Engineers find that a new memory technology may be more energy efficient than previously thought

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Stanford engineers are developing new memory chips, based on materials other than silicon, to provide more energy-efficient ways to store data as digital zeros and ones. Credit: iStock / matejmo

Scientists often discover interesting things without completely understanding how they work. That has been the case with an experimental memory technology in which temperature and voltage work together to create the conditions for data storage. But precisely how was unknown.

But when a Stanford team found a way to untangle the chip's energy and heat requirements, their tentative findings revealed a pleasant surprise: The process may be more energy efficient than was previously supposed. That's good news for next-generation mobile devices whose batteries would last longer if they were powering lower energy chips.

The group that made this discovery, led by Stanford electrical engineer H.-S. Philip Wong, is presenting the paper when the IEEE International Electron Devices Meeting (IEDM) brings leading researchers to San Francisco Dec. 5.

The new technology the team investigated is called resistive random-access memory, or RRAM for short. RRAM is based on a new type of semiconductor material that forms digital zeros and ones by resisting or permitting the flow of electrons. RRAM has the potential to do things that aren't possible with silicon: for instance, being layered on top of computer transistors in new three-dimensional, high-rise chips that would be faster and more energy efficient than current electronics, which is ideal for smartphones and other mobile devices where energy efficiency is a vital feature.

But while engineers can observe that RRAM does store data, they don't know exactly how these new materials work. "We need much more precise information about the fundamental behavior of RRAM before we can hope to produce reliable devices," Wong said.

Jolting memory

So to help engineers understand some of the unknowns, Wong's team built a tool to measure the basic forces that make RRAM chips work.

Graduate student Zizhen Jiang of the Stanford team explained the basics: RRAM materials are insulators, which normally do not allow electricity to flow, she said. But under certain circumstances, insulators can be induced to let electrons flow. Past research had shown how: Jolting RRAM materials with an electric field causes a pathway to form that permitted electron flows. This pathway is called a filament. To break the filament, researchers apply another jolt and the material becomes an insulator again. So each jolt switched the RRAM from zero to one or back, which is what makes the material useful for data storage.

But electricity is not the only force at play in RRAM switching. Pumping electrons into any material raises its temperature. That's the principle behind electric stoves. In the case of RRAM, it was the elevated temperature caused by introducing voltage that induced filaments to form or break. The question was what voltage-induced temperature was needed to cause the switching. No one knew.

Before the new Stanford study researchers thought short bursts of voltage, sufficient to generate temperatures of about 1,160 degrees Fahrenheit – hot enough to melt aluminum – was the switching point. But those were estimates because there was no way to measure the heat generated by an electric jolt.

"In order to begin to answer our questions, we had to decouple the effects of voltage and temperature on filament formation," said Ziwen Wang, another graduate student on the team.

Dissecting the heat needs

Essentially, the Stanford researchers had to heat the RRAM material without using an electric field. So they put an RRAM chip on a micro thermal stage (MTS) device – a sophisticated hot plate capable of generating a wide range of temperatures inside the material. Of course the objective was not merely to heat the material, but also to measure how filaments formed. Here they took advantage of the fact that RRAM materials are insulators in their natural state. That makes them digital zeros. As soon as a filament formed electrons would flow. The digital zero would become a digital one, which the researchers could detect.

Using this experimental model, the team put RRAM chips on the burner and cranked up the heat, starting at about 80 F – roughly the temperature of a warm room – all the way up to 1,520 F, hot enough to melt a silver coin. Heating the RRAM to various temperatures in between these extremes, the researchers measured precisely if and how RRAM switched from its native zero to a digital one.

To their pleasant surprise, the researchers observed that filaments could form more efficiently at ambient temperatures between 80 F and 260 F, which is hotter than boiling water – contrary to prior expectation that hotter was better.

If confirmed by subsequent research, this would be good news because in a working chip the switching temperature would be created by the voltage and duration of the electric jolt. Efficient switching at lower temperatures would require less electricity and make RRAM more energy efficient and extend battery life when used as the memory in mobile devices.

Much work remains to be done to make RRAM memory practical but this research provides the test bed to vary conditions systematically instead of relying on hit-and-miss hunches.

"Now we can use voltage and temperature as design inputs in a predictive manner and that is going to enable us to design a better memory device," Wang said.

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