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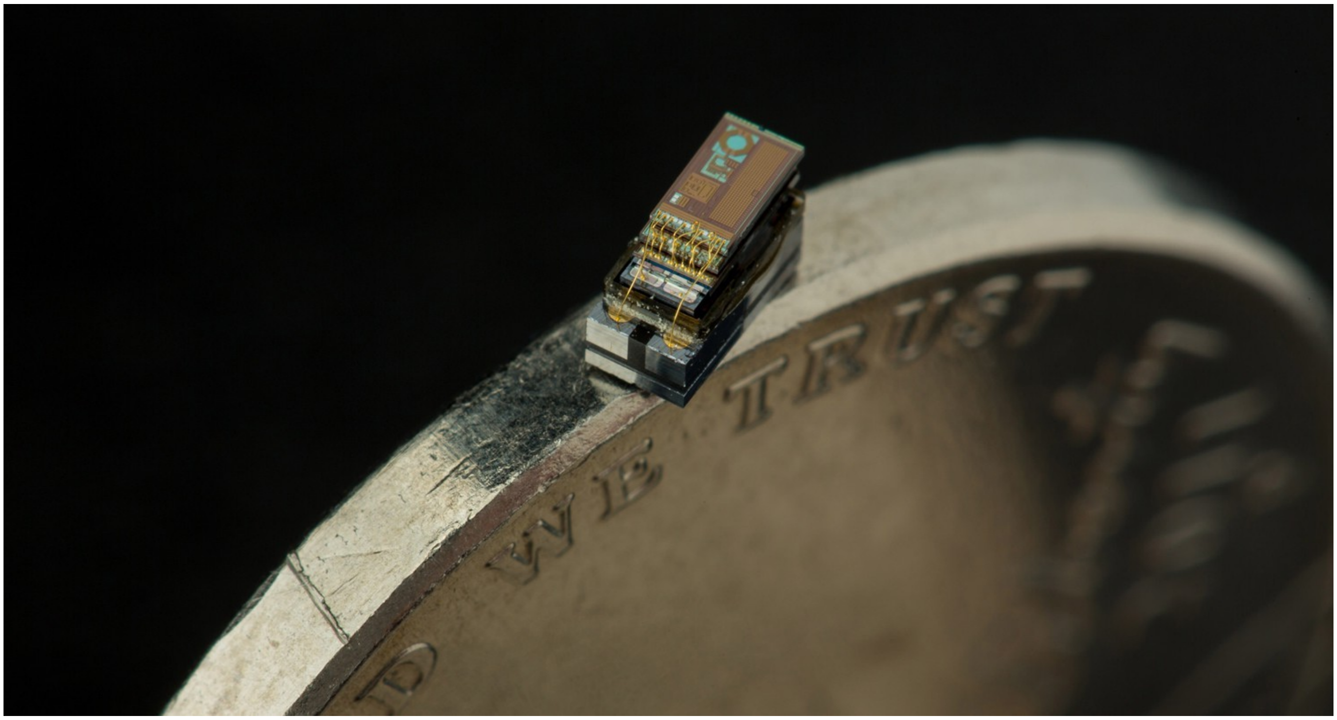


The Crazy-Tiny Next Generation of Computers

"Smart dust," long heralded in research papers and sci-fi, is now a reality. Just don't sneeze.

When Prabal Dutta accidentally drops a computer, nothing breaks. There's no *crash*. The only sound you might hear is a prolonged groan. That's because these computers are just one cubic millimeter in size, and once they hit the floor, they're gone. "We just lose them," Dutta says. "It's worse than jewelry." To drive the point home, Dutta, an assistant professor of electrical engineering at the University of Michigan, emails me a photo of 50 of these computers. They barely fill a thimble halfway to its brim.

What's in the thimble is the culmination of a decade's worth of research into microelectromechanical systems (MEMS)—the technology of very tiny computers. MEMS are also called "smart dust," and Dutta's dust is the smallest known to humankind. Dutta is part of the Michigan Micro Mote, or M3, project at the University of Michigan, and M3 is on the cusp of releasing the blueprints for the "motes," as Dutta calls them. As soon as the motes get approved by the University's licensing office—which will happen any day now, says Dutta—M3 will release the blueprints on their mbus.io website, so that nimble-fingered researchers, hackers and Maker Faire enthusiasts alike might begin to build them. After years of trial and error, smart dust, long predicted by members of the scientific community, is finally here.

In order to fully test the motes' real-world limits, the M3 team decided that they would define the mote's overall architecture, but entrust the last bits of components (such as a camera and solar cell) to MEMS enthusiasts. "They can use it to go build crazy stuff," Dutta says.

