

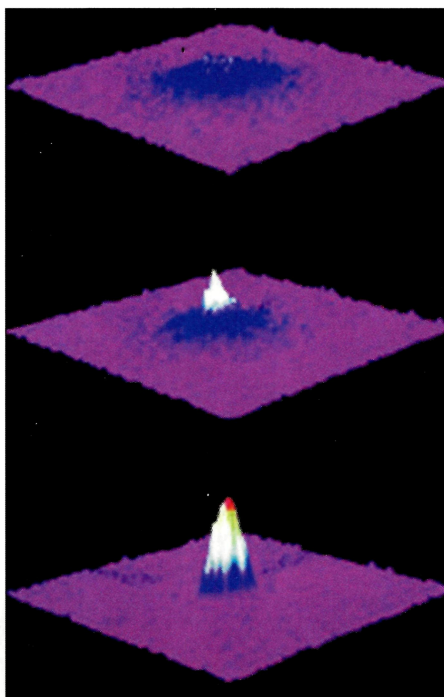
Edited by Archana Sharma

Cold atoms promise versatile atomic chips

Using a microelectronic chip to hold a cloud of cold atoms hovering above it, physicists in Germany may have developed an "atomic chip" that might eventually shunt Bose-Einstein condensates around an atom chip – just as electrons are shunted around a conventional silicon chip.

This tiny circuit creates and manipulates a peculiar state of matter called a Bose-Einstein condensate (p21). Previously these condensates were made using light or magnetic fields to cool and confine a gas of atoms. Electric currents travelling through wires in the atom chip create a confining magnetic field barely 1 mm wide. This field holds a cloud of 1600 rubidium atoms at a height of less than a tenth of 1 mm above the chip surface.

Quantum mechanics dictates that atoms, being so small, have wavelike properties. Normally each wave bobs up and down independently. However, in a Bose-Einstein condensate all of the atomic waves are "coherent" – moving in step, in the same quantum state. Instead of behaving like a



Bose-Einstein condensate – a new route for microelectronics?

collection of atoms, such a condensate behaves as a single superatom – as one quantum-mechanical wave containing many identical particles. Condensates can be fashioned into very small structures, below the resolution limits of existing fabrication techniques. This may permit the increasing miniaturization of electronics.

There are also fundamental reasons for wanting to control and manipulate Bose-Einstein condensates. For example, they allow researchers to look at poorly understood aspects of quantum theory, such as the process of decoherence – when coherent quantum systems are disturbed by interactions with their environment. Such studies should be easier with the new atom chip. Because the device confines the condensate on such a small scale and in very tight traps, it will be easier to tailor the properties of the atom cloud to suit a particular experiment.

Further reading

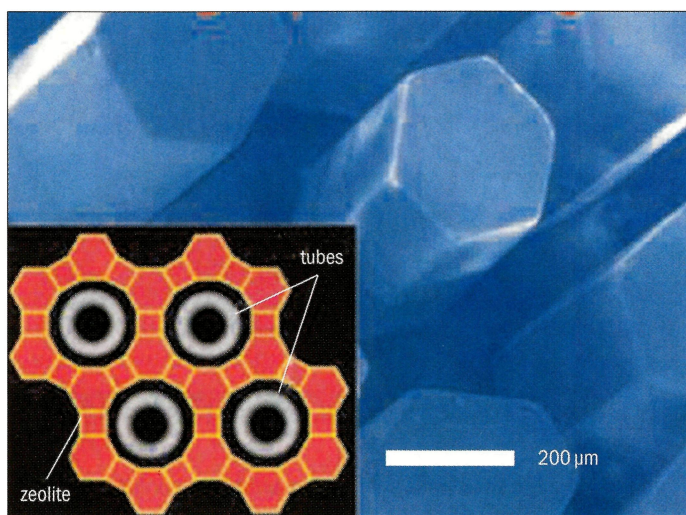
W Hansel et al. 2001 *Nature* **413** 498–501.

Small-diameter nanotubes can become superconducting

Nanotubes (p15; *CERN Courier* January p26) may be made only of carbon, but their unusual shape and size give them a host of intriguing electronic properties, the most recently discovered being superconductivity.

