Nanodevices could use quantized current to operate future electronics

November 26 2007, By Lisa Zyga

For the past several decades, virtually all electronics devices have been based on the CMOS logic system, which uses semiconductors and transistors to form digital circuits. However, researchers today are investigating the use of novel materials and technologies to create superior circuitry, which would lead to smaller, faster and smarter computers, cell phones, and other devices.

Most recently, scientists Wancheng Zhang, Nan-Jian Wu, and Fuhua Yang from the Chinese Academy of Sciences in Beijing have designed logic gates—a basic component of digital circuits—that use the quantization of electric current to perform operations. The recent development of two unique nanodevices has enabled scientists to control the flow of individual electrons, allowing the team to propose novel universal logic gates that are more compact than conventional logic gates.

"When talking about future digital circuits using nanodevices, researchers usually focus on their potentially high density and fast speed," Zhang told *PhysOrg.com*. "The greatest significance of this work is that we show that the unique operating principles of novel nanodevices can be used to implement smarter logic circuits with very compact structures. Therefore, future nano-based-circuits can have advantages both in size and in circuit structure."

In their study published in *Nanotechnology*, the researchers proposed two different designs for building "periodic-threshold threshold logic gates"

(PTTGs).

In the first method, the researchers proposed using an electron waveguide—which is essentially a one-dimensional channel—to take advantage of the wave nature of the electron. Because the channel is narrower than a single electron, an electron wave can travel through the channel without scattering, in a discrete number of modes. By using two of these electron waveguides, and combining their current values, the logic gate could have an output consisting of the combined input currents.

In the second method, the scientists proposed a PTTG using a single-electron turnstile, a device that can accurately control the number of transferred electrons using a quantum effect called the Coulomb-blockade effect. This effect, which only exists in a tiny area about the size of a single electron particle, ensures that the number of electrons transferred by the turnstile is a quantized function of its voltage. By controlling the voltage, the researchers could theoretically determine the number of captured electrons, and use two single-electron turnstiles to transfer electrons to a storage node, with the difference of electrons between the two turnstiles determining the output signal.

Then, the researchers suggested how PTTGs made in either of these two ways could be used to create universal logic gates. Due to the flexible quantization characteristics of the current-quantization devices, a single PTTG could implement nearly all 256 three-input Boolean functions (the most common computing method in digital electronics). Also, two PTTGs put together could implement all 65,536 four-input Boolean functions.

“The quantized current devices have several quantization states that can be used to represent discrete logic states,” Zhang explained, “while conventional CMOS transistors have only two logic states: on and off.

That's why the quantized current device can enable complicated and compact periodic-threshold threshold logic gates.”

The researchers also explained that the current-quantized logic gates could have several advantages over conventional logic gates. For one thing, they have both a simple and more universal circuit structure. Compared to the 40 transistors required by a conventional three-input logic gate, a PTTG would only require 10 equivalent devices. Further, the two current-quantized logic gates both have very small sizes, offering the potential for high density circuitry. Finally, due to their small size and low resistance, the new logic gates may also have a significant speed advantage.

“The key to achieving quantized current devices is small device geometry,” Zhang said. “Both the ballistic transport of electrons in electron waveguides and the Coulomb-blockade effect in the single-electron turnstile require small device geometry to overcome the thermal energy. With recent advances in fabrication, room-temperature operations of the electron waveguide and single-electron turnstile are possible.”

More information: Zhang, Wancheng, Wu, Nan-Jian, and Yang, Fuhua. “Compact universal logic gates realized using quantization of current in nanodevices.” *Nanotechnology* 18 (2007) 495201 (8pp).

26) retrieved 23 April 2024 from https://phys.org/news/2007-11-nanodevices-quantized-current-future-electronics.html