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GENERATIONS OF MOORE'S LAW-LIKE DOUBLING NEEDED BEFORE THIN-FILM TRANSISTORS ARE AS DENSELY PACKED AS TODAY'S FASTEST GPUs AND FPGAs

PLOTTING A MOORE'S LAW FOR FLEXIBLE ELECTRONICS

A five-year project at Imec aims to make big boosts in the density of thin-film transistor circuitry

IMEC

NEAR FIELD COMMUNICATOR: There are 1,700 transistors on the flexible chip in this NFC transmitter.

At a meeting in mid-town Manhattan, Kris Myny picks up what looks like an ordinary paper business card and, with little fanfare, holds it to his smartphone. The details of the card appear almost immediately on the screen inside a custom app.

It's a simple demonstration, but Myny thinks it heralds an exciting future for flexible circuitry. In January, he began a five-year project at the nanoelectronics research institute Imec in Leuven, Belgium, to demonstrate that thin-film electronics has significant potential outside the realm of display electronics. In fact, he hopes that the project, funded with a €1.5 million grant from the European Research Council (ERC), could demonstrate that there is a path for the mass production of denser and denser flexible circuits—in other words, a Moore's Law for bendable ICs.

Five years ago, Myny and his colleagues reported that they had used organic thin-film transistors to build an 8-bit micro- »

processor on flexible plastic. In the years since, the group has turned its focus to IGZO—a metal-oxide semiconductor that is a mixture of indium, gallium, zinc, and oxygen. Thin-film transistors based on this substance can move charge significantly faster than their organic counterparts do; at the same time the transistors can still be built at or around room temperature—an important requirement when attempting to fabricate electronics directly onto plastic and other materials that can be easily deformed or damaged by heat.

To build that business card, Myny and his colleagues engineered a flexible chip containing more than 1,700 thin-film IGZO transistors. What sets the chip apart from other efforts is its ability to comply with the ISO14443-A Near Field Communication (NFC) standard. For flexible circuitry, this is a demanding set of requirements, Myny says, as it requires logic gates that are fast enough to work with the 13.56-megahertz standard carrier frequency.

Adding to the challenge is that while IGZO is an effective *n*-type semiconductor, allowing electrons to flow easily, it is not a particularly good *p*-type material; there is no comparable material that excels at permitting the flow of holes—the absence of electrons that are treated as positive charges. Today's logic uses both *p*- and *n*-type devices; the complementary pairing helps control power consumption by preventing the flow of current when transistors are not in the act of switching. With just *n*-type devices to work with, Myny and his colleagues have to devise a different kind of circuitry.

With the ERC project, Imec aims to tackle a suite of interrelated problems in an effort to boost transistor density from 5,000 or so devices per square centimeter to 100,000. That figure isn't far from the density of thin-film transistors in conventional rigid-display backplanes today, Myny says. However, it's another matter to try to achieve that density with digital logic circuits—which require more complicated designs—and to make sure those devices are reliable and consistent when they're built on a delicate and irregular substrate.

The group also wants to prove this density is achievable outside the lab, by adapting manufacturing techniques that are already in use in display fabs. Myny says that if he and his team hit their goals, a square centimeter of fast, flexible circuitry could be built at a cost of 1 U.S. cent (assuming high-volume manufacturing). At the same time, while the density of the circuits increases, the group will also have to boost the transistor frequency and drive down power consumption to prevent overheating. The overall goal, Myny says, is to demonstrate "that you can indeed make flexible circuits—that it is not science fiction but that it is going to market."

When it comes to the fabrication of complex digital circuits on flexible substrates, "Imec is in my opinion the biggest player," says Niko Münzenrieder, a lecturer at the University of Sussex, in England, who specializes in flexible electronics. He notes that metal-oxide flexible circuitry is already starting to make commercial inroads, and he expects the first big applications to be in RFID and NFC technology. "It's not a mature technology," he says, "but it's nearly ready for everyday use."

—RACHEL COURTLAND

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SILICON VALLEY'S LATEST CRAZE: BRAIN TECH

Elon Musk, Mark Zuckerberg, and other big players have started neurotech initiatives

Silicon Valley's biggest influencers want to get inside your head. Over the past year, four leading figures have announced plans to make gadgets that will either nestle into the fleshy folds of your brain or sit atop your head to read your thoughts from the outside.

The proposed hardware and applications are varied, but all signify ambitious—even audacious—undertakings. Whether working on medical devices to fix a neural deficiency or consumer gizmos to augment normal brainpower, each of the four Valley visionaries promises to have something ready for the market in just a few short years.

Neural engineers have mixed feelings about these high-profile announcements from the likes of Elon Musk and Mark Zuckerberg. "There's a lot of excitement when this cast of characters gets involved," says Paul Sajda, a professor of biomedical engineering at Columbia University, in New York City, and an expert on advanced technologies for brain research.

But Sajda wonders if these deep-pocketed individuals know what they're getting into. "The typical Silicon Valley attitude is that if you throw enough money at something, you can solve the problem," Sajda says. While that approach may work for applied technology, he says, it doesn't necessarily work if there are fundamental science