Karlsruhe Institute of Technology

Division V – Physics and Mathematics

Institute of Applied Physics (APH)

World's Smallest Transistor Improves IT Energy Efficiency

Quantum-electronic Device Switching Current with a Single Atom

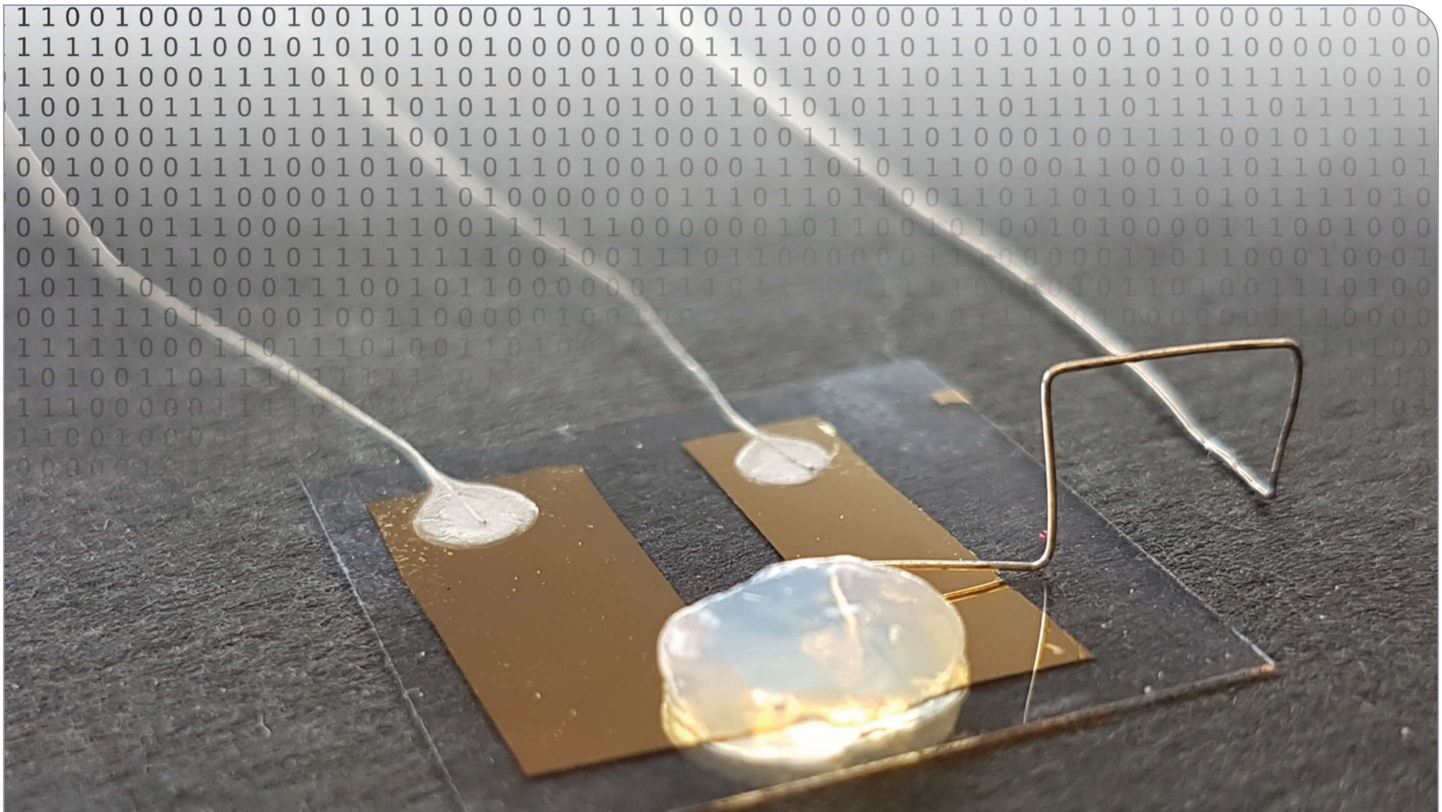
Digitization consumes enormous amounts of energy. Whether in data processing centers, PCs, smartphones, or embedded systems for applications ranging from washing machines to airplanes - transistors are the central elements of digital data processing. A USB memory stick available for just a few euros already contains several billions of transistors. A single-atom transistor developed at KIT's Institute of Applied Physics (APH) could make a considerable contribution to energy efficiency in information technology in the future. This quantum-electronic element enables switching energies that are by a factor of 10,000 below those of conventional silicon technologies.

