

were connected so they would become part of the same transistor. Stacking the nanowires boosts the amount of current that can pass through a given area of transistor—and thus how much can pass through a given area on a chip.

The great advantage of this approach, explains Imec logic program manager Naoto Horiguchi, is that the fabrication process is quite close to that used to make the FinFET transistors in today's high-performance chips. "This is kind of a natural extension from FinFET to the next generation," he says.

Imec's is the first demonstration of stacked-nanowire devices at such a small scale, says Michael Guillorn of IBM's Thomas J. Watson Research Center in Yorktown Heights, N.Y. Guillorn has been involved with IBM's gate-all-around device research program since 2009.

IBM presented results at last year's VLSI event that explored the limits of performance for a single layer of horizontal nanowires at an advanced chip manufactur-

ing level. Because resistance increases as a channel narrows, a common concern has been that nanowires would too strongly resist the flow of current, Guillorn says. But the IBM group's results suggest that is not the case. They also suggest that more ribbonlike nanowire structures—wide and flat instead of square or round in cross section—could help improve performance.

There is still plenty of work to be done. One focus at Imec, Mertens says, is on ways to better isolate the gate that surrounds the channel of the nanowire from the source and drain regions. Because the source and drain are so close to the gate in the small device, they tend to exchange energy via capacitive coupling.

Guillorn says researchers are, one by one, "knocking things off the list of reasons" why nanowires might not be desirable. Assuming engineers work out all the kinks in manufacturing and performance, the devices could potentially enter chipmakers' production lines in three to six years, he says. The timing will hinge on how long companies believe they can extend the FinFET, the cadence at which they decide to introduce future generations of chips, and how aggressive they want to be with the underlying technology. "Early adoption of gate-all-around," Guillorn says, "is a great way for a semiconductor company to differentiate itself."

—RACHEL COURTLAND

"This is kind of a natural extension from FinFET to the next generation"—Naoto Horiguchi, Imec

THE INTERNET OF FEWER THINGS

Early predictions of 50 billion connected devices by 2020 are being scaled back

▶ If you follow discussions about the Internet of Things, you've probably heard this stunning prediction at least once: The world will have 50 billion Internet-connected devices by 2020. Ericsson's former CEO, Hans Vestburg, was among the first to toss out that number, when he gave a 2010 presentation to shareholders. The following year, Dave Evans, who worked for Cisco at the time, published the same prediction in a white paper.

Today, that figure has arguably done more than any other statistic to set sky-high expectations for potential IoT growth and profits. Remarkably, those projections weren't even close to the highest at that time. A 2012 IBM forecast predicted 1 trillion connected devices by 2015. "The numbers were getting kind of crazy," recalls Bill Morelli, director of the IHS Markit division that handles IoT and digital security.

Both Ericsson and Evans have since lowered their expectations for 2020: Evans, a cofounder of Stringify, who now serves as its chief technology officer, says he expects to see 30 billion connected devices by then; Ericsson figures on 28 billion by 2021. Other firms have adopted similar tones: IHS Markit projects 30.7 billion IoT devices for 2020; Gartner expects 20.8 billion by that time (excluding smartphones, tablets, and computers); and International Data Corp. anticipates 28.1 billion (again, not counting those devices).

That's likely because it's the third quarter of 2016, and we're nowhere near 1 trillion IoT devices—or even 50 billion for that matter. The true total is somewhere between Gartner's estimate of 6.4 billion (excluding smartphones, tablets, and computers), and IHS Markit's estimate of 17.6 billion (with all such devices included).

But the popular 50 billion figure continues to be widely cited. Even Evans is a bit surprised by its staying power. "I think people do tend to latch onto numbers that seem really hard to fathom," he says. "Fifty billion is pretty staggering."

Peter Middleton, a research director at Gartner



involved in the firm's IoT forecasts, says such projections are intended to create "market efficiency," by helping companies make smart choices about whether they should enter a new area and informing venture capitalists as they decide where to place their investments.

This is why the wild divergence in the numbers is problematic. But Vernon Turner, a senior IoT analyst at IDC, says it's more practical—at least at this stage of a nascent market—to think of the estimates as a signal, rather than to focus on the specific numbers.

Bob Heile, standards director for the Wi-SUN Alliance and chair of the IEEE 802.15 WPAN effort (a working group for wireless personal area networks), says the general trend that early IoT analysts predicted has proven true. "What I do know, because the trend is absolutely undeniable, is more and more things are getting the ability to communicate and connect to something else," says Heile.

But why isn't there one plausible set of numbers? Two reasons: arithmetic and avarice. To begin their analyses, many firms collect annual sales data from manufacturers that produce connected devices or components such as semiconductors, as well as from companies that sell and ship those products to customers. Next, the firms subtract a percentage of devices to account for those that will be replaced or thrown out each year, and then they add estimates from past years. The result of this arithmetic is the "install base," or approximate number of connected devices in use at a given time.

Some firms include other variables, such as industry growth rates or the amount of money that companies spend annually on information technology. And some conduct consumer and business surveys to gauge how devices are used, so they'll know how many of the devices that are sold and shipped actually wind up connected to the Internet. Morelli at IHS Markit estimates that 90 percent of communications devices (including smartphones) are switched on, but perhaps only 50 percent of Internet-capable gadgets for cars are ever connected.

Janna Anderson, an expert in emerging technologies at Elon University, in North Carolina, says there is a degree of self-interest at play in projections, too. In 2013, she helped the Pew Internet Project survey more than 1,600 experts about what the IoT might look like in 2025. Not sur-

prisingly, she found that "those who are marketing it and those whose bottom line is somehow impacted by enthusiastic predictions are more likely to make them."

At this point, even the strictest definitions of IoT remain fuzzy because of breathless hype, including attempts to anticipate demand for devices that have yet to be invented or commercialized. But Stringify's Evans, one of the original IoT optimists, is confident that entrepreneurs will find many millions of practical ways to serve customers through the IoT in due time. "I think technology needs to solve real problems, and if it doesn't...[it] will die on the vine," he says.

As the next 10 billion IoT devices come online, the industry will face some formidable challenges, such as ensuring the security of its devices, powering billions of sensors, and handling all the resulting e-waste. Despite those issues, Evans isn't bashful about anticipating connected device ubiquity. "I could see trillions of connected things, ultimately," he says. —AMY NORDRUM

IoT in 2020

Analysts' original projections for the number of connected devices by 2020 [solid bars] varied by many billions. Some have ratcheted down expectations in newer forecasts [striped bars]. Conflicting definitions make it difficult to compare expectations. Some firms count smartphones, tablets, and laptops, while others (Gartner, International Data Corp.) do not.

