Flat-pack brings creativity to AFM

The Størmlingo AFM provides one of the most accessible nanoscopes to date.

The first atomic force microscope (AFM) images on non-conducting surfaces marked a feat of ingenuity and technical skill bordering on the improbable. Thirty years on and the same technique capable of nanoscale resolution has now been flat-packed into an affordable unit that can be assembled by 11-year-old schoolchildren. The Størmlingo flat-packed atomic force microscope is an open-platform nanoscope imaging device that can be readily assembled and modified, thereby opening up the technology for the user’s creativity to come to play.

Størmlingo’s AFM weighs in at an affordable $2999 and has been stress tested by a group of 11-year-old schoolchildren who were able to assemble the device in an hour. It operates in both contact and non-contact mode and achieves better than 20 nm resolution on 128 × 128 pixels in 15 minutes in its standard format.

“The keywords that inspired us were ‘play’ and ‘creativity’,” says Weili Liu, CEO of Størmlingo Nano. Nanoscope imaging tools are not available for most people to “play” with because of the high complexity and price of the systems – with the low-cost flat-packed AFM this could change. Liu lists the main challenges of traditional AFMs as precise optics to monitor the AFM probe, a high-voltage signal for driving the high-resolution scanner, and a rigid framework that holds these two parts for nanoscale imaging. “It’s very challenging to make a complicated system simple and low cost,” says Liu.

One of the breakthroughs was the realization that a conventional DVD head provides the perfect optical-mechanical read out for a cantilever. “By using our disruptive technologies, we were able to take advantage of components from consumer products such as a DVD/Blu-ray optical pick-up unit for replacing AFM optics and an AFM scanner made by piezo buzzers.”

The company also uses printed circuit boards to provide a rigid mechanical structure and wiring for the electrical signal, which is key to the operation of the flat-packed AFM. “In the past 200 years, classroom microscopy has been limited to the microscope,” says Liu. He describes the company’s goal as bringing the flat-packed AFM to classrooms for students to explore nanotechnology. He adds: “We believe there will be millions of people in the world who can explore nanotechnology with our flat-packed, low-cost, easy-assemble AFM.”

To celebrate the 30th anniversary of the AFM and the Nobel prize for scanning tunneling microscopy, Nanotechnology is preparing a focus collection of the current state-of-the-art developments with these tools. There is also a webmovie series and an STM and AFM favourite images board.

Anna Demming is editor of nanotechweb.org.

Nanotechnology announces first award winner

When Nanotechnology invited nominations for its first ever Young Researcher Award, the wealth of talent and achievements highlighted among early-career researchers was striking. Jae Hyun Lee at Harvard Department of Chemistry & Chemical Biology stood out among this elite crop of promising young scientists.

“In 2003 there was a huge boon in nanoparticle chemistry,” says Lee. “Quantum dots were highly prad – such as cadmium sulphide and tellurium selenide. But at the same time my advisor and I saw opportunities for other types of nanoparticles, that is magnetic nanoparticles.”

Lee describes how his work on nanoparticles for MRI and cancer theranostics required a deep understanding of magnetism, biology and medicine, as well as inorganic chemistry. “It took three to four years to understand magnetism, but at the same time I needed to know biosystems such as protein-protein interactions – the terminology is very different.”

His move to Harvard to work with Lieber now requires him to also rapidly assimilate the knowledge and understanding at the vanguard of nanoelectronics research. Despite the difficulties associated with changing research focus, Lee enjoys learning new fields. He tells nanotechweb.org that in fact changing subjects has not been the hardest thing in his research career so far.

Lee has had fortunate encounters with keen scientists throughout his life. His interest in science started at school, where he was encouraged by his father who was a science teacher. An excellent chemistry teacher at school further fostered his interest in science and prompted him to opt for a major in chemistry at college. “The best luck of my life was when my advisor at Yonsei University, Jinwoo Cheon,” says Lee. “He is really enthusiastic about science.”

Nanotechnology will be presenting the Young Researcher Award annually. To make your nomination for the 2016 Young Researcher Award visit iopscience.org/nano.

Anna Demming is editor of nanotechweb.org.
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Innovation with Integrity
Nanostructures, such as carbon nanotubes, are often added to polymers and composites to enhance their strength. The extreme mechanical properties of carbon nanotubes suggest an obvious rationale behind this approach. However, as Markus Buehler and Isabelle Su at Massachusetts Institute of Technology in the US highlight in their recent topical review (Nanotechnology 27 302001), the behaviour that renders nanomaterials soft or strong can be far from trivial, often involving interactions on a range of scales from macrostructures to nanostuctures and—in the case of biostuctures—the amino acids and proteins they are built from.

Bone is a classic example of excellent natural material engineering. It primarily consists of tropocollagen fibrils—which would be too soft to support the weight of the skeleton under its daily loads—and hydroxyapatite, a stiff but fragile material prone to fracture. However, the alliance of these two imperfect candidates is an extremely tough, lightweight and robust material.

Based on a simple molecular model of mineralized collagen fibrils, Buehler showed that, as might be expected, the stiffness of mineralized fibrils lies somewhere between the two extremes of the component materials, with the mineral components bearing up to four times the stress of the collagen fibrils as more recent studies reveal. However, in addition, his 2007 study pointed out that the mineralization increases the energy dissipation during deformation. As he explains in his report, “The fibrillar toughening mechanism increases the resistance to fracture by forming large local yield regions around crack-like defects, a mechanism that protects the integrity of the entire structure by allowing for localized failure.”

**Strength through compromise**

Spider silk is another material that invokes give and compromise at nanoscale dimensions to achieve miraculous strength at the macroscale. Hydrogen-bonded beta sheets in the spider silk are embedded in a glycine-rich semi-amorphous protein structure—the main component of the material. The hydrogen-bond interactions between the sheets are weak but they work together, and under stress they readily break and reform, accommodating a slip-stick mechanism that makes spider silk incredibly resilient to fracture. As Buehler and Su explain in their review: “Cooperative deformation of hydrogen bonds transforms weakness into strength within the crystalline regions.”

The stick-slip mechanism of beta sheets also underpins the observed resilience to defects so that it can withstand fractures that span 50% of a fibril’s width or length. Here the nanoscale of the structures is key. For fibrils narrower than 50–80nm, the stresses and strains are evenly distributed, so the fibre behaves as if it were defect-free; above these critical dimensions, the stress and strain experienced begins to increase.

**Tuning of mechanical properties**

The beta sheets and other protein structures that give rise to the impressive macroscopic mechanical properties of spider silk are in turn determined by the complex molecular structure of amino-acid sequences. As an example, Su and Buehler break down the components of dragline silk, which spiders produce to escape predators.

The two main proteins—major ampullate dragline silk protein 1 (MaSp1) and major ampullate dragline silk protein 2 (MaSp2)—differ in terms of the quantity of proline protein residue and the main repeats. Both contain poly-Ala and poly-Gly—where the polyaniline domains form the stiff β-sheet nanocrystals responsible for the silk’s strength. However, MaSp1 also contains GGX motifs, which fold into 310-helices, and MaSp2 contains GPXXX, which forms β-spirals producing the semi-amorphous and disordered domain responsible for silk’s elasticity. The structures these proteins form can thus be controlled by modifying these sequences, such as increasing the number of polyaniline domains to form silk with more β-sheet crystals, and consequently a stronger fibre.

**The role of protein folding**

The structures of proteins are crucial to all their biological functions, and understanding how protein chains fold into their three-dimensional configurations has been the focus of academic research and citizen science projects to crowd source computational power. The aim is to gain invaluable insights into the causes and potential remedies for diseases including Alzheimer’s, Mad Cow (BSE), CJD, ALS, AIDS, Huntington’s and Parkinson’s disease. The Nanotechnology Focus on Protein Folding provides a collection of some of the latest research pushing the frontiers in this field.