Physicists in Hong Kong have shown that nanotubes with exceptionally small diameters become superconducting at relatively high temperatures. The researchers used their own technique to synthesize single-walled nanotubes inside the channels of zeolite crystals. The tubes, which have diameters of only 4×10^{-8} cm, appear to become superconducting at about 15 K – much higher than the liquid helium temperatures normally associated with superconductivity.

These latest results have come soon after a report from French and Russian researchers



Carbon nanotubes have intriguing electronic properties.

that reveals that small bundles of single-walled nanotubes superconduct – albeit at a low temperature of 0.55 K.

Calculations indicate that the smaller the tube diameter, the higher the superconducting

temperature. This is due to the greater curvature of the tube, which increases the interaction between electrons and lattice vibrations (phonons) – a property that is essential for superconductivity.

Some scientists associate this extreme curvature with the superconductivity of fullerenes (large carbon molecules). Alkali metal-doped fullerenes superconduct at up to 40 K and electron hole-doped fullerene crystals superconduct at 52 K. The group will now try doping the nanotubes to see if it can increase the superconducting temperature even further.

Further reading

M Kociak et al. 2001 *Phys. Rev. Lett.* **86** 2416.

Z K Tang et al. 2001 *Science* **292** 2462.

Dutch team uses nanostructures to produce logic gates, an oscillator and electron beams

Developments show that carbon nanotubes – rolled-up sheets of graphite about 1 nm in diameter (p14; *CERN Courier* January p26) – could provide the technology of tomorrow.

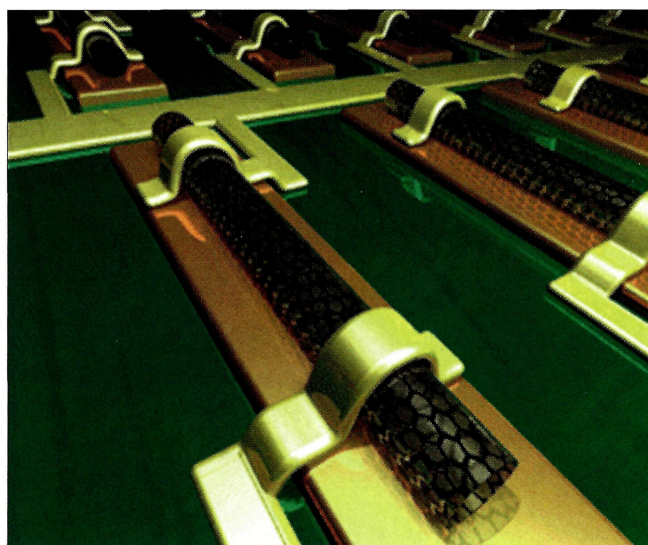
The ever-shrinking world of electronics has become even smaller following the first demonstration of digital logic circuits made from carbon nanotubes. A research team in the Netherlands used different combinations of “nanotube transistors” to create several devices, including a voltage inverter and a NOR logic gate. As conventional silicon microelectronics approach a fundamental size limit, these devices, operating at room temperature, are an important step towards nanoelectronics.

Carbon nanotubes have been used to make a variety of electronic components, including diodes and field-effect transistors (FETs). A FET can be made from a nanotube by attaching gate, source and drain electrodes.

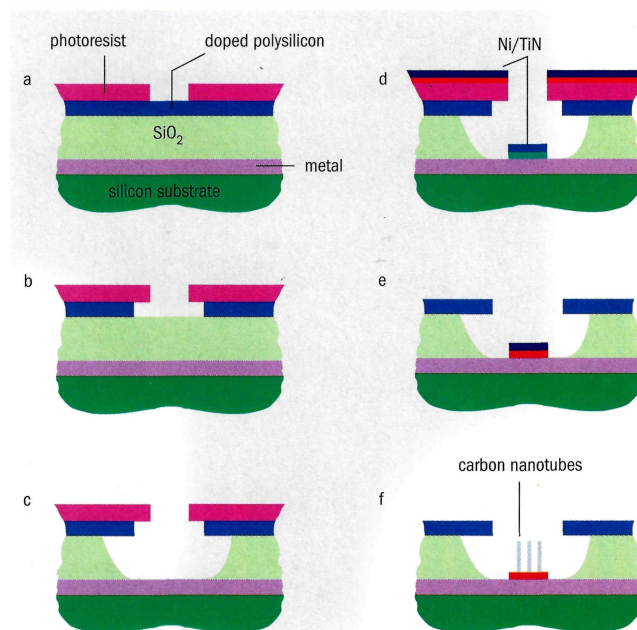
Now several of these FETs have been placed together on a single silicon chip to form different circuits. Their simple inverter device consists of a nanotube FET and a large bias resistance. It converts a high-input voltage to a low one – that is, “one” to “zero” – and vice versa. By adding an extra FET in parallel, the researchers made a NOR gate, needing two “zero” inputs to give a “one” output or two “ones” to give a “zero”.

