

# Nanotechnology: Chemistry to the Fore

Shreyas Mukund, Sophie Deltour, Suryani Lukman

Nanotechnology is commonly used as an umbrella term for a wide range of structures and devices that are ordered at a nanometre scale (around 1000th of the width of a human hair). Until quite recently, most of these devices were fabricated using large machines as found in microchip manufacturing – so-called ‘top-down’ nanotechnology. In this article, we introduce some of the contributions of chemistry to developing the next frontier of nanotechnology, the ‘bottom-up’ approach, where nano-machines assemble themselves.

Living organisms are made up of functional assemblies of building blocks, which are assembled into natural polymers, such as DNA and proteins. Taking inspiration from nature, Cambridge chemists and their peers worldwide are assembling inexpensive and responsive

producing nanoscale motors. Examples of these include artificial muscles, micro-robots, solar cells, and molecular ‘conveyor belts’ (Steiner Group, Department of Physics, University of Cambridge [3]).

Polymers have also been applied to make artificial antibodies for diagnostic blood tests, in a process known as molecular imprinting [4]. Natural antibodies are proteins that our immune system produces to recognise the proteins, or antigens, from viruses and bacteria. To make

“ **The next frontier of nanotechnology, the ‘bottom-up’ approach** ”

artificial antibodies, highly branched polymers known as dendrimers are introduced to an antigen-shaped template. The dendrimers are then chemically cross-linked and water is added to remove the template from the centre, leaving an antigen-shaped cavity. This method promises to be cheaper than the widely used monoclonal antibodies technique, which requires living cells (and was developed by former Cambridge researcher, Cesar Milstein, for which he won a Nobel Prize in 1984).

With over a century of innovation, synthetic organic chemists already possess a wide arsenal of methods to construct complex molecules with a considerable level of control. Building on this progress, the field of supramolecular chemistry has sought to refine the control of interactions between molecules to promote molecular recognition and the self-assembly of novel nanostructures, including a wide variety of molecular switches, sensors and motors.

Among the best known of these are planar rings with linear molecules threaded through them, collectively known as rotaxanes, and pairs of interlinked rings, known as catenanes. Both have been demonstrated to be capable of reorganising in response to light and chemical agents [5]. Recently, researchers from the University of Edinburgh showed the power of these supramolecular arrangements by constructing a lawn of self-assembled photoresponsive rotaxanes [6]. The rings of these molecular shuttles could shift position by several nanometres upon exposure to ultraviolet light, resulting in an overall change in hydrophobicity (level of water repellance) of the surface. Using these changes in hydrophobicity, tiny droplets of liquid could be driven over the surface by light alone. This development heralds another step towards a microscopic Lab-on-a-Chip, where controlled chemical experiments



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synthetic polymers. The Melville Laboratory (Department of Chemistry, Cambridge) is researching the nanoscale arrangement of individual polymers and their supporting surfaces [1]. They have created a variety of polymer brushes comprising end-anchored polymer chains built up from a surface [2].

Using diverse physical and chemical stimuli, such as temperature, light, pH, and electric fields, the polymers can either be stretched or curled up, moving the entire brush surface up and down. As polymers prefer to be curled up, this stretching process leads to the conversion of chemical energy to mechanical work, hence opening the door for



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can be performed on a miniature scale.

A complementary approach in organic nanoscience builds on the current boom in biological chemistry, where proteins act as the nanomachines. Indeed, the contribution of such biological nanomachines to commercial science is not a new one; re-engineered DNA polymerase is an enzyme and biomotor, used in the Polymerase Chain Reaction, a technique for rapidly copying DNA that is crucial in genetics and biotechnology. However, precise control over

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the DNA polymerase biomotor has only been achieved at the nanoscale more recently. This was done by controlling tension in the single DNA molecule being copied using a laser, a method known as optical tweezers [7]. Control of biomotors by chemical means has also been demonstrated as to have uses in the propulsion of nanomachines, in targeted therapeutics *in vivo*, and for molecular assembly lines [8].