Despite the importance of protein conformation, the crowded cell environment can cause aggregation into toxic species and make it difficult for proteins to reach the target morphology, as María Rosario Fernández-Fernández, Begoña Sot and José María Valpuesta from the Universidad Autonoma de Madrid describe in their review in the collection (Nanotechnology 27 324004).

“To avoid this, nature has developed protein quality-control mechanisms that include a complex surveillance system to guide protein homeostasis, or proteostasis, which is carried out by a large, diverse group of proteins termed molecular chaperones.” They go on to describe the structure and function of some of these chaperones and summarize some of the efforts to exploit them in nanotechnology.

Collagen fibrils, actin and beta sheets are just a few examples of nanostuctures and proteins with key structural functions that lead to observable macroscale mechanical properties. As with so many hierarchical systems the interactions between the proteins and nanostructures underpin the macroscopically observed behaviour. In the words attributed to Aristotle, “the whole is more than the sum of its parts.”

“Hierarchical systems the interactions between the constituent components are key to many of the natural materials that have superlative mechanical properties, and progress in understanding how to exploit these relationships may be a gold mine for materials science.”

Anna Demming is editor of nanotechweb.org.

**Can atomic force microscopy really measure the thickness of graphene?**

The major issue with imaging one-atom-thick materials is that there is rarely a perfect contact between the substrate and sample. This is often the case when investigating graphene, which is prepared by transfer onto a silicon wafer. This imperfect contact can be further exacerbated by the presence of a single layer of water atoms, often present on all surfaces under standard conditions. This issue is most commonly observed when imaging with an atomic force microscope (AFM), which directly images a sample in three dimensions using an atomically sharp tip. Reporting in Nanotechnology, researchers at Flinders University have optimized an AFM technique called PeakForce Tapping AFM to accurately measure graphene by imaging with high pressure.

The measured height of a graphene flake has been shown to vary with applied force from 1.7 to 0.4nm, with a linear correlation. As the thickness of a single graphene layer is expected to be 0.34nm (atomic layer spacing in graphite), the error in measured thickness has decreased drastically simply by imaging with a higher applied force.

The key parameter to accurately measuring graphene is found to be the applied pressure. At low applied pressure the measured height is equivalent to the sum of the graphene layer thickness and the buffer layer thickness. As the pressure applied to the graphene by the AFM tip increases, the graphene is pushed into the buffer layer and a more accurate value is measured, until finally the graphene is pushed through the buffer layer to the underlying substrate.

**The effect of applied force on measured graphene height.**

Cameron Sheetar is a research associate at the Centre for NanoScale Science and Technology at Flinders University, South Australia.

**Open for submission**

**Focus on protein folding**

Guest Editors: Jorge Alegre-Cebollada, Sergi Garcia-Manyes and Raul Perez-Jimenez

www.iopscience.org/nano
Neuromorphic device recognizes correlations

Traditional programmable computers are facing fundamental limitations in terms of speed and size, inspiring increasing interest in alternative paradigms such as neuromorphic computing. Researchers at IBM Research – Zurich and EPFL in Lausanne have now developed a spiking neural network computing architecture that mimics the physical separation between the memory and the computational components. This results in a bottleneck or processing component, which is the key difficulties facing traditional architectures is the physical separation between the memory and the computational or processing components. This results in a bottleneck or processing component, which is the key difficulties facing traditional architectures.

A new generation

“We are currently going through a transition from the programmable to the cognitive era,” says Angeliki Pantazi, research staff member at IBM Research – Zurich and lead author of this latest report. “With the vast data sets currently generated, the challenge is to extract knowledge – we are developing a new generation of computers to work with big data.”

Pantazi tells nanotechweb.org that the key difficulties facing traditional “von Neumann” computing architectures is the physical separation between the memory and the computational or processing components. This results in a bottleneck as greater processing speeds with larger data sets are attempted on ever-decreasing chip areas.

Planar meta-lens works in visible range

Researchers at the Harvard John A Paulson School of Engineering and Applied Sciences (SEAS) have made the first highly efficient planar lens that works in the visible part of the electromagnetic spectrum. The lens, which contains an ultrathin array of tiny waveguides (known as a meta-surface), can resolve nanoscale features smaller than the wavelength of light. In its current form, it might be used to replace bulky lenses in laser fabrication/lithography systems, and in laser-based microscopy and spectroscopy. If made achromatic, it could even replace the conventional lenses in portable phones, digital cameras and telescopes.

Bulky challenge

The lenses used in high-performance microscopes, cameras or telescopes today are curved and stacked on top of each other to reduce distortions (or aberrations) and produce a clear image. This is why they are relatively bulky. Although lens technology has come along in leaps and bounds in recent decades, it is still difficult to make a compact and thin lens.

Researchers would ideally like to replace these curved lenses with flat (or planar) ones, but this has proved difficult until now.

The new lens made by Federico Capasso’s team is made from a single layer of nanoscale fins of titania and allow analogue programming in between phases. The team tailored a learning rule for this phase-change material system using “spike-timing-dependent plasticity”, a characteristic of spiking neural networks. In addition, they incorporate biologically inspired level-tuned artificial neurons that allow the system to differentiate multiple patterns and the correlations between them, which would not otherwise be possible.

SEM micrograph of the fabricated meta-lens. Scale bar, 300 nm.

In contrast, neuromorphic architectures mimic the neural systems in organisms, where a key characteristic is the learning and processing capabilities of synapse-like memory components. The system devised by Pantazi and colleagues at IBM Research, Zurich, and École Polytechnique Fédérale de Lausanne (EPFL) uses phase-change chalcogenide alloys, which have a high resistivity contrast for their amorphous and crystalline states, and allow analogue programming in between phases.

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“This kind of architecture could coexist with traditional computing architectures to accelerate key tasks.”

How to compute in analogue

In natural neural systems the conductivity or weight at the synapses that join neurons is dependent on the timing of electrical impulses or spikes. This “spike-timing dependent plasticity” allows learning. An array of phase-change devices can mimic this behaviour when they change phase in response to input pulses. The presynaptic pulses are weighted by the phase-change synapses to form the total “postsynaptic potential”.

Pantazi’s system uses a so-called mushroom-type cell with doped GeSbTe, as the phase-change material situated between a wide top and a narrow bottom electrode. Crystalization pulses cause a phase change from amorphous to crystalline, which can be reversed by means of a “reset” pulse that melts and abruptly quenches the material. Since crystallization mainly occurs around the edges of the amorphous area of the chalcogenide layer, the system can be in an intermediate state with analogue values depending on the size of the amorphous area.

“At present, people use the presence of activity to spike for neuromorphic systems, but the internal state gives more information about the pattern,” explains Pantazi. Recognizing the role of the internal state of the artificial phase-change neuron triggered Pantazi and colleagues to use this information for level-tuning. Here the neurons are interconnected based on their internal state to enhance the system for multiple neurons. The approach is similar to the level-tuning in the auditory cortex where neurons are tuned to particular sound levels.

“This kind of [neuromorphic computing] architecture could coexist with traditional computing architectures to accelerate key tasks,” says Pantazi, suggesting how it could benefit applications that use or collect large data quantities, such as the internet of things. Further research is needed before such systems become available. Next, Pantazi and colleagues will investigate challenges for scaling to a larger system, improving the connectivity and operating more complex tasks.

Anna Demming is editor of nanotechweb.org.

Belle Dumé is contributing editor at nanotechweb.org.

Open for submission...

