals used in many of today's flat-panel displays, LEPS are electro-luminescent—ie, their molecules can emit light on their own. The displays are made by applying a thin film of the polymer on to a glass or plastic substrate that has been coated with transparent electrodes. Light is emitted from the polymer when an electric field is applied across the electrodes. Not having to heat up a tungsten filament to create light, LEPS can light up in a fraction of a microsecond—making them, in effect, instant on-off bulbs. Also, because unlike liquid-crystal displays they do not need backlighting, LEPS can be used out-of-doors in daytime as well as at night. As a display, they are lighter and more energy-efficient than liquid crystals or other display technologies. More interesting still, LEPS can be dissolved in a solution and printed on a variety of surfaces, making it possible to turn an entire wall into a screen.

Initially, LEPS will compete in niche markets such as alphanumeric and dot-matrix displays. Even so, Cambridge Display Technology of Cambridge, England, is out to knock the conventional liquid-crystal display off its pedestal. In 2000, along with Seiko Epson of Japan, the company demonstrated a 2.8-inch LEP display that was less than a tenth of an inch thick. The display, with 100 pixels per inch, was made using ink-jet printing techniques. Drops of red, blue and green LEP material were sprayed on to the substrate to allow the various colours in the image that was being displayed to be flipped on and off as required.

LEP there be light

Cambridge Display hopes to be producing small, full-colour displays in volume by 2003, at a new development centre it has set up nearby. Kevin Yallup, the centre's manager, expects revenue to come from licensing the technology and joint-ventures. One such joint-venture, called Polyink, is with Seiko Epson and is aimed at developing an inkjet printer for making displays. Independently, Philips Research, based in the Dutch city of Eindhoven, is also developing inkjet-printing technology for LEPS.

Because they are robust, LEPS are ideal for flexible displays. The problem with flexible displays is not so much the screen but the drive electronics that switch the individual polymer pixels on and off. Be- ▸▸



Try this with a liquid-crystal display

"If scaled up, a square centimetre of such material could store a staggering 6.4 gigabits."

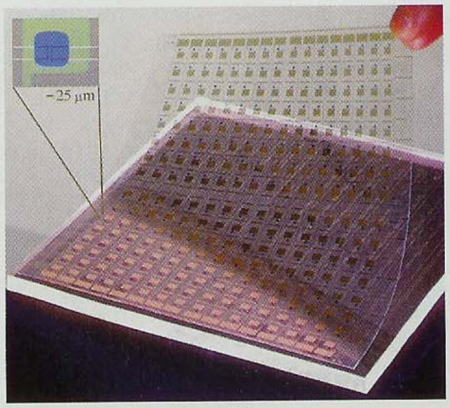
ing made of silicon, the transistors in the drive circuitry tend to be rigid, fragile and to operate at temperatures high enough to melt the plastic display. Ideally, the drive circuitry should be made of plastic. Hence the widespread interest in developing organic thin-film transistors.

Plastic circuitry promises as large a market as light-emitting polymers, but the technology is taking longer to commercialise. Even so, its biggest application is expected to come from printing plastic chips on consumer items such as T-shirts, drink cans and food cartons for displaying health messages or providing sales and restocking data.

Plastic Logic, also located in Cambridge, England, is developing display drivers using plastic circuitry. The polymers used can be dissolved in water to form an ink, which can be sprayed on the product. The first layer printed is a conducting polymer, which creates the transistor's "source" and "drain" electrodes. The second layer is composed of a semiconducting polymer. In the final layer, an insulating polymer and a transistor "gate" are laid down. Although polymer transistors operate at only a small fraction of the speed of the crystalline silicon transistors used in microprocessors such as Intel's Pentium, they are fast enough to replace the amorphous (ie, non-crystalline) silicon transistors used in the "active matrix" form of liquid-crystal display.

