Eidgenössische Technische Hochschule Zürich
Swiss Federal Institute of Technology Zurich

Background
Embargoed until: Tuesday, May 17 2011, 01:00 p.m.

IBM Research – Zurich uses nanowires to build transistors of the future

Novel transistor technology promises a 10 times reduction of the energy consumption of processors

Rüschlikon, Switzerland, May 17, 2011 – The traditional scaling of semiconductor technology is approaching fundamental physical limits. To improve the performance of future computers, new techniques and innovative device concepts are required. Scientists of the Nanoscale Electronics group at IBM Research – Zurich are bringing about a change of paradigm by using semiconducting nanowires as circuits for future processors. Nanowires, which measure only a few millionths of a centimeter in diameter, allow not only further structural miniaturization, but also have the potential to enhance the energy efficiency of processors by more than one order of magnitude.

For almost half a century, the semiconductor industry has doubled the number of transistors per chip surface area every two years. Today’s standard processors, which are no larger than a fingernail, already comprise more than a billion of these basic components. The characteristic size – the so-called gate length – of today’s transistors measures only some 30 nanometers. “The miniaturization is continuing, but the voltage necessary to switch the transistors on and off has remained virtually constant at 1 Volt and cannot be reduced significantly just by scaling. An improvement of computational performance therefore goes hand-in-hand with higher energy consumption and cooling requirements,” explains Dr. Heike Riel, head of the Nanoscale Electronics research group at IBM Research – Zurich. The so-called gate electrode in a transistor switches the current flow on and off, which corresponds to “0” and “1” in binary notation. However, today’s structures have become so tiny that the gate electrode can no longer fully control the current flow, causing current leakage during operation of the device, even in standby mode. This wastes energy and heats the circuit needlessly.

The trend towards ever-growing energy consumption is what scientists are endeavoring to halt by integrating new transistors based on the nanowire architecture. This novel approach consists of replacing today’s planar architecture with a three-dimensional one whereby the gate electrode is wrapped entirely around the cylindrical nanowire. “This wrapping allows the electrode to control the current flowing through the ultrathin nanowire from all directions, enabling the transistor to switch ‘on’ and ‘off’ in an optimal way,” explains physicist Heike Riel. But not only the current leakage could be eliminated. IBM scientists have shown that previously noncombinable semiconductors such as indium arsenide (InAs) and silicon can be joined into so-called heterostructures on the small nanowire cross-section area of smaller than 50 nanometers in diameter. These material combinations are particularly suitable for the fabrication of so-called tunnel field-effect transistors (tunnel FETs). The novelty about these transistors is that they switch based on the quantum mechanical tunnel effect, and thus require a voltage of less than 0.3 V to switch the transistor between the “on” and “off” states. Thanks to this reduced operation voltage, these novel transistors consume only about one-tenth of the power required by today’s transistors. In standby mode, their energy consumption is virtually zero.

Reducing energy consumption while improving computational performance by means of novel nanotechnological approaches such as the nanowire architecture promises to allow significant progress to be made in the fields of electronics, computer technology and communication technology.

In around a decade from now, supercomputers are predicted to achieve exaflop/s performance, i.e. 10^{18} operations per second. This means that an exascale supercomputer will be approximately 300 times faster than the fastest computer today. Without improved energy technologies, however, the energy consumption would grow proportionately to the point where such a future supercomputer would require its own dedicated power plant. At IBM Research, scientists are investigating technologies at various levels of the entire stack. In terms of individual transistors, tunnel FETs based on nanowires appear to be a promising approach to achieve a massive reduction of energy consumption at the processor level. For mobile devices such as smart phones, tablet PCs or notebooks, significantly lowering the energy consumption by nanowire transistors would not only extend the duration of a battery charge, it could allow such mobile devices to be operated in an autonomous manner. “That is our long-term vision,” says Riel, “and it could well become possible by means of more energy-efficient components and improved energy harvesting from the environment, such as energy produced by solar cells or transforming a user’s body temperature.”

For the semiconductor industry, this paradigm change is particularly enticing because nanowire transistors of silicon will allow further generations of conventional CMOS semiconductor technology scaling. Tunnel FETs also lend themselves to be integrated using classical process technologies. Until this vision can become a reality, however, intensive research is needed to develop nanowires to the point of commercial viability. The impact of fundamental nanoscale physical effects must first be explored. For example, changing the diameter of a nanowire changes its electrical and optical properties, and further different material combinations can influence the quantum-mechanical tunnel effect.

To investigate the underlying physical properties, the Nanoscale Electronics research group will benefit greatly from the infrastructure of IBM’s new Nanotechnology Center. It offers cutting-edge process facilities in addition to ultrastable conditions in the so-called “noise-free” labs. These specially constructed laboratories are shielded against a wide range of interference sources such as electromagnetic fields, acoustic noise, vibrations and temperature fluctuations. The degree of insulation from all such noise sources is unparalleled and promises to provide scientists an environment in which they can work at unprecedented levels of measurement sensitivity and accuracy.

Dr. Heike Riel and her team will use the ‘noise-free’ labs to investigate such phenomena as how the current in a nanowire changes if the nanowire is stretched or compressed. In classical CMOS technology, these so-called strain effects led to massive improvements of performance. For the highly sensitive experiments with a “strain tool”—a special instrument developed in-house by IBM scientists—the electronic properties of a nanowire during stretching will be accurately monitored, thanks to the optimal conditions provided by the ‘noise-free’ labs.

The Nanotechnology Center will play a vital role in IBM’s cooperation with its strategic partner, the world-renowned ETH Zurich, the Swiss Federal Institute of Technology. “There will be intensive collaboration with ETHZ on basic research projects, and we will also supervise graduate students jointly,” research team leader Riel explains. “We will learn from each other, with each other and complement each other with regard to theoretical and experimental projects.”

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Binnig und Rohrer Nanotechnology Center

With the 2011 inauguration of the state-of-the-art Binnig and Rohrer Nanotechnology Center, jointly operated by IBM Research and ETH Zurich in a strategic partnership, the Zurich metropolitan area has further solidified its leadership in the field of fundamental research. “In collaborating with leading universities and industrial partners as well as IBM’s global R&D organization, we are exploring novel nanoscale structures and devices for enhancing future information technologies,” states Dr. Matthias

Kaiserswerth, Director of IBM Research – Zurich. “The focus of our work encompasses nanowires, spintronics, nanophotonics and the development of novel storage technologies such as phase change memory.” There are manifold collaborations in exploratory research projects between IBM and ETH Zurich, which has already established three professorships for this new facility. Nanotechnology is a key technology for the 21st century and has the potential to revolutionize not only the future of IT but also fields such as medical diagnostics or energy technologies.
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