Nanotechnology focus on metamaterials

Guest Editors: Anatoly Zayats and Stefan Maier

www.iopscience.org/nano
GraphExeter enables large, flexible displays

The high demand for flexible, transparent conductors has posed a seemingly promising avenue for capitalizing on the substantial research already invested in graphene. However, the conductivity of pristine single-layer graphene is poor compared with its brittle counterpart indium tin oxide. Researchers at Exeter have demonstrated the first prototype of the material in an electronic luminescent device, showing its feasibility for luminescent textiles and flexible displays.

“We live in the future,” says Saviero Russo, who heads the team of researchers working on GraphExeter. He describes how the discovery of the material’s superlative properties consigned certain limitations of current technology to history, in theory. The working prototypes using the materials—like this recently reported display—have now provided optimistic proposals for GraphExeter to have a sound footing in realizable devices.

The high conductivity of GraphExeter does more for flexible displays than just brighter screens, Russo tells nanotechweb.org. Large screens using existing materials like indium tin oxide are a darker region in the middle due to the sheet resistance. This places a practical limitation in the range of square centimeters on how large the screen can be. The extremely low sheet resistance of GraphExeter—less than 8Ω□ compared with 1000Ω□ for pristine single-layer graphene and 850Ω□ for the more commonly used PEDOT/PSS—means that screens several square metres in size are now feasible.

What is GraphExeter?

Russo describes the material as “like a lasagne”, with FeCl3 molecules sandwiched between the single layers of graphene. These molecules donate additional charge carriers, which are responsible for the huge decrease in sheet resistance compared with pristine graphene. The researchers discovered the material while exploring a different potential application of graphene altogether. “We were interested in whether it could be used to make commercializing copper nanowires,” says Russo. Iron chloride molecules are ferroelectric, so incorporating them seemed a promising approach. Although this is still an open avenue of research within the group at Exeter, it soon became apparent that the material had other very readily exploitable attributes.

As well as its high conductivity, GraphExeter has 85% transparency and is stable up to 100% humidity and 150 °C. It is also easy to fabricate with a large surface area using chemical vapour deposition-grown graphene, and resists degradation for more than 1000 bending cycles to a radius of curvature of 3 mm.

GraphExeter is also free from many of the undesirable features of the alternatives—PEDOT/PSS has a blue tinge and is hygroscopic, so that at a humidity any higher than 40% it begins to absorb water and the conductivity deteriorates. The nanowire meshes that have also been explored are prone to optical haze, electromigration and poor electrical stability. “It is 50% brighter than commercial graphene and 30% more efficient than commercially available transparent electrodes such as PEDOT:PSS,” adds fellow team member Elias Torres Alonso.

What are its uses?

Such a high-performing, flexible display could be useful for foldable displays, lighting systems with expandable screens for smart phones, wallpaper lights and optoelectronic textiles. In particular, Russo suggests how useful the material could be as a biocompatible light source for medical treatments such as clothing for premature babies. With GraphExeter, a UV source directed towards the skin can be integrated into the fabric so the eyes are safe from harmful radiation without the need for goggles.

The researchers had previously demonstrated the use of GraphExeter in a pressure sensor that can be worn on the wrist to monitor heartbeat. The hope is that these working prototypes will emphasize the value of the material for facilitating new technologies, and thereby attract further corporate or government investment to take the commercialization further.

Anna Demming is editor of nanotechweb.org.

Copper nanowires make effective transparent electrode materials

Researchers at the University of California at Berkeley and the Lawrence Berkeley National Laboratory have developed a new solution-based, cost-effective way to wrap reduced graphene oxide around the surface of ultrathin transparent conducting copper nanowires. The technique significantly improves the stability of the wires in air and reduces the amount of light scattered by the materials. Thin films made of the wires might be used in optoelectronic devices, particularly in displays and flexible electronics.

Although indium tin oxide (ITO) has been the transparent electrode material of choice for a long time, the material is relatively expensive and brittle, and absorbs light in the near-infrared region of the electromagnetic spectrum, which makes it unsuitable for photovoltaic and photodetector applications.

Metal nanowire films could make good replacements for ITO in next-generation electronics, thanks to their excellent electrical and optical properties and the fact that they can be easily processed in solution. Thin films made from silver nanowires boast a low sheet resistance of less than 20 Ω/sq and are transparent to 90% of the light passing through them (at a wavelength of 550 nm)—similar to those of commercial ITO substrates. However, silver is expensive, and the diameter of silver nanowires made thus far is quite large, which means that they strongly scatter light. This light scattering produces a lot of haze, which means that the pixels in a display behind the transparent conductor start to blur.

Protecting copper nanowires

Copper nanowires could come into their own here—for one, they are as electrically conducting as silver while being 20 times cheaper. And because copper nanowires with diameters of less than 20 nm can be produced, they scatter light a lot less than their thicker silver nanowire cousins. However, thin copper nanowires are unstable in air and rapidly oxidize, something that dramatically reduces their conductivity. Attempts to protect them with a layer of nickel or an alumina coating either decrease the total transparency of thin films made from the nanowires or their overall conductivity.

A team led by Peidong Yang has now overcome this problem with a room-temperature solution-based technique to produce high-quality ultrathin copper reduced-graphene oxide core–shell nanowires. The graphene not only improves their stability in air but also the electrical and thermal conductivity of the nanowires. Previous attempts to coat copper nanowire with graphene required temperatures of 500–700 °C, which becomes unfeasibly expensive.

The core–shell conducting films are as good in terms of performance as ITO and silver nanowire thin films, adds team member Letican Dou. “Our work demonstrates a new approach to improve and stabilize ultrathin metal nanowires, and takes us one step further towards making copper nanowire films as low-cost transparent conductors for optoelectronic devices.”

How do quantum dots transfer energy to 2D materials?

The rate of non-radiative energy transfer from semiconductor nanocrystals (or quantum dots) to 2D materials can vary greatly depending on the thickness of these materials. Researchers at Columbia University and Stanford University have now found that the rate of energy transfer increases with increasing thicknesses of adjacent graphene layers, but decreases with increasing thicknesses of molybdenum disulphide ones. The new result is important both fundamentally and for real-world applications because energy transfer processes are ubiquitous at nanoscale interfaces, such as those in solar cells and photodetectors.

“Our work also corroborates recent results from the Tisdale group at the Massachusetts Institute of Technology, who reported the counterintuitive trend for MoS2 and ties together with the trend observed for graphene,” explains team member Archana Raja of Columbia University in New York.

Metallic, semiconducting and insulating nanostructures are ideal building blocks for optoelectronic and photonic devices. Colossal semiconducting quantum dots absorb and emit light over a wide spectrum of wavelengths thanks to the fact that their bandgap can be tuned by simply changing the size of the nanoparticle, but they suffer from poor carrier transport properties when compared with conventional semiconductors.

In contrast, graphite and the family of transition metal dichalcogenide crystals, to which MoS2 belongs, have high mobilities. Researchers are now actively looking into combining these two classes of materials to exploit the good characteristics of each.

Belle Dumé is contributing editor at nanotechweb.org.
Supercapacitors empower sustainable storage

In 1957 petrol became the world’s most used fuel, and nuclear energy began to gain ground as a credible alternative. However, more recently, as the world’s energy needs have grown, and the environmental impact of both fuels has become more apparent, there has been a renewed interest in more sustainable forms of energy storage.

Supercapacitors, which use the electrostatic double-layer capacitance approach, have been studied for many years. However, their adoption has been limited by issues with their low energy density and slow operating speeds. In recent years, however, there has been a surge in research into new materials and structures that could help overcome these limitations and make supercapacitors a viable alternative to traditional energy storage systems.

Getting the right materials

Progress in material science has unearthed a number of options that offer great advantages for supercapacitor research. These include novel materials such as transition metal dichalcogenides (TMDCs), which can be used to make high-performance electrodes for supercapacitors. TMDC nanoflakes can also be used to make a new type of photosynthetic solar cell.

