MOLECULAR COMPUTATION

Twisted logic

Chem. Commun. doi: 10.1039/b613201d; 2006

At its most fundamental level, computation requires that a number of inputs undergo a sequence of logic operations (AND, OR, NOT, and so on) to generate an output. Although silicon is the conventional hardware on which these processes run, replacing it with organic molecules could lead to new computational methods. Now, Wataru Yoshida and Yohei Yokobayashi from the University of California, Davis in the USA have used DNA aptamers (sequences that bind to small molecules) to build logic gates.

Aptamers that bind to the molecules adenosine and thrombin were linked through a spacer containing a fluorescent dye. Two shorter DNA strands, each partially complementary to one of the aptamer sequences, bind to the parent strand. Each carries a quenching group that reduces the fluorescence of the dye. If either adenosine or thrombin binds to its respective aptamer on the long strand, the base pairing is disrupted and the corresponding short strand is released. Fluorescence stays low, however, because one quencher remains. Only when both small molecules are present — and both short strands are released — does the fluorescence 'output' become significant, representing AND logic based on adenosine and thrombin 'inputs'.

Moreover, the DNA structures were reconfigured to give OR type logic, where the binding of either small molecule results in an enhanced fluorescence output.

NANOWIRE ARRAYS

Sensing with silicon

Appl. Phys. Lett. **89,** 153102 (2006)

Nanowires can be used for the detection of chemicals as well as biomolecular recognition events such as DNA hybridization. However, methods currently used to make the nanowire sensors are time consuming and involve photolithographic processing of semiconductors. Furthermore, the electrical properties of nanowires produced by such 'top-down' methods are non-uniform, leading to inconsistent device performance.

Now, Alec Talin and colleagues of Sandia National Laboratories in the USA have demonstrated the versatility of nanoimprint lithography for making chemical sensors based on silicon nanowire arrays. A silicon-on-insulator wafer was thermally imprinted using a silicon mold with 100-nm-wide parallel lines spaced 100 nm apart. Pattern transfer was achieved by ion etching to give large-area, highly uniform arrays of Si nanowires, each with a width of approximately 75 nm.

The array was built into a field-effect transistor structure by depositing aluminium electrodes, and was used to detect chemicals such as ammonia, nitrobenzene and phenol. The output from these sensors depends upon the polarity of the analytes and is proportional to their concentration. Nanoimprinting of Si nanowires may offer a simpler route than the use of carbon nanotubes for making chemical and biological sensors.

PATTERNING

Etch a sketch

Nature Mater. **5**, 914–919 (2006)

Photolithography is adept at patterning the same feature over large surfaces, whereas chemical etching and metal plating offer a high level of control over feature dimensions on nanometre scales. A hybrid of these techniques is the strategy behind lithographically patterned nanowire electrodepostion, a fabrication method developed by Reginald Penner and co-workers at the University of California, Irvine in the USA.

The process begins by making a 'sandwich' of a thin nickel layer between a glass substrate and a top layer of photoresist. Thin strips of the photoresist are removed to expose the nickel, which is then 'over-etched' to leave behind carved out spaces under the remaining photoresist. Standard electroplating is used to fill this space with gold, platinum or palladium to make thin metal wires.

The thickness and width of the metal wires — both of which can be controlled with 5 nm precision — are determined by the thickness of the nickel layer and the electroplating time. This technique can be used to make wires that are as small as 18 nm thick and 40 nm wide, though the minimum wire separation is limited by the photolithography step.

NANOELECTRONICS

Rapid writing

Appl. Phys. Lett. **89,** 163101 (2006)

Flash memory offers high-density, low-cost data storage, but it suffers from poor write speeds. To write a bit of data in one of these devices, which are essentially metal-oxide-semiconductor field-effect transistors, electric charge has to be injected onto a 'floating gate'. However, this involves electrons tunnelling through the thick insulating barrier that isolates the floating gate, which is a slow process.

To increase this write speed, Claes Thelander and co-workers at Lund University in Sweden have fabricated a new type of floating gate in a nanowire flash memory device. They replaced the thick barrier with a series of 17-nm quantum dots made of indium arsenide that are separated by thin (3–4 nm) tunnel barriers made of indium phosphide. The electrons are able to tunnel through the InAs/InP heterostructure much faster than they can through a single thick barrier.

The new structure permits write speeds of as little as 10 ns — nearly one thousand times faster than before. Although the device only works below 150 K at present, Thelander and co-workers hope that the use of smaller quantum dots and a different barrier material might make room-temperature operation possible.

MAGNETIC NANOPARTICLES

Safe for sperm

Langmuir **22**, 9480–9482 (2006)

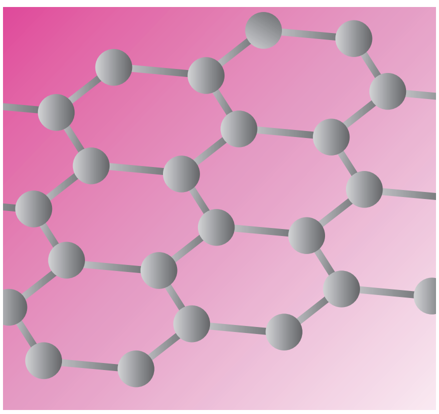
The low toxicity and magnetic properties of iron oxide nanoparticles have led to their use in various biomedical and diagnostic applications such as cell labelling and targeting, drug delivery and tissue repair. However, their affect on sperm cells has never been investigated. Researchers at the Bar-Illan University in Israel now show that loading sperm cells with magnetic nanoparticles does not affect the way they move or their ability to fertilize an egg.

