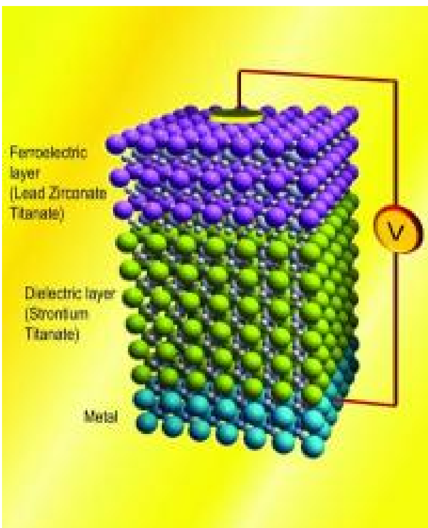
Ferroelectrics could pave way for ultra-low power computing

September 12 2011



Shown is a rendition of an experimental stack made with a layer of lead zirconate titanate, a ferroelectric material. UC Berkeley researchers showed that this configuration could amplify the charge in the layer of strontium titanate for a given voltage, a phenomenon known as negative capacitance. Credit: Asif Khan, UC Berkeley

Engineers at the University of California, Berkeley, have shown that it is possible to reduce the minimum voltage necessary to store charge in a capacitor, an achievement that could reduce the power draw and heat generation of today's electronics.

"Just like a Formula One car, the faster you run your computer, the hotter it gets. So the key to having a fast microprocessor is to make its building block, the transistor, more energy efficient," said Asif Khan, UC Berkeley graduate student in electrical engineering and computer sciences. "Unfortunately, a transistor's power supply voltage, analogous to a car's fuel, has been stuck at 1 volt for about 10 years due to the fundamental physics of its operation. Transistors have not become as 'fuel-efficient' as they need to be to keep up with the market's thirst for more computing speed, resulting in a cumulative and unsustainable increase in the power draw of microprocessors. We think we can change that."

Khan, working in the lab of Sayeef Salahuddin, UC Berkeley assistant professor of electrical engineering and computer sciences, has been leading a project since 2008 to improve the efficiency of transistors.

The researchers took advantage of the exotic characteristics of ferroelectrics, a class of material that holds both positive and negative electrical charges. Ferroelectrics hold electrical charge even when you don't apply a voltage to it. What's more, the electrical polarization in ferroelectrics can be reversed with the application of an external electrical field.

Getting more bang for the buck

The engineers demonstrated for the first time that in a capacitor made with a ferroelectric material paired with a dielectric – an electrical insulator – the charge accumulated for a given voltage can, in effect, be amplified, a phenomenon called negative capacitance.

The team report their results in the Sept. 12 issue of the journal *Applied Physics Letters*. The experiment sets the stage for a major upgrade to transistors, the on-off switch that generate the zeros and ones of a computer's binary language.

"This work is the proof-of-principle we have needed to pursue negative capacitance as a viable strategy to overcome the power draw of today's transistors," said Salahuddin, who first theorized the existence of negative capacitance in ferroelectric materials as a graduate student with engineering professor Supriyo Datta at Purdue University. "If we can use this to create low-power transistors without compromising performance and the speed at which they work, it could change the whole computing industry."

The researchers paired a ferroelectric material, lead zirconate titanate (PZT), with an insulating dielectric, strontium titanate (STO), to create a bilayer stack. They applied voltage to this PZT-STO structure, as well as to a layer of STO alone, and compared the amount of charge stored in both devices.

"There was an expected voltage drop to obtain a specific charge with the dielectric material," said Salahuddin. "But with the ferroelectric structure, we demonstrated a two-fold voltage enhancement in the charge for the same voltage, and that increase could potentially go significantly higher."

Computer clock speed hits a bottleneck

Since the first commercial microprocessors came onto the scene in the early 1970s, the number of transistors squeezed onto a computer chip has doubled every two years, a progression predicted by Intel co-founder Gordon Moore and popularly known as Moore's Law. Integrated circuits that once held thousands of transistors decades ago now boast billions of the components.

But the reduced size has not led to a proportional decrease in the overall power required to operate a computer chip. At room temperature, a minimum of 60 millivolts is required to increase by tenfold the amount of electrical current flowing through a transistor. Since the difference between a transistor's on and off states must be significant, it can take at least 1 volt to operate a transistor, the researchers said.

"We've hit a bottleneck," said Khan. "The clock speed of microprocessors has plateaued since 2005, and shrinking transistors further has become difficult."

The researchers noted that it becomes increasingly difficult to dissipate heat efficiently from smaller spaces, so reducing transistor size much more would come at the risk of frying the circuit board.

The solution proposed by Salahuddin and his team is to modify current transistors so that they incorporate ferroelectric materials in their design, a change that could potentially generate a larger charge from a smaller voltage. This would allow engineers to make a transistor that dissipates less heat, and the shrinking of this key computer component could continue.

Notably, the material system the UC Berkeley researchers reported shows this effect at above 200 degrees Celsius, much hotter than the 85 degrees Celsius (185 degrees Fahrenheit) at which a current day microprocessor works.

The researchers are now exploring new ferroelectric materials for room temperature negative capacitance in addition to incorporating the materials into a new transistor.

Until then, Salahuddin noted that there are other potential applications for ferroelectrics in electronics. "This is a good system for dynamic random access memories, energy storage devices, super-capacitors that charge electric cars, and power capacitors for use in radio frequency communications," he said.

Provided by University of California - Berkeley