What kinds of stuff? There are the obvious military-minded uses such as surveillance, but these tiny motes are small enough to literally get inside your head and, say, check out a tumor before it grows too large for surgery, or maybe assess the level of brain trauma after a head injury. On a broader scale, one might deploy smart dust to fly into a sandstorm or wildfire and report back on conditions. Or scientists might use it to assess the level of toxicity deep in a coal mine—or on Mars.

Dutta's own goals are decidedly more down to Earth. For him, the real payoff might mean using motes to measure everyday data, in an effort to solve issues of critical sustainability. Dutta thinks the M3 mote and its kin have the potential to determine the real energy costs of your house: for example, they might determine exactly how much water comes out of your shower head. In other words, these motes have the ability to show us the true cost of energy consumption and, in an era when the state of California is facing one of the worst droughts in its history, smart dust just might help to save us from ourselves.

The race to build the world's smallest computer has been in the works since UC Berkeley professor Kristofer Pister coined the phase "smart dust" in 1997, back when Apple computers were the size of large lapdogs, and smart dust the stuff of fan-boy fiction. Pister envisioned a future where pinhead-sized computers would blanket the earth like a neural cloud, relaying real-time data about people and the environment. Each particle of "dust" would function as a single autonomous computer: a tiny bundle of power, sensor, computing and communication chips that could incorporate and relay information about their environment, perform basic data-processing and communicate with one other, using almost zero energy consumption. And each computer would be no larger than one cubic millimeter in size.

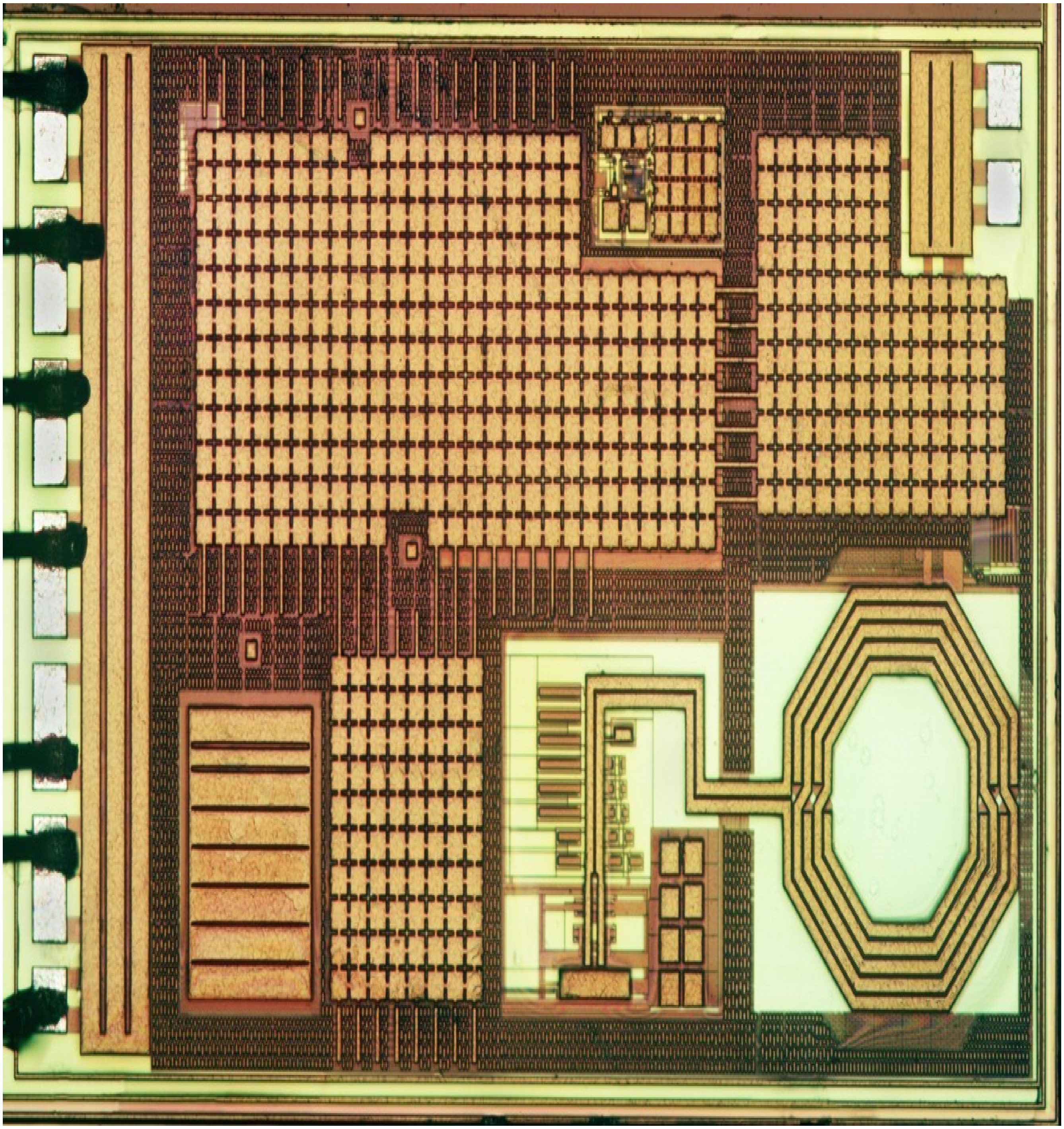
But Pister's smart dust vision never came to pass. After leaving academia to found a company called Dust Networks in early 2003, Pister got derailed by the mechanics of running a company and stopped scaling computers full time. The smallest mote his company currently makes is about the size of sugar cube: good for performing diagnostics on utilities, not so good for exploring the brain or anything else that requires a very small and unobtrusive presence—qualities essential for meshing with the much-ballyhooed Internet of Things. "Probably my single most important contribution is coming up with a catchy name," Pister laughs, though he is quick to add that Dust Networks is quite successful. "We're basically in every oil refinery in the world, and in industrial applications from the Saudi Desert to the Arctic Circle," Pister says.

