lenge for teams from the very beginning, and it will continue to be until the end," says Gonzales-Mowrer.

A mission can easily cost more than the top prize. SpaceIL, for example, estimates its mission will cost $70 million. So far the team has raised $50 million of that total, but SpaceIL member Elana Lichtenstein says the team is confident it will be able to make up the difference.

As it can appeal to a higher purpose, SpaceIL may have an easier time than others raising funds for its mission, says Lichtenstein: "We're asking people to make a social and emotional investment in STEM [science, technology, engineering, and math] education for the future of Israel." So far, the team estimates that its educational outreach efforts have reached 250,000 students. It hopes to double that total by the end of this year.

As with other teams, SpaceIL is still readying its spacecraft, which is being built at an Israel Aerospace Industries facility. The team's launch contract is for a six-month window that extends into 2018. If it can't make the 2017 deadline, SpaceIL still aims to go to the moon: "We have an educational mission that we are intent on achieving that has little to do with the time frame of the competition," Lichtenstein says.

Some teams that were expected to advance to the final round did not. The Germany-based group Part Time Scientists, for example, announced last year that it had secured a launch contract. But the team did not meet the prize requirements, because its launch did not have the potential to occur before the 2017 deadline, Gonzales-Mowrer says.

Longtime front-runner U.S.-based Astrobotic Technology is also missing from the list of finalists. The team withdrew from the competition, explaining that the prospect of rushing to make the XPrize deadline conflicted with the company's goal of building a sustainable, long-term business. The group now aims to fly its first mission in 2019. —RACHEL COURTLAND

GRAPHENE COULD BUTTRESS NEXT-GEN COMPUTER CHIP WIRING

Current can literally blow copper interconnects away, but graphene could keep them intact

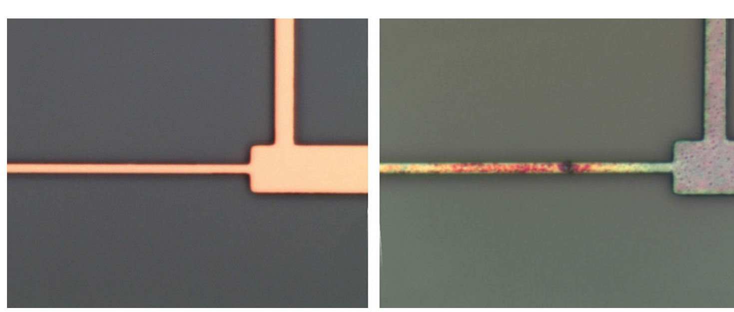
Most of the hand-wringing over the fate of Moore's Law focuses on the ever-shrinking silicon transistor. But increasingly researchers are concerned with another critical part of the infrastructure: the copper wires that connect individual transistors to form complex circuits.

At the IEEE International Electron Devices Meeting in San Francisco in December, researchers described the coming problems for copper interconnects and debated ways of getting around them. One approach, studied by a group led by Stanford electrical engineer H.-S. Philip Wong, is to gird copper with graphene. Wong's group found that the nanomaterial can alleviate a major problem facing copper, called electromigration.

Copper wires are getting so thin, and must carry so much current, that the atoms in the wire can literally get blown out of place. "The electron wind can physically move the copper atoms and create a void," says Wong. Growing graphene around copper wires prevents this, according to research that Wong's group presented at the meeting. It also seems to bring down the resistance of the copper wires.

Ruth Brain, an Intel Fellow and director of interconnect technology and integration at the company's Hillsboro, Ore., location, explained how interconnects are being pushed to their limits. More transistors per chip area means more interconnects have been installed to connect them. The first chips to use copper interconnects, which were produced in 2000, had 1 kilometer of wiring per square centimeter. Today's 14-nanometer-node processors contain more than 10 km of copper wiring in the same area, she said.

In order to improve performance, the ever-narrowing copper wires must carry ever more current. The amount



DEATH BY ELECTROMIGRATION: Copper interconnects are now so narrow that current can cause a break by knocking atoms out of place.

STANFORD UNIVERSITY

of current per area in a wire is called its current density, which has been increasing on cutting-edge chips for two reasons: Wires are shrinking, and higher currents must course through them to enable the faster switching speeds that boost performance.

And herein lies the challenge: The narrower the wire, the higher its resistance. "Interconnects have had to shrink while increasing the current densities by 20 times," said Brain. "You would burn your house down if you did this in your house."

Today's solution is to deposit copper interconnects within trenches lined with 2-nanometer-thick walls of tantalum nitride. This lining keeps the copper from escaping, and Wong says copper will probably endure through the coming 10- and 7-nm nodes. As device features keep shrinking, though, 2-nm walls will be far too thick, says Wong. Researchers are investigating other linings that may prevent electromigration, including ruthenium and magnesium, but at 0.3 nm, he says, graphene is thinner than anything else.

The semiconductor industry avoids integrating new materials as long as possible, but Wong says there isn't much choice in this situation: If copper's life can't be extended, it will have to be replaced with a new material anyway, such as cobalt.

The Stanford group worked with Lam Research Corp., which makes chip manufacturing tools, as well as researchers from Zhejiang University, in China, to make and test the composite interconnects. The materials make a good pair; graphene is often made by growing it on copper. Lam Research has developed a proprietary process for doing this at temperatures that won't damage the rest of the chip—below 400 °C. Compared to copper alone, the composite limited electromigration by a factor of 10. And the composite wires had half the electrical resistance.

> "Interconnects have had to shrink while increasing the current densities by 20 times. You would burn your house down if you did this in your house"
> —Ruth Brain, Intel

Wong says the interconnect problem can no longer be dismissed. "Before, most of the time we were hearing about transistors," he says. "Now it's not just transistors but wires, memory—many other things that were previously not a problem are beginning to be a problem."

—KATHERINE BOURZAC

AT-HOME ELECTRIC HEADBAND FOR DEPRESSION COULD GO MAINSTREAM

A consumer-friendly gadget could help tDCS treatment catch on

A doctor's prescription for clinical depression could one day sound like this: In the comfort of your own home, slip on a brain-zapping headband a few times per week. For 20 minutes, it will send a tiny stream of electricity through your brain.

The treatment would be delivered by a user-friendly type of brain stimulation called tDCS (transcranial direct-current stimulation). This mind-altering technique has become a hot topic in neuroscience research over the last decade, and it's now beginning the transition from lab to doctor's office.

In South Korea, the startup Ybrain is betting that its tDCS headband, specifically designed to treat depression, will be the product that brings the electric treatment into the medical mainstream. Ybrain founder and CEO Kiwon Lee expected his device to receive regulatory approval in Korea in February. He plans to roll out the device in 70 Korean hospitals this year to reach thousands of patients with clinical depression. The company will use data from all those patients to build a case for approval first in Europe, Lee says, and then in the United States, where the regulatory requirements are most stringent. "After one device is approved [in the United States], it will be seen as a mainstream treatment," he says.

tDCS is considered an exciting new possibility for clinical use because the gear is cheap, portable, and easy to use. The headsets press electrodes against particular locations on the scalp to channel a few milliamperes of current through a specific brain region, and they can be powered by a 9-volt battery. Last year there were nearly 700 papers published about tDCS, with studies on every topic imaginable: Researchers have experimented with physical rehab for stroke patients,