TMDC nanoflakes make new type of photosynthetic solar cell

Tungsten diselenide nanoflakes can be used to chemically convert carbon dioxide to carbon monoxide in an acidic liquid. This is the new finding from researchers at the University of Illinois at Chicago whose “photosynthetic” device works using only sunlight. The new type of solar cell could be used to remove carbon from the atmosphere and produce fuel at the same time.

Electrochemically reducing CO₂, could, in principle, be a good way to recycle this greenhouse gas back into fuels. However, existing catalysts for this reaction are just too inefficient. A team led by Amin Salehi-Khojin has now tested the efficiency of a class of 2D materials called transition metal dichalcogenides (TMDCs) as catalysts for this reaction. The researchers paired the materials with an ionic liquid as an electrolyte inside a two-compartment, three-electrode electrochemical cell.

They found that tungsten diselenide was the best and in its nanoflake form it outperformed bulk catalysts (made of silver, for example) by a factor of 60. It was at least twice as good as the other nanoflake compounds analysed in the study and is also 20 times cheaper than a silver catalyst.

The team then used its catalyst to build an artificial leaf made up of two silicon triple-junction photovoltaic cells measuring 18 cm² to harvest light. The tungsten diselenide and ionic liquid catalyst made up the cathode in the cell, while cobalt oxide metallic CO₂. By growing the nanowires directly onto their substrates, the team of researchers have used TMDCs to create a new type of artificial leaf that could help convert CO₂ into useful fuels. Using this method, they demonstrated a 1% conversion rate of CO₂ into hydrocarbons.

An ‘artificial leaf’ solar cell.

In a potassium phosphate electrolyte made up the anode, the researchers found that the artificial leaf mimics the photosynthesis process, which explains Salehi-Khojin’s idea. In a real leaf, the CO₂ is converted into sugar, but in our leaf it is converted into syngas.” Syngas, or synthetic gas, is a mixture of hydrogen and carbon monoxide, and it can be burned directly in gas turbines and syngas engines or converted into diesel or other high-density hydrocarbon fuels such as naphtha. Salehi-Khojin says that he and his colleagues can also engineer their catalyst to directly produce sugar or other hydrocarbons. The measured catalytic activity was 1000 times better than that measured for silver nanoparticles and 60 times better than their previous work on bulk molybdenum disulphide.

Mimicking photosynthesis

“An artificial leaf mimics the photosynthesis process,” explains Salehi-Khojin. “In a real leaf, the CO₂ is converted into sugar, but in our leaf it is converted into syngas.” Syngas, or synthetic gas, is a mixture of hydrogen and carbon monoxide, and it can be burned directly in gas turbines and syngas engines or converted into diesel or other high-density hydrocarbon fuels such as naphtha. Salehi-Khojin says that he and his colleagues can also engineer their catalyst to directly produce sugar or other hydrocarbons. The measured catalytic activity was 1000 times better than that measured for silver nanoparticles and 60 times better than their previous work on bulk molybdenum disulphide.

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Tools are useful when they meet all of the demands of a particular objective and invaluable when they continue to meet requirements that are evolving over time. Atomic layer deposition (ALD) was already a useful tool for thin films in the 1980s, although commercial use was then limited to electro-illuminescent displays. By the 1990s use of ALD was making inroads in the microelectronics industry, but it wasn’t until the end of that decade that the great match between the fabrication requirements in nanotechnology and the precision and control that the technique can achieve became apparent. Since then, more than 1200 research papers, 80 reviews and two books have been published on ALD in nanotechnology. Over the past year, a Nanotechnology focus collection has highlighted the latest research using the technique to fabricate devices for energy, environment and sustainability, where ALD is still crucial to developments at the frontiers of nanotechnology.

A kind of variation on chemical vapour deposition, ALD involves exposing the surface to atomic elements of the chemicals to be deposited in separate stages, and then clearing the excess between each stage. In a paper published in the late 1990s exploring how ALD might be used in nanofabrication, Mikkko Ritala and Markku Leskelä listed the merits this tweak introduces – accurate and simple film thickness control, sharp interfaces, uniformity across large areas, excellent conformation, good reproducibility, multilayer processing capability and high film qualities at relatively low temperatures. These attributes have proved particularly valuable for attempts to improve the efficiency and scalability of alternative energy technologies.

Coating electrolytes

Many of the processes key to energy harvesting and storage devices are improved by the increased surface area that 3D structures bring. In lithium ion batteries (LIBs), a higher surface area means higher energy and power densities, as well as space to accommodate the addition and removal of lithium ions, which can introduce mechanical strain during use. LIB researchers are increasingly looking towards solid-state as opposed to liquid electrolytes to avoid risks of leakage and corrosion. As a result, sophisticated coating techniques to add electrolyte and counter-electrode layers to complex 3D nanostructures are in high demand. ALD not only provides pinhole-free coatings of solid-state electrolytes on 3D electrode structures, but it also offers the ability to tailor the coating thickness, which can significantly improve performance, as some of the papers in the collection highlight.

Super capacitors are a very attractive energy resource in nanotechnology, where space is at a premium. As with LIB research, the advantages of macromolecular solid-state electrolytes have been noted. In the focus collection, researchers at Delft University of Technology report on supercapacitors comprising carbon nanotube bundles as high-aspect-ratio electrodes that can improve the capacitance by a factor of five. The electrode is coated with aluminium oxide as the electrolyte, followed by titanium nitride as the counter-electrode, using ALD in work that not only demonstrates "the first known example of large-scale manufacturable nano-structured capacitors", but also provides useful insights for coating such high-aspect-ratio nanostructures.

Electrochemical cell structures can also take on elaborate hierarchical forms as demonstrated by Xudong Wang and colleagues at the University of Wisconsin-Madison and the Forest Products Laboratory in the US. They combine ALD and cellulose nanofibrils as a large-area low-cost green fabrication approach to produce extensively branched structures for photoelectrochemical water splitting. With respect to solar energy harvesting, ALD is already a well entrenched technique, and has been used to coat the inverse opals and other 3D structures often employed to reduce the distances charge carriers must travel to reach electrodes. Researchers at Nanyang Technological University in Singapore and the University of New South Wales in Australia review the application of ALD in solar-power technologies, focusing on its use for surface passivation, surface sensitization and band-structure engineering.

Lateral confinement

As well as providing an excellent tool for coatings, ALD has long been recognized to offer great potential for controlled lateral confinement. This is the subject of detailed scrutiny in the catalyst work of Marcel Verheijen at Philips Innovation Services and Eindhoven University of Technology in the Netherlands. Coating thickness is still key for catalysis performance, as demonstrated by Ai-Dong Li and colleagues at Nanjing University in China. However, as the work by Verheijen and his colleagues in the group of Wilhelmus Kessels at the university demonstrates, ALD can also help with size matters. In a study of four ALD processes for the preparation of nanoparticle catalysts made of platinum and palladium, they identify the potential for size control, as well as its dependence on process conditions. It is perhaps the ability to accommodate innovation that makes ALD so invaluable. The use of plasmonic metamaterial absorbers has only really gained notice in the past few years, and ALD is already proving invaluable for work exploring the essential mechanisms in these systems too. Reporting in the collection, Xin Chen and colleagues at the Shanghai Institute for Technical Physics exploit ALD control over dielectric layers in order to distinguish between different plasmon modes.

It is typical of science to break down problems into manageable pieces that can be tackled step by step. By breaking down deposition to an atomic level with step-by-step self-limiting stages, ALD mirrors this approach and in so doing seems to provide a multipurpose tool for a diverse range of applications, as the Nanotechnology focus collection highlights.

Available to read...

