

Highlights in Chemical Technology

Large area carbon nanotube film shows promise in solar cells

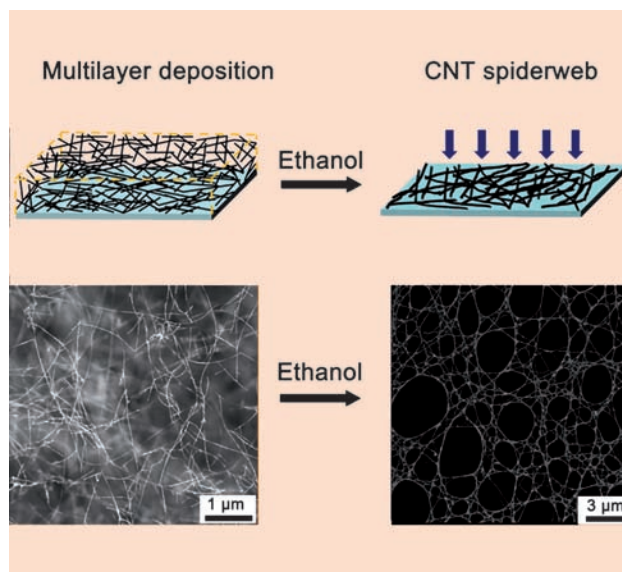
Nanotube spiderweb catches the rays

A transparent spiderweb-like film formed from interconnected carbon nanotubes (CNTs) is highly efficient in solar energy harvesting, say Chinese scientists.

CNTs are well known for their excellent electrical properties, which offer the potential for use in a broad range of modern technologies from sensors to flexible display panels. However, an appropriate method to produce CNT films that are both conductive and transparent has proved elusive, limiting their applications.

Anyuan Cao and colleagues at Peking and Tsinghua Universities, Beijing, have developed a direct synthesis technique to achieve highly conductive and transparent CNT spiderwebs. They use chemical vapour deposition to grow ultra-long CNTs, followed by ethanol addition to condense them into bundles.

'We use an extremely slow feeding rate of the chemical precursor, resulting in well controlled formation of thin, uniform CNT films,' explains



Cao. The thinner the film, the higher the transparency – a property essential for its effective use as an electrode in solar cells. By tuning the transparency, Cao ensures that most of the incident sunlight can

Carbon nanotube spiderwebs are efficient

Reference
Z Li *et al.*, *J. Mater. Chem.*, 2010, 22, 7236 (DOI: 10.1039/c0jm01361g)

reach the underlying silicon wafer for conversion into electricity, without compromising the film's conductivity.

'CNTs play multiple roles in the solar cells: capturing the solar energy, forming junctions, collecting the photo-generation carriers and also as the transparent electrodes,' according to Yanqui Zhu at the University of Nottingham in the UK, who has expertise in nanomaterials fabrication and CNTs. He believes the successful fabrication of the 100 cm² films brings CNTs a step closer to practical applications and paves the way for even larger scale production.

The spiderwebs are sticky yet robust and sufficiently flexible to be transferred easily to various substrates including metal, paper and micro carbon fibres. Cao foresees numerous potential applications for his CNT spiderwebs, and is pursuing research into their use in flexible devices and window coatings with self-cleaning, sensing, UV-blocking and heating functions. *Erica Wise*

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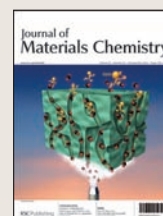
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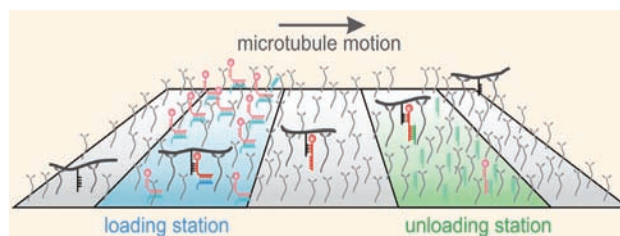
Specific pick-up and delivery zones makes chip into a nanoscale ‘train track’

Nanocouriers transport molecular cargo

A train-like system that transports molecular cargo between specific pick-up and delivery zones on a chip has been created by Swiss scientists. The technology could lead to nanoscale assembly lines, they claim.

Developing systems that use nanomotors to move cargo around inside nanoscale devices has become popular recently. Unlike in random diffusion, cargo can be moved against a concentration gradient; and in contrast to microfluidic devices, an external power supply or pump isn't needed.

Now, Claudia Schmidt and Viola Vogel based at Swiss Federal Institute of Technology (ETH) in Zurich have – for the first time – successfully integrated separate pick-up and delivery zones into one system. The team already had a working system in which a



Cargo is picked up and delivered using DNA strands

microtubule is propelled along a carpet of motor proteins inside a chip: the ‘train’ and ‘track’. To improve their system, Schmidt and Vogel have added ‘departure and arrival stations’.

