Ferroelectric memristors may lead to brain-like computers

October 4 2012, by Lisa Zyga

(Phys.org)—As electrical pulses travel through the body's nervous system, they are passed from neuron to neuron by synapses. A synapse, which consists of a gap junction and the cell membranes of the transmitting and receiving neurons on either side of this gap, has a structure that is a lot like the electrical component called a memristor. Memristors and synapses also function in a similar way: by remembering the resistance of a current passing through them, they enable memory.

In a new study, a team of researchers from France, the UK, and Japan has demonstrated that a device called a ferroelectric tunnel junction (FTJ) that experiences voltage-controlled resistance variation represents a new class of memristor. Due to the FTJ's quasi-continuous resistance variations exceeding two orders of magnitude, along with its rapid 10-ns operation speed, the device could one day serve as the basic hardware of neuromorphic computational architectures, or computers that function like brains.

The study, led by Agnès Barthélémy, a professor at Paris-Sud University in Orsay, France, is published in a recent issue of Nature Materials.

"We have conceptualized, designed and realized a completely new type of memristor that performs as well as classical ionic memristors, but operates through an electronic mechanism," coauthor Manuel Bibes, a CNRS research scientist, told *Phys.org*. "While this should have clear advantages in terms of reproducibility, the key breakthrough is that our ferroelectric memristor behaves according to well-established physical models. This allows a precise understanding of the memristive response, and also opens the door for engineering memristive functions on-demand."

An FTJ consists of two metal electrodes separated by a thin ferroelectric layer, with the ferroelectric material defined by its spontaneous electric polarization. As previous research has shown, switching the polarization between "up" and "down" using an applied electric field changes the FTJ's electrical resistance from "low"/"on" to "high"/"off."

In the current study, the researchers have shown that they can produce a virtually continuous range of resistance levels between the low and high states by controlling the pulse amplitude, duration, and number of pulses. By applying a consecutive sequence of positive pulses, the researchers could gradually increase the resistance, demonstrating the cumulative effects of multiple pulses. Likewise, a sequence of negative pulses results in a gradual decrease in resistance.

To model the resistance switching dynamics, the researchers first analyzed the relative fraction of ferroelectric domains with "down" polarization orientation. The fraction of down domains varies from 0 in the "on" state to 1 in the "off" state. So the application of positive pulses increases the fraction of down domains, increases the resistance, and eventually leads to the "off" state. Negative pulses do the opposite.

Experimental tests showed that the fraction of down domains does not evolve smoothly with the application of pulses, but instead has more of a "wavy dependence." This type of evolution suggests that different zones of the FTJ have different switching dynamics, causing some zones to flip their domains more easily than others. The researchers modeled this observation by accounting for different propagation speeds and nucleation kinetics throughout the FTJ. Their model closely agrees with the experimental data.

The ability to reversibly tune the FTJ's resistance by more than two orders of magnitude by varying the pulse amplitude and/or number qualifies FTJs as memristive devices. And they're good ones, too, compared with previous purely electronic memristors where the resistance can be tuned over a range of no more than a factor of two.

These features make FTJ memristors promising components for brain-inspired computational architectures. In particular, the ability to change the resistance level by applying consecutive pulses makes them appealing for fabricating artificial synapses, since the pulses act similarly to the consecutive spikes emitted by neurons.

"Ferroelectric memristors may be arranged in complex architectures to connect electronic neurons (typically based on CMOS elements), just as biological synapses connect to 'real' neurons on the brain," Bibes said. "If the number of both the neurons and the memristive connections between them is sufficiently large, the architecture may be used very efficiently to perform tasks such as pattern recognition, data mining, and eventually for 'learning.'"

In the future, the researchers plan to make further improvements in the memristors along with pursuing applications.

"On one hand, we want to get deeper into the physics of our ferroelectric memristors by studying, for instance, the role of the materials involved (not only the ferroelectric but also the electrodes)," Bibes said. "On the other hand, we also plan to build small-scale neuromorphic architectures and run brain-inspired computing tasks."

More information: Andre Chanthbouala, et al. "A ferroelectric memristor." *Nature Materials* 11, 860–864 (2012)
DOI:10.1038/nmat3415