Focus on atomic layer deposition

Guest Editors: Hongjin Fan, Yongfeng Mei and Mato Knez

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Clinicians and academics tackle cancer

The third Nano World Cancer Day on 2 February saw experts from 12 countries gather simultaneously to discuss the development and deployment of cancer diagnostics and treatments. Nanotechweb.org reported from the UK contingent, where attendees reviewed progress in using nanomedicine and examined some potential solutions for overcoming the wide-ranging challenges for oncological research.

“Apoptosis – programmed cell death – is fundamental to life,” said Arwyn Tomos Jones of Cardiff University. He described how cancer ravages organisms by upsetting the fine balance between cell death and cell division, and highlighted some recent advances aimed at preventing the imbalance from spreading.

Jones explained that with the need to minimize debilitating side effects and boost the efficacy of cancer drugs, simply delivering a drug into the human body isn’t enough. Even drugs delivering glucose levels to the cancerous part of the body can miss the mark. Modern techniques aim to deliver large therapeutic molecules to the right components within the actual cells affected by the disease.

All of this may seem a tall order, but Jones’s group at the Cardiff School of Pharmacy and Pharmaceutical Sciences are among those that have been making serious headway. For instance, the team is describing how cancerous” lymph nodes from the patient – causing great discomfort and possibly nerve damage or death from blood dysplasia can be creatively trapped within the lymphatic system as individual cells are caught in the mesh of the lymph-node filters. In the past, surgical treatments for breast cancer would have removed up to 30 “potentially cancerous” lymph nodes from the patient – causing great discomfort and possibly nerve damage or death from blood dysplasia. With only these lymph nodes, allowing them to achieve better patient outcomes while still halting the disease.

The only problem is that not all hospitals have nuclear medicine units. In those that do, scheduling is often a problem because the unit can be quite far from the operating theatres – such costs and workflow issues are problematic when you are a recurring theme throughout the talks and panel discussion.

Nanomedicine is also helping when detecting cancerous” lymph nodes from the patient – causing great discomfort and possibly nerve damage or death from blood dysplasia. With only these lymph nodes, allowing them to achieve better patient outcomes while still halting the disease.

A panel from industry, academia and clinical practice discusses the future of oncological research. From left to right: chair, Gabriela Juarez Martinez, Knowledge Transfer Network; Thamos Mittraleas, CEO Cavendish Nanotherapeutics; Christopher Halloran, consultant pancreato-biliary surgeon; Arwyn Tomos Jones, Cardiff University; and Eric Mayes, CEO Endomag.

Endomag's hand-held probe tracks the company's magnetic nanoparticle tracer Sienna. + Because the Sienna + tracer is not radioactive, the surgeon can inject it themselves to patients already anaesthetized. “Surgeons love to have this control and for the patient’s less discomfort,” says Mayes. The Endomag technology has already helped 10 000 cancer patients across the world.

Nanoparticle tracers are made with iron oxide nanoparticles that are coated with an antibody that allows them to target cancer cells while leaving healthy cells unharmed. Kathyrn Hill from AstraZeneca described drug carriers that allow controlled release of medication, and Christine Duftes at the University of Strathclyde explained how tumour-targeting dendrplexes can be used to deliver therapeutic DNA; and Maya Thanou at King’s College London reported how heat-sensitive liposomes can release their cargo when highly focused ultrasound beams raise the temperature to a critical 42°C.

Minimizing the grief of surgery

A panel from industry, academia and clinical practice discusses the future of oncological research.

Patients are generally injected with the radioactive tracers before undergoing anaesthesia, which many find frightening. As Eric Mayes, CEO of Endomag pointed out, when you ask patients what they hate the most it’s having the injection.

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While prevention is always better than cure, the disease in its early stages is the next best thing for cancer patients. For many types of cancer, a greater than 90% five-year survival when caught in the early stages dwindles to less than 10% for treatments of more progressed forms of the disease.

Billy Boyle, co-founder of Owlstone Medical, stressed the need to make patients comply with diagnostic tests for early-stage cancer. He highlighted the falsal tests that are traditionally used to detect colorectal cancer, where the accuracy is only 66% and only 48% of patients take the test. “If it’s invasive or unpleasant people don’t show up,” said Boyle. Instead, Owlstone Medical has developed biosensors that can detect early-stage cancer from patients’ breath. “At first as an engineer I was looking to improve the chip,” said Boyle. “But it turns out it’s not just how good the test is, but also the nature of the test.”

The company’s breathalyser detects colorectal and lung cancer using a mass-spectrometry-type technology that measures the mobility of different molecules, and offers a sensitivity of 88% for a screening population group. The device, which makes the regulatory clearance much more straightforward, was showcased at the conference.

The sensor might easily be miniaturized further, said Gao and Emamnejad. “The number of biochemicals we target can also be ramped up so we can measure a lot of things at once. That makes large-scale clinical studies possible, which will help us better understand athletic performance and physiological responses to exercise.”

Javey’s team used a hand-held probe that tracks the company’s magnetic nanoparticle tracer Sienna+. Because the Sienna+ tracer is not radioactive, the surgeon can inject it themselves to patients already anaesthetized. “Surgeons love to have this control and for the patient’s less discomfort,” says Mayes. The Endomag technology has already helped 10 000 cancer patients across the world.

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Radiotherapy enhancer brings back mass medicine

Radiotherapy is used in 60% of cancer cases, but it is prone to damaging nearby healthy cells and is ineffective against cancer that has spread in metastasis. Nanobiotix has developed a nanomaterial product that enhances the X-ray exposure to tumour cells without increasing the dose inflicted on nearby healthy cells. They now show that the same product can be used to arm the immune system to attack cancer in metastasis as well.

"We are going in the opposite direction from medicine at present," says Nanobiotix CEO Laurent Levy. "Pharma and biotech in general is going more and more in the direction of personalized medicine – so it is more effective but for fewer patients. We wanted to introduce the idea of a mass medicine product."

The trend towards more personalized medicine stems from the hit-or-miss efficacy of traditional treatments, which often had little effect without the right treatment to debilitating levels. A return to a "one-size-fits-all" approach may seem a backwards step, but Nanobiotix believes it has produced an effective response to treatment with less physical responses common to all human beings.

Their core product NBTXR3 tackles the limitations of radiotherapy, which is used to treat the majority of cancer patients by exposing the cancerous tissue to a level of X-rays that will destroy the diseased cells. Although radiotherapy can destroy all cancers, it is indiscriminate and attacks both diseased and healthy cells. In some cases doses sufficient to eliminate the cancer may be fatal to the patient. By injecting NBTXR3 into tumours, the X-ray exposure is enhanced for the tumour cells but not the surrounding tissues.

One product, two tactics
While NBTXR3 is already in the final stages of clinical trials, Nanobiotix has now revealed another killer attribute of the product, which could make it effective against non-localized cancer in metastasis too.

For non-local cancer, immune oncology can be used to boost the immune system so that it attacks the tumour. However, it only works well in a few patients who have tumours that the body recognizes as immunogenic – so-called hot tumours.

Radiotherapy can also cause tumours to release antigens and other immunogenic molecules that stimulate the immune system into action, prompting oncologists to combine immuno and radiotherapy.

"We thought if we can make a product that makes tumours release more of these immunogenic molecules we could turn cold tumours into hot tumours," says Levy. As it turned out they already had the product that would do this with NBTXR3.

How NBTXR3 works
The product consists of hafnium oxide nanoparticles with a coating that makes them stick to cells. They are 50 nm in diameter – small enough to inject – and biologically inert so that they are safe in the body. Most importantly, HfO2 has a high density of electrons, so it absorbs X-rays particularly well, and cells of tumours directly injected with the nanoparticles experience a higher radiation dose than healthy cells nearby.