Inorganic chemical systems have been at the core of more conventional nanoscale devices. Conducting and semiconducting materials exhibit unique behaviour at the nanoscale and strange quantum effects are brought into play. Physicists and materials scientists now work routinely

with chemists to develop objects such as nanotubes and nanowires for applications ranging from quantum computers to bullet proof vests. A related innovation already making widespread impact is that of semiconductor nanoparticles, or ‘quantum dots’. The crucial feature of quantum dots is that their fluorescent colour can be controlled simply by changing the size of the nanoparticle [9]. Consequently, quantum dots have found applications as fine-tunable probes for biological imaging [10], high-efficiency solar cells [11], energy efficient displays [12] and novel lasers for high speed communication networks [13].

Whilst we have sampled exciting developments in the different disciplines of chemistry, it must be noted that some of the most successful innovations in nanotechnology combine these disciplines. Oxford Nanopore Technologies is currently using supramolecular chemistry with biological nanopores for faster methods of DNA sequencing [14]. In another example, the combination of inorganic and biological chemistry has led to the creation of self assembled digital memory devices from viruses and platinum nanoparticles [15]. As all chemistry focuses in some way on creating and controlling order on the molecular scale, it is set to remain a cornerstone of future developments in ‘bottom-up’ nanotechnology. ■

*Shreyas Mukund is a first year PhD student in the Department of Chemistry. Sophie Deltour is a Post-Doctoral Researcher at the Wellcome Trust/Cancer Research UK Gurdon Institute. Suryani Lukman is a second year PhD student in the Department of Chemistry.*

#### References:

- [1] University of Cambridge, Department of Chemistry [Homepage on internet]. [Updated 2007; cited 17 Jan 2009]. Available from [www-melville.ch.cam.ac.uk](http://www-melville.ch.cam.ac.uk)
- [2] Zhao B, Brittain WJ. Polymer brushes: surface-immobilized macromolecules. *Progress in Polymer Science*, 2000; 25(5): 677-710(34)
- [3] University of Cambridge, Department of Physics [Homepage on internet]. [Updated 16 Dec 2008; cited 17 Jan 2009]. Available from [www.bss.phy.cam.ac.uk/steiner/](http://www.bss.phy.cam.ac.uk/steiner/)
- [4] Zimmerman et al. Synthetic Hosts by Monomolecular Imprinting Inside Dendrimers. *Nature*. London. 2002; 418:399-403
- [5] Balzani V et al. Artificial molecular machines. *Angew. Chem. Int. Ed.* 2000; 39(19): 3348-3391
- [6] Zerbetto F et al. Macroscopic transport by synthetic molecular machines. *Nature Materials*. 2005; 4:704-710
- [7] Bustamante C et al. Single-molecule studies of the effect of template tension on T7 DNA polymerase activity. *Nature*. 2000; 404:103-106
- [8] Goel A, Vogel V. Harnessing biological motors to engineer systems for nanoscale transport and assembly. *Nature Nanotechnology*. 2008; 3:465-475

- [9] Klimov V et al. Optical Gain and Stimulated Emission in Nanocrystal Quantum Dots. *Science*. 2000; 290(5490):314-317
- [10] Bakalova R et al. Designing quantum-dot probes. *Nature Photonics*. 2007; 1:487-489
- [11] Kamat PV et al. Quantum Dot Solar Cells. Tuning Photoresponse through Size and Shape Control of CdSe-TiO<sub>2</sub> Architecture. *J. Am. Chem. Soc.* 2008; 130:4007-4015
- [12] QD Vision [Homepage on the internet]. [Updated 2008; cited 17 Jan 2009]. Available from [www.qdvision.com](http://www.qdvision.com)
- [13] Fujitsu [Homepage on the internet]. [Updated 10 Sep 2004; cited 17 Jan 2009]. Available from <http://www.fujitsu.com/global/news/pr/archives/month/2004/20040910-01.html>
- [14] Reza Ghadiri M et al. Recognizing a Single Base in an Individual DNA Strand: A Step Toward DNA Sequencing in Nanopores. *Angew. Chem. Int. Ed.* 2005; 9:1401-1404
- [15] Ozkan C, Yang Y et al. Digital memory device based on tobacco mosaic virus conjugated with nanoparticles. *Nature Nanotechnology*. 2006; 1:72-77