Single-atom Transistor Operating at Room Temperature

For the transistor, which has reached the limits of miniaturization, the Karlsruhe researchers have manufactured two tiny metal contacts between which there is a gap the width of a single metal atom. A tiny electrical control voltage is used to push a silver atom into this gap to close the circuit. When the silver atom is pushed out again, the electric circuit is broken. The smallest transistor in the world thus switches an electrical current via the controlled and reversible movement of a single atom. Unlike conventional quantum-electronic components, however, the single-atom transistor does not only function at extremely low temperatures near the absolute zero of minus 273 degrees Celsius. It already works at room temperature, which is a decisive advantage for future applications.

A Gel Electrolyte Improves Safety and Handling

The world's smallest transistor is made entirely of metal and does not require a semiconductor. This results in extremely low electrical voltages and thus an extremely low energy consumption. Initially, the Karlsruhe single-atom transistor relied on a liquid electrolyte. In the meantime, the researchers have produced the first transistor that works in a solid electrolyte: The gel electrolyte obtained by



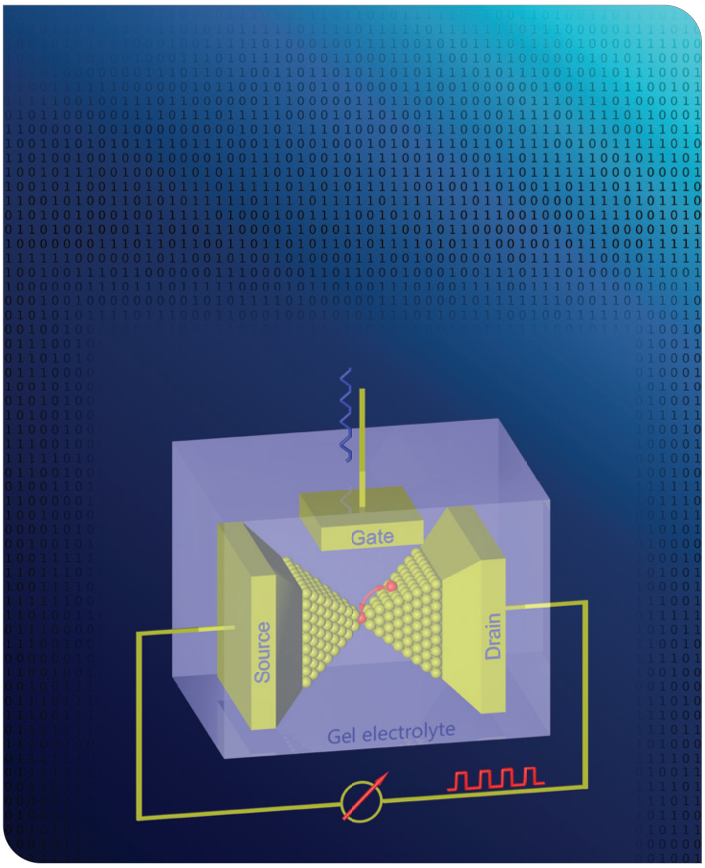
The single-atom transistor has reached the limits of miniaturization (Image: Research Group Professor Thomas Schimmel/KIT).

gelling an aqueous silver electrolyte with pyrogenic silicon dioxide combines the advantages of a solid with the electrochemical properties of a liquid, thereby improving both the safety and the handling of the single-atom transistor.

Concept Opens up Perspectives for Quantum Technologies and Ultrahigh Frequencies

In addition to reducing energy consumption, quantum-electronic systems based on atomic transistors open up new perspectives: In the future, they could enable logic devices to operate at ultrahigh frequencies, which cannot be achieved with conventional concepts. Since they are true quantum devices, the conductance values for the logical "zero" and "one" are clearly defined. Thanks to quantization, there is, in principle, no danger of undesirable intermediate values.

This project is currently funded by the Werner Siemens Foundation in cooperation with ETH Zurich. Research at KIT is carried out at the newly established Center for Single-Atom Technologies (C. SAT) headed by KIT Professor Dr. Thomas Schimmel. Besides, the development of the world's first single-atom transistor at KIT was already previously funded by the Volkswagen Stiftung, the German Research Foundation, and the Baden-Württemberg Foundation.



Schematic representation of the mode of operation: In the single-atom transistor, a very low control voltage at the gate electrode moves a single atom in a controlled manner, thereby closing or breaking an electrical circuit (Image: Research Group Professor Thomas Schimmel/KIT).

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