The released fragments of destroyed tumour cell nucleus and other molecules trigger immunogenic reactions from the body. The company has announced that using NBTXR3 significantly promotes the release of these immunogens after radiotherapy. "This improves the number of patients that can be treated with immuno oncology," says Levy.

Deployment prospects
A spin-off from the State University of New York (SUNY), where Laurent Levy completed his postdoctoral training, Nanobiotix was incorporated in 2003 and now has headquarters in Cambridge, Massachusetts in the US and Paris in France, as well as a partner in Asia. Its core product NBTXR3 is already in registration phase III/IIIb clinical trials for use as a radiotherapy enhancer, and Levy expects to see it approved in Europe for its soft-tissue sarcoma indication by the end of the year, when it is running trials for five other cancer indications.

Although the use of NBTXR3 for immunotherapy is still in the early stages, having clearance for its use in radiotherapy enhancement should help. The company has announced that it will be able to explore how immuno oncology could benefit from the use of NBTXR3 too, potentially heralding an effective therapeutic that can help all patients fighting cancer, not just a lucky few.

Anna Demming is editor of nanotechweb.org.

Quantum-dot barcodes diagnose disease

Researchers at the University of Toronto and Toronto University Health Network in Canada have performed the first full clinical study showing that quantum-dot (QD) barcodes can be used to diagnose patients infected with the hepatitis B virus. The new work is a "critical step" to translating QD technology into medical applications, they say.

"Researchers first proposed QD technologies for medical applications back in the late 1990s, but there were concerns that QDs could be toxic inside the human body," explains team leader Warren Chan. "However, toxicity is not an issue for QDs when they are used for patients outside of the body. Our group has now demonstrated, for the first time, that QDs can identify the hepatitis B virus in blood samples taken from infected patients."

In their study, the researchers performed a blind experiment by analysing patient samples using both traditional PCR techniques and the QD barcodes. They then compared the results from the two analyses to see if they matched, which was indeed the case. "We also found that if we use multiple QD barcodes we can enhance the accuracy of the diagnosis," explains team member Jisung Kim. Indeed, sensitivity can be increased from 54.9−66.7% for single QD barcodes to 80.4−90.5% for multiple ones.

Barcoding diagnostic technologies such as this have been around for more than 15 years, and most of these work using "Lumines" or similar types of barcodes doped with organic fluorophores. Here, microbeads are colour coded into up to 100 distinct sets by dicing them with fluorescent molecules and each set of signature beads carries specific detection reagents – such as oligonucleotide probes, antigens or proteins – on its surface. Molecules to be analysed in a sample bind to these detection reagents and a "reporter" molecule coupled with another fluorophore measures the reaction on the bead surface. These interactions are then measured by exciting with laser beams and the signal measured with a detector.

While efficient in such an application, the fluorophore molecules themselves do suffer from inherent limitations because they have very broad fluorescence spectra, which makes it difficult to differentiate between similar emission colours. And, microbeads doped with multiple organic fluorophores usually require multiple lasers to excite them, which makes for bulky and costly instruments.

As an alternative to fluorophores, Chan's team has been developing QDs for more than a decade now. These QDs contain biorecognition molecules on their surface to detect genetic biomarkers of pathogens like HIV, malaria, hepatitis B and C, and syphilis, all of which are carried in blood. QDs have many advantages over organic fluorophores for making unique optical barcodes, including the fact that they have a narrower spectral line width. What is more, different light emissions from the dots can be excited with a single wavelength of light.

The team, reporting its results in ACS Nano DOI: 10.1021/acs.nanolett.4b01254, says that it will now be trying to figure out how best to commercialize its technology so that QDs can be used in hospital for diagnosing diseases. "This could be the first medical use of QD technology," Chan tells nanotechweb.org.

Bacteria help treat tumours

Researchers at the Polytechnique Montréal and McGill University have discovered a way to deliver drugs to hypoxic (or low oxygen) regions in tumours. The technique, which relies on magneto-aerotactic bacteria (MC-1), could be used to treat a variety of solid tumours, which account for roughly 85% of all cancers.

As cancer cells proliferate, they consume large amounts of oxygen. This results in oxygen-poor regions in a tumour. It is notoriously difficult to treat these hypoxic regions using conventional pharmaceuticals. Even in nanoparticles, such as liposomes, micelles and polymeric nanoparticles.

MC-1 bacteria use the geomagnetic field to search and swim deeper towards low oxygen concentrations because they are microaerophilic (meaning that they survive in low oxygen environments). The researchers created an artificial environment to allow these bacteria to migrate towards the hypoxic regions in mice with colorectal cancers.

According to the researchers, these bacteria are general transport vehicles that can move a huge variety of therapeutic agents, such as drugs, genes, drugs, molecules, radiotherapeutic agents, stem cells and immunotherapeutics.
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**Graphene nanoplatelets self-assemble**

A bottom-up procedure shows promise for fabricating a graphene contact in a microstrip circuit. The procedure is based on the low-cost synthesis of graphene nanoplatelets and self-assembly procedure driven by an external electric field. Reporting in Nanotechnology, researchers at the University of Cassino and Southern Lazio in Italy present their innovative technique.

The advantages of integrating graphene, and graphene-related materials, into electronic devices are strongly dependent on the quality of the fabrication process. Presently, no monolithic technology process is available for this purpose. Hence, graphene devices are realized by growing graphene on suitable catalytic substrates, and then transferring it to the final substrate used in the envisaged application. This top-down procedure is not only inefficient, difficult to reproduce and hardly scalable, but also has a huge impact on the environment due to the acids, solvents and other chemicals required. Finding a cheap and easy way to mass-produce devices is integral to the success of pure carbon consumer electronics.

An innovative procedure developed by the NEXT nanotechnology group of Stefano Bellucci at the INFN in Italy suggests a bottom-up, scalable route to the realization and positioning of graphene nanoplatelets (GNPs) to form an electrical contact.

**Few-layer flakes**

The GNPs used in this work were obtained from exfoliable graphite, which is commercial graphite where sulfates and nitrates are intercalated between the layers. The graphite was expanded using a household microwave oven, and the GNPs were then maintained with mild sonication in an ultrasonic bath. Few-layer flakes of about four layers or less were produced with a typical size ranging from 2 to 10 µm.

A microstrip-like device was designed with a gap between the two copper electrodes, whose sizes range from 100 to 150 µm. The graphene contact was created by dropping a solution of alcohol and GNPs down the gap, whilst applying an external electric field across the gap. The GNPs were attracted into the gap and aligned themselves.

Once the alcohol had evaporated, the contact was created, and as a result of the technique a GNPs contact was realized by self-assembly. The electrical resistance showed a good thermal stability and agreement with theoretical models. We also demonstrated a possible use of this device as a gas sensor.

**Silicon etch has multiple benefits**

Silicon still has 90% of the market share in solar cells, despite the proliferation of potential alternative materials. While the advantages of silicon – high efficiency, abundance and decades of investment – are hard to ignore, challenges remain to improve the efficiency while minimizing costs. Reporting in Nanotechnology, Ming Lu and colleagues at Fudan University in Shanghai, China, have demonstrated a simple industry-compatible material-processing approach that enhances the light absorption of silicon solar cells while simultaneously diminishing carrier recombination, yielding devices with an efficiency of 18.97%.

Increasing the absorption of light is a primary strategy when trying to improve the efficiency of a photovoltaic device. Using a simple chemical etch, Lu and colleagues hoped to show that this standard process for nanostructuring crystalline silicon would decrease the recombination of the device, thereby improving the efficiency. The resulting efficiencies measured were beyond their expectations.

“When we get an efficiency much higher than 15%, we realized that other effects in addition to the low reflectivity are at work,” says Lu, a professor at Fudan University’s School of Information Science and Technology.