The researchers labelled their cargo with stretches of DNA, and placed complementary strands on the pick-up and delivery stations. By tuning the length of the DNA strands on the stations, the team could control the strength of the different

interactions and, crucially, the force needed to break them. This ensures the cargo is collected at the pick-up station and deposited at the delivery station. The relative strengths of the interactions mean that the cargo cannot be collected at the delivery station – so it doesn't make the return trip.

‘Recreating the intracellular transport systems in a synthetic environment has been a goal in nanotechnology for the past decade,’ says Henry Hess, an expert in biomedical engineering at Columbia University, New York, US. ‘The work is remarkable for harnessing diverse concepts and approaches – including DNA nanotechnology, microfabrication, self-assembly and molecular motors – to realise a complex nanoscale process,’ he adds. *Russell Johnson*

Reference
C Schmidt and V Vogel, *Lab Chip*, 2010, **10**, 2195
(DOI: 10.1039/c005241h)

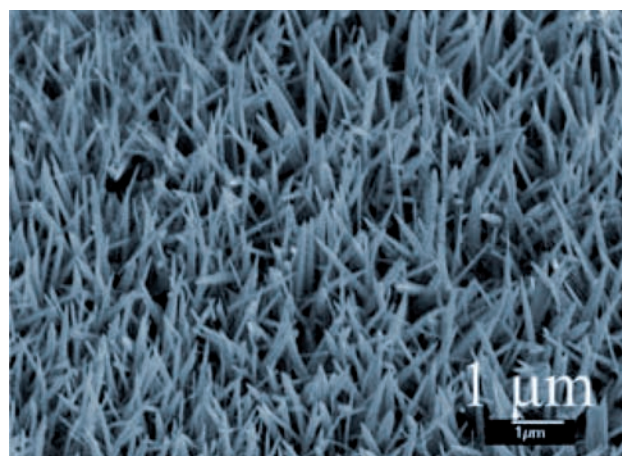
ZnO nanorods coated with carbon makes a stable hydrazine detector

Electrochemical sensor for toxic compound

Scientists in China have developed a highly efficient and chemically stable hydrazine sensor using carbon-modified zinc oxide nanorods.

Hydrazine, N_2H_4 , is highly neurotoxic and carcinogenic and can cause severe damage to the liver, lungs and kidneys. It is used extensively in industry, primarily in the manufacture of polymer foams, as well as a precursor in the synthesis of catalysts, agrochemicals and pharmaceuticals. Therefore, for safety considerations, a reliable hydrazine sensor is highly desirable.

Of the wide range of hydrazine detection techniques reported, electrochemical devices are the most promising since they are low cost, portable and generally offer fast response times and good sensitivity. Nanostructured zinc oxide electrodes are particularly useful because of their increased surface area, reduced resistance and a high signal-to-noise ratio. But, while highly sensitive, the



electrodes are too unstable for practical applications.

Jinping Liu and colleagues at Huazhong Normal University have overcome this problem by coating zinc oxide nanorods in a layer of carbon just a few nanometres thick. The high electrical conductivity of carbon improves the sensitivity of the sensor, and its chemical inertness improves its stability by

Carbon-modified zinc oxide nanorod array has improved sensitivity and durability

protecting the ZnO nanorod from corrosion.

‘Our electrode design also avoids conventional electrode fabrication processes, which are typically laborious and expensive,’ adds Liu.

Gregory Wildgoose, an expert in surfaces for sensing and catalysis at the University of East Anglia, UK, comments, ‘the synergy between the amorphous graphitic coating and the underlying ZnO material is intriguing. There are clearly some interesting nano-scale interactions occurring in this system worthy of further investigation.’

The electrode may also find applications in other devices such as batteries and photoelectrochemical cells, Liu says, ‘the next step is to optimise the synthetic techniques to grow large, uniform and reproducible carbon coated nanorod arrays.’

Jacob Bush

Reference
J Liu *et al*, *Dalton Trans.*, 2010, DOI: 10.1039/c0dt00258e

Hydrogen from ammonia boranes using an iridium catalyst

Stable catalyst for hydrogen generation

A robust catalyst that produces hydrogen from ammonia-boranes with high efficiency under atmospheric conditions has been developed by Spanish scientists.

The search for new energy sources to substitute depleting fossil fuels and decrease greenhouse gas emissions is a high priority. One of the best pollution-free alternatives to coal and oil is hydrogen. However, a different and very important concern arises with the use of hydrogen: safety.

Incorporating hydrogen into chemical compounds, such as ammonia borane (NH_3BH_3) that can store and release it in a controlled manner could be a way of overcoming safety issues. Catalysts based on metals including titanium ruthenium and rhodium can efficiently release up to one equivalent of hydrogen gas, but it must be carried out under inert conditions.

Maria Angeles Garralda and her team at the University of Pais Vasco



in Spain have demonstrated the first homogenous catalysis reaction, using an iridium catalyst, for hydrolysing amino-boranes, which produces up to three equivalents of hydrogen in a very efficient reaction. As well as being more efficient than previous systems, the iridium catalyst has the added advantage that it is stable in water and air, so does not require an inert atmosphere.