Aharon Gedanken and co-workers incubated polyvinyl alcohol-coated iron oxide nanoparticles with bovine sperm cells for different periods of time. This coating, which protected the nanoparticles from oxidation, improved the particle uptake by the cells. Nearly half of the nanoparticles that entered the sperm were bound to various parts of the cell, with the highest density seen in the mitochondria, where energy is generated.

Nanoparticle-treated sperm was able to fertilize eggs with the same success rate as untreated sperm. Consequently, the presence of iron nanoparticles has no effect on the sperm's motility or its ability to undergo the acrosome reaction — the process in which it fuses with an egg. In the future, magnetic nanoparticles could be used to transport drugs into sperm cells.

GRAPHENE

Through thick and thin



Phys. Rev. Lett. **97,** 187401 (2006)

Graphene — a single layer of graphite — is the structural unit that wraps to form carbon nanotubes and fullerenes. Because the electron conduction is nearly collision free, even at room temperature, this atomically thin carbon sheet is also interesting in its own right. Only recently have researchers figured out how to cleave a layer or layers of graphene from graphite, and even then, atomic force microscopy has been the only reliable method to determine the number of layers.

Now, Andrea Ferrari of Cambridge University and colleagues show that Raman spectroscopy provides a unique fingerprint of the number of graphene layers. Raman spectroscopy measures the energy shift of light in a solid that results from interactions with atomic vibrations, electrons or a combination of the two. In this study, it is shown that a single, strong peak in the spectrum of graphene — the so-called '2D' peak — splits and shifts to a higher energy when there is more than one layer.

The fact that single and multiple layers of graphene have distinct Raman spectra reflects the difference in the electronic properties of a two-dimensional layer of carbon and three-dimensional graphite. This crossover appears to occur around five layers, when the spectrum of several layers of graphene and graphite become indistinguishable.

NANOWIRES

Pores for thought

J. Am. Chem. Soc. **128,** 14258–14259 (2006)

The unique electrochemical properties of cobalt oxide make it an important material for a range of applications. Now, researchers at Ohio State University in the USA have shown how hollow nanowires made of porous Co_3O_4 can be grown directly onto conducting substrates.

Yiying Wu and co-workers made nanowires that contained both cobalt hydroxide and Co_3O_4 by immersing the substrate in a hot solution of cobalt nitrate and concentrated ammonia. These nanowires were then converted into pure single-crystal Co_3O_4 nanowires by heating them. Scanning electron microscope images showed that the nanowires were hollow, approximately 500 nm in diameter and up to 15 μm long. They were also porous, with pore sizes of 3–4 nm. The nanowires were grown on a variety of substrates including silicon, transparent conducting glass and copper foil. Furthermore, it was possible to pattern the substrate, covering parts of it with gold and therefore preventing nanowire formation in these areas.

The ability to make good electrical contact with conducting substrates, combined with a high surface area, means that the nanowires could prove useful for applications such as lithium-ion batteries, gas sensing and electrochromic devices.

TOP DOWN BOTTOM UP

Organics take control

Molecules and silicon devices can work together, as can chemists and engineers.

Building a molecular computer is a challenge that calls for expertise in a variety of different disciplines. James Tour, a chemist at Rice University in Texas, was already collaborating with John Reif, a computer scientist at North Carolina State University, on such a project when he realized that he needed help from someone who knew about the packaging and fabricating of electronic devices. Reif put Tour in contact with Paul Franzon, an electrical engineer at North Carolina, and they have now shown that organic molecules can control the electronic characteristics of silicon field-effect transistors (*J. Am. Chem. Soc.* **128,** 14537–14541).

Tour, Franzon and co-workers fabricated a pseudo-MOSFET — a form of field-effect transistor that serves as a proof-of-concept device — that consisted of boron-doped source and drain electrodes with a channel in between. After Franzon prepared the devices, Tour grafted organic molecules with different electronic properties onto the channel region of the transistors. Electron-poor molecules increased the conductance of the channel, whereas electron-rich molecules had the opposite effect. Grafting molecules in this way is similar to doping, which is central to all semiconductor devices, and this approach could prove to be useful when electronic devices become so small that the traditional methods of doping no longer work.

What has Tour learned from the collaboration? "Be prepared to learn a new language and explain yourself very simply," he says. "Even simple terms like 'hole mobility' can cause a synthetic chemist to scratch his head, but once he realizes that we are simply talking about the flow of cations, then discussions become easy." The two sides also had different approaches to laboratory chemicals. "Engineers are sometimes skittish about using solvents like dichloromethane," says Tour, "but they will use terribly dangerous compounds such as silane without batting an eye".

The definitive versions of these Research Highlights first appeared on the *Nature Nanotechnology* website, along with other articles that will not appear in print. If citing these articles, please refer to the web version.