They were expecting the etch to diminish the silicon content, and that the gradually decreasing silicon content towards the top surface would give a gradient to the refractive index, reducing the reflectivity. However, based on the effects of improved reflectivity alone, this simple modification could only account for an efficiency of around 15%, similar to other simple-structure “black silicon” solar cells. The additional contribution they found was from a gradient in the band gap, also caused by the etching. The band-gap gradient suppressed carrier recombination to further improve the device efficiency.

The Fudan team added a layer of silver to crystalline silicon to catalyse etching with hydrofluoric acid. An 80-nm-thick ITO layer was then deposited onto the front surface as the front electrode and aluminium for the rear.

**Coming to the point**

The team characterized the resulting structure using scanning and high-resolution transmission electron microscopy, as well as X-ray photoelectron and photoluminescence spectroscopy. The researchers observed nanocone shapes of porous nanosilicon caused by the etching, which led to a gradually decreasing silicon content towards the etched surface. The result was the expected gradually increasing refractive index towards the opposite surface and an ultralow reflectivity less than 0.3% at UV and visible wavelengths.

However, their study also identified amorphous and crystalline silicon, and in particular they found that the crystal size increased with distance from the etched surface. The crystal size affects the band gap of crystalline silicon due to quantum confinement effects. As a result, the gradually increasing crystal size led to a gradually decreasing band gap, which slows down carrier recombination so that more carriers reach the electrodes. This also contributed to improving the efficiency.

In addition, UV photons were absorbed and re-emitted in the infrared. This helped to raise the efficiency because while UV photons are ineffective for photovoltaic effects, infrared photons work well. “This effect was expected,” says Lu. “From our experience, this wavelength shifting can increase the silicon solar-cell efficiency by ~4%, relatively speaking.”

**Getting better still**

The team further improved the efficiency of its device by passivating the surface with silicon oxide and aluminium oxide at the front and rear surfaces. The oxide layers saturate dangling bonds, and introduce interfacial fields, which further impedes recombination.

The researchers are now investigating further optimizations for the charge collection, rear passivation and open circuit voltage. “The aim is a broadband–response crystalline–silicon solar cell with efficiency obviously higher than 20%.”

Anna Demming is editor of nanotechweb.org.

**Oxidation ripening boosts efficiency**

The Ostwald ripening process can be used to make large-grain, high-quality perovskite thin films from lower elemental abundance and decades of investment – which slows down carrier recombination. The researchers are now investigating of graphene nanoplatelets (GNPs) to form an electrical contact.

**Few-layer flakes**

The GNPs used in this work were obtained from exfoliable graphite, which is commercial graphite where sulfates and nitrates are intercalated between the layers. The graphite was expanded using a household microwave oven, and the GNPs were then maintained with mild sonication in an ultrasonic bath. Few-layer flakes of about four layers or less were produced with a typical size ranging from 2 to 10 µm.

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**Antonio Maffucci** is an associate professor of electrotechnics at the University of Cassino and Southern Lazio, Italy.
Atomistix ToolKit (ATK) offers unique capabilities for simulating electrical transport properties of nanodevices on the atomic scale. Based on an open architecture which integrates a powerful scripting language with a graphical user interface, ATK is a comprehensive platform for studies in nanoelectronics, using both accurate first-principles (FP) and fast semi-empirical methods and classical potentials. Moreover, ATK includes a very advanced electronic model to allow realistic simulations of nanodevice transistors, structures, and nanomaterials.

Virtual NanoLab (VNL) works as a graphical user interface for ATK. Also, it can operate as a standalone interface to various different codes (FH-aims, VASP, QuantumESPRESSO, LAMMPS, GPAW, and more) with many powerful and extendable capabilities.

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DNA molecules make tiny thermometer

Researchers at the Université de Montréal in Canada have made a new, programmable nanothermometer from DNA molecules. The device might be used in a wide range of applications, including real-time monitoring of temperature inside living cells, to sense small temperature variations during laser-based nanosurgery and in nanoelectronics to detect hotspots caused by defects in nanometric circuits. It might even be used in nanomedicine to create thermally responsive platforms that deliver therapeutics via local heating thanks to laser-induced heating.

Researchers have known for more than 60 years now that DNA molecules unfold when heated and refold when cooled down again. More recently they also discovered that living organisms employ biomolecules such as proteins or RNA (a molecule similar to DNA) as nanothermometers – thanks to this unfolding and folding. "Inspired by these natural nanothermometers, we have now created various DNA structures that can fold and unfold at specifically defined temperatures," explains team leader Alexis Vallée-Bélisle.

The team used the simple Watson–Crick base pair code of DNA and the so-called Hoogsteen interactions to create their DNA structures. The good thing about DNA is that its chemistry is relatively simple and programmable, says team member David Garreau. "DNA is made from four different nucleotide molecules, A, C, G and T. Nucleotide A binds weakly to nucleotide T, whereas nucleotide C binds strongly to nucleotide G. Using these simple rules, we were able to create DNA structures that can be programmed to fold and unfold at specific temperatures."

Easily detectable fluorescence

By adding optical reporter molecules to these DNA structures, the team have succeeded in creating thermometers just 5 nm wide that produce an easily detectable fluorescence signal as a function of temperature. "As well as real-world applications, the new devices might even help us better understand molecular biology," says Vallée-Bélisle. "There are still many unanswered questions in biology. For example, we know that the temperature inside the human body is maintained at 37 °C, but we have no idea whether there is a large temperature variation at the nanoscale inside each cell." "Near-termer applications could involve using these thermometers to monitor local temperature variations in nanometric circuits – for example to detect hotspots caused by defects in electronic materials," Vallée-Bélisle tells nanotechweb.org. "The team says that it is now looking into whether natural nanomachines and nanomotors, which developed over millions of years during evolution, overheat (like their artificial counterparts do) when functioning at a high rate."

Detecting knots in nanopores

Researchers in the Netherlands, the US and Israel have succeeded in observing DNA knots as they pass through solid-state nanopores. The presence of such knots had been largely ignored in such studies until now, but a new experiment shows that it is important to take them into account in applications such as detecting DNA-bound proteins.

Nanopores are nanosized holes in thin solid-state membranes. Ions flow through the pores if a voltage is applied across the membranes when they are immersed in an ionic solution. This ion flow constitutes an electric current. If DNA molecules are present in the solution, they travel through the pores and block the flow of some of the ions. This results in a current drop (or blockade) that can be monitored using an apparatus sensitive to an electronic set-up. The size of this current drop and how long it lasts can be used to glean information about the structural state of the DNA – for example, whether there are proteins bound to it or not.

Long DNA molecules can become entangled, producing knots, but until now, there was no way to identify whether there are knots bound to it or not. "Knots are most prevalent in long DNA molecules and our approach allows us to determine how the number of knots scales with DNA lengths," says Plesa. "We are also able to determine other properties such as the DNA knot's size and its position on the molecule."

Surprisingly small

From the time it takes for the knot to translocate through a nanopore, the team was also able to calculate that the majority of the knots are smaller than 100 nm. "It is surprisingly small and indicates that knots in DNA are remarkably tight," says Dekker. Such small-sized knots were already theoretically predicted by Yitzhak Rabin and Alexander Grosberg in 2007 but have never experimentally confirmed until now.

"I think the presence of knots has been largely ignored in many nanopore applications because of the limited resolution of the measurements, which prevented us from observing them," says Plesa. "But now we have shown that the knots are there and it will be important to take them into account in applications such as detecting DNA-proteins, particularly when probing long DNA lengths."

Dekker adds that the study has been "gratifying." "Ever since I started working on DNA translocation through nanopores over 15 years ago, I wondered why the DNA would not go through a nice head-to-tail fashion without encountering any knots," he tells nanotechweb.org. "Imagine doing the same exercise with your garden hose as you pull it through a four-inch hole in the garden fence – I bet you get stuck with a knot."