As with LEPs, inkjet-printed circuitry has advantages of cost, weight, robustness and flexibility, as well as the ability to cover large areas. Plastic Logic's first commercial application is likely to be as backplanes for liquid-crystal displays or electronic paper. A second might be radio-frequency identification tags ("smart labels"). In both cases, silicon chips are too rigid and expensive to be practical. The company, which hopes to market the technology in partnership with display makers, expects to be shipping products by 2004.

Meanwhile, E-Ink, based in Cambridge, Massachusetts, is attempting to create flexible, paper-like displays using inks that are electronically addressable. The main advantage for flexible displays of electronic inks over LEPs is that the inks have a "bistable" molecular structure that allows them to store their information without a power supply. This feature, plus the ink's high contrast ratio, provides a display that can offer a truly paper-like reading experience. Again, however, the technology needs a flexible backing to drive it. With technology from Bell Laboratories in Murray Hill, New Jersey, E-Ink recently demonstrated a prototype of a flexible page display that was driven by plastic transistors.



Stamped out by the million

Work at Bell Labs has also shown that, besides printing and spraying, flexible circuits can be stamped continuously on to rolls of plastic. John Rogers, head of nanotechnology research at Bell Labs, reckons that the stamping approach will provide much higher resolution than is possible with inkjet printing. This should translate directly into higher electrical performance from the transistors. But Hewlett-Packard, which is also making a big effort in plastic electronics using inkjet techniques, argues that the advantage of printing over stamping is that it makes it possible to produce customised circuitry more quickly and easily, with changes in design being incorporated instantly.

Floppy memories

A polymer's molecular structure can be altered by applying an electric field, causing changes in the material's conductivity at any given spot. This can then be read as either a one or a zero in binary arithmetic. The implication is that, besides being cheap to produce, plastic memory can store data even when power to the device is turned off.

Several chip makers are out to make polymer memories with large storage capacities. Intel is collaborating with Thin Film Electronics of Linköping, Sweden. Advanced Micro Devices of Sunnyvale, California, is working with Coatue of Woburn, Massachusetts. Hewlett-Packard is developing a polymer memory that can be made in long sheets capable of providing permanent, high-capacity archives for digital cameras, personal digital assistants and mobile phones.

Early in 2002, Hewlett-Packard announced that it had created an electronically switchable memory device using clusters of molecules known as "rotaxanes". Although these are not organic materials, they are polymers. The demonstration device contained only 64 bits. But if scaled up, a square centimetre of such material could store a staggering 6.4 gigabits of information. Furthermore, the components of this rudimentary circuitry had been stamped cheaply on to the chip. Although probably five years away from commercialisation, this kind of cheap, non-volatile technology could be a handy replacement for the "flash" memory used in digital cameras.

A long way to go

It is still early days for organic electronics. Plastic transistors have nothing like the switching speed of those made from crystalline silicon—and will probably never have. That is because polymers that can conduct (or at least semiconduct) have electrons that become part of the molecular orbit of the entire polymer chain, rather than simply the orbit of the individual molecules. That means the energy required to pull electrons free—and so allow conducting to happen—depends on the shape and structure of the polymer. Unfortunately, polymers tend to vary in chain length and composition.

Although plastic transistors and diodes seem to have a promising future in displays, they are unlikely to replace silicon devices at the high end of performance. Their most useful role will be in throwaway products or in hybrids that take advantage of robustness and flexibility of plastic circuitry. For instance, Rolltronics of Menlo Park, California, is working on a cheap roll-to-roll printing process that deposits amorphous silicon transistors on to a continuous sheet of flexible polymer. Meanwhile, IBM is developing transistors from hybrid organic and inorganic materials. These and other firms, such as Lucent and Plastic Logic, are pursuing the large market for hybrid backing electronics used for flexible displays.

Already talk in labs around the world is of "polymer nanoelectronics" and "plastic spintronics". But any thought of silicon's demise is premature. What is not is the fact that, henceforth, silicon will have to share its dominance of the semiconductor world with a remarkable range of upstart materials based on polymers. Welcome to the era of organic chips. ■