The history of MEMS dates back almost half a century, to the Vietnam War. In 1967, a military operation known as Igloo White airdropped thousands of sensors disguised as plants along the Ho Chi Minh Trail to monitor truck movement with the intent to reveal enemy activity. Ultimately the operation failed due to an overwhelming number of false alarms. Still, DARPA began funding similar distributed sensor networks around 1980.

By July of 1999, Pister had developed a mote with a volume of 100 cubic millimeters that had a working transmitter. Jason Hill, a colleague of Pister's, created the TinyOS operating system to be compatible with Pister's new wave of motes, combining them with hardware known as the "Mica" mote, in 2001. Hill also created the "Spec" mote in 2002, which measured 2.5 mm on each side and was equipped with a radio that could transmit but not receive signals. Soon came the matchbox-sized Mica2 Motes, also designed at Berkeley.

It was around this time that Dutta first stumbled on MEMS technology. The Ohio State graduate was roaming the halls of his alma mater when he saw a group of students working on circuit boards in a lab. For Dutta, the motes laid out on the desk were like eye candy. So Dutta decided to pursue his masters in electrical engineering and immersed himself in MEMS.

By 2010, Dutta was at the University of Michigan, where colleagues David Blaauw and Dennis Sylvester had created a 1.5-mm^3 marvel called the Phoenix Chip. The solar-powered sensor system was intended to measure intraocular pressure for glaucoma patients. Dutta was impressed. But he wanted to push towards “tagging” things in the environment, particularly for monitoring scarce natural resources.



So Blaauw, Sylvester and Dutta sketched plans for what would become the M3 project. They worked from the top down, meaning that they'd design one system entirely before any coding began, and they built the motes to operate on a power budget of mere nanowatts. They created new circuit structures for RAM and for dealing with heat, and created new ways of processing and programming, done optically and using strobes. The result was a wireless mote consisting of several fleck-like modules that autonomously subsisted on minute amounts of energy harvested from heat or light via photovoltaic cells.

Functioning at such a low amount of energy was a giant leap towards the team's vision of smart dust. These motes would be too small to be rechargeable, and once deployed—or dropped on the floor—they might be irretrievable. So the motes needed to have a decent energy lifetime.

Enter something called the MBus. As a chip-to-chip interconnecting module for the M3 mote, the MBus enables ultra-low-power standby modes of eight nanowatts, and reduces the mote's overall power consumption by 23 percent.

M3 has spoken with corporations for the inclusion of smart dust in wearables, and they've recently launched a for-profit company called CubeWorks. They intend to improve existing devices using their new energy-harvesting methods, like a Fitbit that needs recharging every six months instead of every couple of days.

As for Pister, Dust Networks became a ten-year distraction from the smart dust he originally wanted to construct. M3 might hold the record right now, but Pister still feels he has skin in the game. "I want to take that mantle back," he says. His work on a single-chip mote is already underway. It could offer a lively dueling spectacle within the scientific community, albeit a very tiny one.

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