Adam Hall of Wake Forest University School of Medicine, who was not involved in this work, says that the new paper is "very interesting and thorough."

"Long, duplex DNA has been the workhorse molecule in the solid-state nanopore field for 15 years, so it is incredible to see that there are now measuring fundamental aspects of it that we never noticed before," he says. "I think this work opens the way to studying a novel concept with fundamental and translational importance. Knot formation is both an interesting polymer dynamics question and an issue that must be dealt with when it occurs in the cell. Let us get unstuck the proper functioning of the cellular machinery. Existing techniques like atomic force microscopy are limited because they require DNA to be surface bound, which can make interpretation challenging. This paper addresses the issue nicely by probing DNA in solution."

"With so much attention on the application of nanoparticles strictly to DNA sequencing, it's important to remember how many other important uses the system may have."

The information gained during this study will also be important for any application involving long polymers, not only DNA molecules, adds Plesa.

Belle Dumé is contributing editor at nanotechweb.org.

Artificial muscles

Actuators (sometimes also called artificial muscles) are needed in applications like micropropellers, sensing, smart windows and walls. Researchers have already succeeded in making devices like micropropellers and DNA “origami” machines, but the forces obtained in these actuators are typically quite small at around 1 femtonewtons per square millimetre. They also work extremely slowly (on second timescales). "Artificial muscles (sometimes also called nanomachines that can move practically in liquid environments. Water, for example, feels like treacle at the nanoscale, so you need large forces to push nano-objects through it."

Using just beams of light, researchers at the universities of Cambridge and Bath in the UK have succeeded in producing such large forces in charged gold nanoparticles coated with temperature-responsive polymers. The nanomachines could be used to make pumps, valves, engines and pistons for a host of applications in the nanoworld. "The forces we can produce on the nanoscale are very large – up to several nanonewtons," explains team leader Jeremy Baumberg of the NanoPhotonics Centre at Cambridge. "Producing such large forces on the nanoscale has proved difficult to do until now, something that has hindered all practical applications of nanomotors – we simply did not have nanomachines that can move practically in liquid environments. Water, for example, feels like treacle at the nanoscale, so you need large forces to push nano-objects through it."

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Nanotransducers see the light

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Theory consultancy catalyses big business

Nanolayers Research Computing aims to bridge the gap between academic physics and real-world products. The company was founded in 2015 to provide consultancy in modelling and simulations rather than “black box” software development, and business opportunities are already piling in.

“Our goal – 10 years down the line – will do really interesting science, and we want to see a real world impact,” says David Gao, founder and director of Nanolayers Research Computing. This may sound like trying to have your cake and eat it, but with an agreement to take part in a 3 year €4.3 million European project already in the bag, the company’s first year is looking very promising.

The project “Towards Replacement of Critical Chemicals by Improved Nanoparticle Control and Rational Design (CritCat)”, aims to tackle the European supply risk associated with platinum group catalysts. Although widely used in Europe, there are no European sources for the materials these catalysts are currently based on.

Gao describes some of the frustrations from his time working in R&D for large companies, which motivated him to set up Nanolayers Research Computing. “The research phase of projects often ends once a working prototype is discovered. But then the next year when you start on something similar you’re back at the starting line because you never worked to get that fundamental understanding.” He adds that in contrast, working in academia can be so focused on the fundamental understanding that there is little sign of a real-world product or application. Nanolayers Research Computing aims to satisfy both.

**Theoretical catalyst discovery Nanolayers Research Computing’s share in the project comes to roughly €400 000. It will focus on catalyst development for four applications:**

- Other groups in the consortium will focus on the nanoparticle synthesis, morphological characterization, and scaled production, as well as other aspects of theory. “There is a lot of emphasis on theory,” adds Gao.
- “The coordinator [project coordinator Jaakko Arola at Tampere University] is really pushing to ensure the project is theory driven.”

From black box to open source

The project leaves about 50% of the company’s resources available for other work, and top of the list of subjects Gao is looking at is related with his previous work in the petroleum industry, such as friction modifiers and wear inhibitors – additives for engine oil that diminish damage and increase fuel economy.

As well as the agreement for the company, David is research associate at University College London and the London Centre for Nanotechnology in the UK. Although his academic commitments will be reduced to 20% of his time over the course of the coming year, he places great value in managing some of the company’s expertise in areas such as modelling and simulation, and consultancy in materials discovery, rather than merely selling protected software. “Philosophically this is the correct issue with only selling software packages – the customer uses it as a black box so they don’t use it properly. They waste a lot of resources that way and often can’t trust the results.”

Nanolayers Research Computing plans to make parts of its software open source, which Gao suggests may not be as tricky a business model as it sounds. “As a consultancy it’s fine, and consulting is already a large part of our business plan. However, we’re still a young company so our strategy may change.”

Anna Demming is editor of nanotechweb.org.
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Atomic force microscopy – 30 years on

nанотехнология.org visits Basel in Switzerland, home to some of the pioneers in atomic force microscopy (AFM) technologies, to find out how far the field has come in the past three decades.

Thirty years since its first inception, the atomic force microscope has proved a hugely versatile tool. More than simply bringing atomic-scale resolution to non-conducting surfaces, modifications of the technology have provided important tools for sensing chemical entities and mechanical properties, with force sensitivities so great they can be used to study and control mitosis in the proliferation of life itself. nanotechweb.org visited Basel in Switzerland, home to some of the pioneers in atomic force microscopy (AFM) technologies, to find out how far the field has come in the past three decades.

The development of scanning probe technologies began with the scanning tunnelling microscope (STM) and was driven by the semiconductor industry in the late 1970s. Christoph Gerber, co-inventor of the AFM, points out that although electronics feature sizes were coming close to the nanoscale in the 1970s, there was no way of obtaining the spectroscopic information of such small features. “We thought that if we established a nanoscale very close – so that due to the proximity there would be tunnelling – we would have an instrument that could do this kind of spectroscopic work,”

The idea led to the STM. “The big breakthrough for STM came when we were able to image the 7 × 7 reconstruction of silicon (1,1,1),” explains Gerber. As the arrangement of atoms at the surface differs from the bulk, glimpsing this reconstruction in a real image was a powerful demonstration of the instrument’s potential.

It was another 3–4 years before the seminal results from IBM’s Zurich lab were later verified at a makeshift lab in his room where he admits he was actually quite happy working on superconductors at the time. “My supervisor was really excited about this new technique and persuaded me to work on it. It was the first time I got a PhD position,” says Meyer.

Meyer leads the way into the base- ment of the lab, where vibrations can be minimized to allow ultra- sensitivities to be measured. He explains that recently the resolution of AFM is getting better than STM,” says Meyer, explaining how you can now non-invasively with a resolution that can detect single hydrogen atoms and carbon rings.

The large shiny instrument behind the door is the Atomic Force Microscope (AFM). “This is the atomic force microscope,” says Meyer, adding “it’s like a lab on a chip.” The large shiny instrument behind the door is the Atomic Force Microscope (AFM). “This is the atomic force microscope,” says Meyer, adding “it’s like a lab on a chip.” The AFM is built on a “piezoelectric” principle, and this device is essentially a bimorph that expands and contracts as a function of an applied voltage. The AFM can then measure forces of the order of a few femtograms (1 femtogram = 10^-15 grams).

The AFM is a powerful tool for imaging surfaces with atomic resolution. The instrument uses a cantilever, which is a tiny spring-like structure attached to the end of which is a tiny tip, to scan the surface of a sample. The tip is brought into contact with the surface and the force between the tip and the sample is measured. This force is used to create an image of the surface, with the height of the tip above the surface determining the brightness of each point on the image.

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