History of Innovation

C-93056

DALLAS
December 8, 1993

Texas Instruments Demonstrates World's First Quantum IC that Operates at Room Temperature

Scientists at Texas Instruments have demonstrated the world's first quantum effect integrated circuit that operates at room temperature (75 degrees F). The circuit, which utilizes a quantum-mechanical effect known as resonant tunneling, is projected to operate three times faster and have three times the density of conventional integrated circuits. The development was described in a paper given this week at the International Electron Devices Meeting (IEDM) in Washington, D.C.

The logic circuit, a one-bit full adder, incorporates both bipolar and resonant tunneling transistors. The resonant tunneling bipolar transistors reside sidy-by-side with conventional double heterojunction bipolar transistors. This marriage of two technologies - conventional bipolar and resonant tunneling - is made possible by a TI-developed process. It allows for more efficient switching operations and more efficient implementation of logic functions. Multiple logic functions can be performed using fewer transistors. The adder consists of 17 transistors - two resonant tunneling transistors and 15 heterojunction bipolar transistors - replacing as many as 40 conventional transistors fabricated using conventional industry processes.

The resonant tunneling transistors in the circuit are based on quantum-mechanical effects. The principles of quantum mechanics apply to the behavior of matter and energy at dimensions of .02 microns and below. At these small sizes, electrons behave as waves and can pass through classically impenetrable barriers.

"Demonstrating resonant tunneling transistors at room temperatures is a significant breakthrough for the practical utilization of quantum effect devices," explained Alan Seabaugh, senior member of the technical staff in TI's Central Research Laboratories. "It means that this technology can be applied to portable and desktop computing applications without the need for refrigerants or thermoelectric coolers."

Previous industry demonstrations of quantum devices were limited to operations at -320 degrees Farenheit, too cold for broad commercial use.

The key technical breakthrough in demonstrating the IC was the development of resonant tunneling transistors with practical values of current gain, 'on-off' current ratio, and breakdown voltage.

"These devices (resonant tunneling transistors) now have the performance needed to construct a complex integrated circuit," explained Seabaugh. "They are compatible with existing functions in a system since they operate at comparable currents and supply voltages."

TI scientists employed resonant tunneling which permits an electron, under certain conditions, to pass through a classically impenetrable barrier. In this case, the transistors operate by transferring electrons from one layer of the circuit to another under the control of a voltage that is applied to a control terminal, as in a conventional transistor. However, the design of the quantum switches exploits the quantum resonances in the electron motion, so that many "on" and "off" switching states can be obtained from a single transistor. This switching characteristic reduces the number of transistors needed, and the number and length of wires required to assemble the transistors into an IC.

"These transistors can be build with the same geometries as conventional transistors, yet there is a 3x improvement in speed and density," said Gary Frazier, nanoelectronics manager at TI. "If we can replace three transistors with one, we get essentially one generation free."

The bipolar resonant tunneling transistors used in the demonstration IC achieved a current gain as high as 100 and an in-resonance to off-resonance current ratio of 70. It operated at 3 volts with a logic swing of 1.2 volts. An NpN heterojunction bipolar transistor structure was used with a resonant tunneling, double barrier heterostructure integrated into its emitter region.

Instead of silicon, the quantum IC is fabricated with compounds of indium, phosphorous, gallium, aluminum and arsenic. A technique called molecular beam epitaxy is used to build the multiple layers of semiconductor materials on the base wafer. Each layer is only a few atoms thick, about 1/10,000 of the thickness of a human hair.

Although quantum effect electronics are normally spoken of in future tense, there are several near-term applications of resonant tunneling transistors. These include microwave (X-band), analog-to-analog converters, high bandwidth digital video, ultra-high speed triggering circuits, and high speed logic.

Researchers in TI's Central Research Laboratories have worked with quantum effect devices since 1982, demonstrating the first quantum effect transistor in 1988. Work on the quantum IC has been supported in part by a contract from the Air Force Wright Laboratories, the Advanced Research Projects Agency, (ARPA), and the Office of Naval Research.