Any of the standard logic gates can be created using different arrangements of these FETs. The team also created a “static random access memory” and an oscillator. The devices have gains of a factor of 10.

Electron-beam lithography was used to deposit aluminium gate electrodes on a silicon wafer. The nanotubes were placed on



Nanologic – a carbon nanotube field-effect transistor.



The self-aligned fabrication process for microcathodes.

top, and gold electrodes were added using an evaporation technique. There are still challenges to overcome, such as the difficulty in positioning the nanotubes accurately on the wafer, but emerging techniques, including a way to grow nanotubes directly on the chip, may solve this problem.

This could lead to electron-beam lithography equipment for chip making that could produce parallel beams as well as electron microscopes, based on a first report of field emission measurements from carbon nanotubes with an integrated gate electrode from a French-UK team.

The nanotubes are used as field-emission sources in the device. The integrated gate electrode enables the device to achieve emissions at low field voltages. The team used a self-aligning technique, similar to the technique used to pattern CMOS gates, to create the gate, the insulator and the base for growing the nanotubes with one lithography mask.

With the gate aperture formed, the nanotubes are grown inside using plasma-enhanced chemical vapour deposition. This ensures that the nanotubes are always centred in the gate apertures, which are just 2 µm in diameter.

The major achievement of this work is the self-alignment of the multiwalled 30 nm diameter carbon nanotubes. The next step is to grow one carbon nanotube per nanohole and to have it perfectly centred in the gate aperture. Preliminary results show that it is possible. A single nanotube per gate would boost the efficiency of the applied field by avoiding the electric field screening when nanotubes are close together. The nanocathode is intended for parallel electron-beam lithography and microscopy. Other applications

could be in instrumentation and microwave vacuum amplifiers.

Further reading

A Bachtold *et al.* 4 October 2001 *Science* “<http://www.sciencemag.org/cgi/content/abstract/1065824>”.

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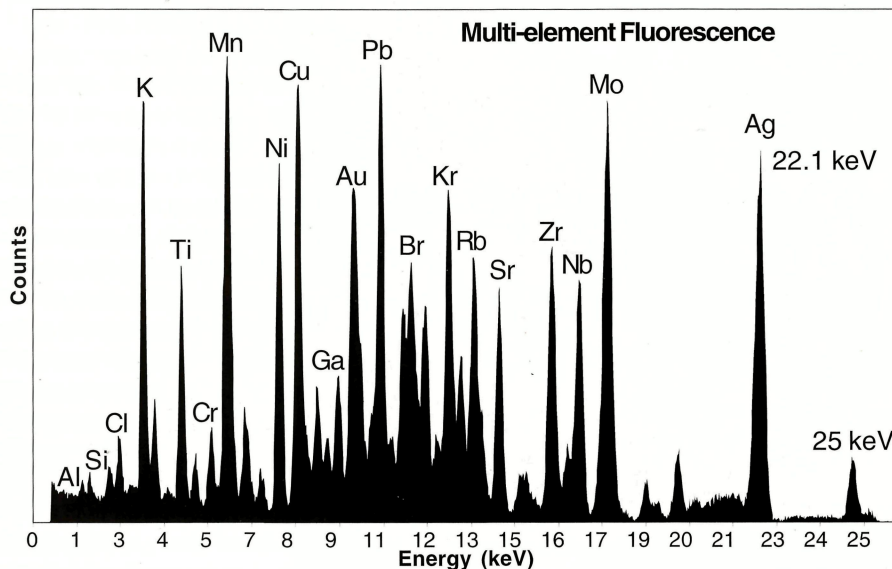
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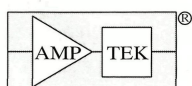
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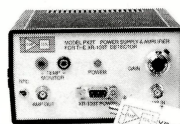
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