'The fact that this system was not active under anhydrous conditions and was, however, extremely efficient and stable in the presence of water was very surprising' says Angeles

A homogeneously catalysed reaction allows hydrogen production

Reference
R Ciganda *et al*, *Dalton Trans.*, 2010, 7226 (DOI: 10.1039/C0DT00091D)

Garralda. 'The great stability in the presence of air and water and the great activity of this homogeneous catalyst will help to understand the mechanisms of hydrogen production.'

The understanding of the mechanism of this type of reaction is vital for the future development of more efficient and cheaper catalysts to generate hydrogen in fuel cells.

'This homogenous catalytic system suggests that finer control over rate and product distribution might be possible in the future,' points out Andrew Weller, an expert on organometallic chemistry and catalysis at the University of Oxford, UK. 'Ultimately, energy efficient re-hydrogenation strategies and cheaper, long-lived, immobilised catalysts are key targets; and research such as presented here suggests new avenues by which the latter of these goals might be achieved.'

Lorena Tomas Laudo

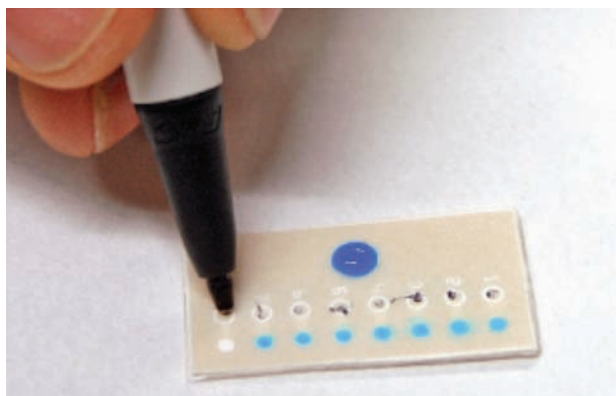
A programmable paper-based microfluidic device for any test

Putting pen to paper gets the fluid flowing

A paper-based microfluidic device that can be programmed on the spot using a ball-point pen has been developed by US scientists.

Microfluidic devices are increasingly being used to detect and analyse chemicals, particularly in areas such as medicine and water purity. Devices made from simple materials such as paper have great potential in developing countries, as they are cheap and easy to use. George Whitesides and colleagues at Harvard University have now developed a paper-based microfluidic device that can be programmed to carry out any test the user wants.

Paper is not an obvious choice for handling fluids, but by soaking it in a polymer solution, and then curing it using light, it becomes impermeable. You can then create a network of channels in the paper through which liquid can travel by capillary action. Whitesides' advance lies in stacking sheets of paper to



give a programmable 3D device, which, he says 'brings another layer of sophistication to microfluidic devices.'

The new gadget works by separating two sheets of treated paper with a layer of double-sided sticky tape. Tiny holes are made in this tape, aligned with the channels in the paper, that act as buttons that are

Pressing the buttons allows the device to be programmed for specific tests

Reference
A W Martinez *et al*, *Lab Chip*, 2010, DOI: 10.1039/c0lc00021c

activated by pressing the two layers of paper together using a ball-point pen. Once the layers of paper are in contact, liquid flows from one to the other.

These single-use buttons make the device as universal as possible, allowing the user to adapt the microchannel system for a specific application on the spot. It could be programmed to test a wide variety of samples, such as blood, water, urine or saliva, for a wide range of analytes. The programmability decreases the cost for each application, as a different test kit is not needed each time.

John McDevitt, an expert in lab-on-a-chip technologies at Rice University, Houston, US, says that this is exciting research, and that 'using these inexpensive materials is key for the medical micro-device field, which has to date been dominated by silicon, glass and polydimethylsiloxane (PDMS) materials.' *David Barden*

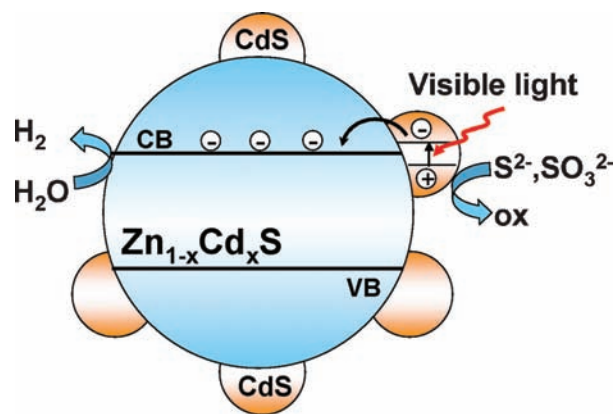
Splitting water under visible light using mixed zinc-cadmium sulfide material

Photocatalytic production of hydrogen

A simple and easy way to make mixed zinc-cadmium sulfide materials that produce hydrogen by splitting water under visible light has been developed by scientists in the US and China. The mixed materials can harvest a wider range of wavelengths than conventional materials, making them more efficient.

Photocatalytic conversion of sunlight to chemical energy, for example by producing hydrogen, is an attractive alternative energy source and a feasible way to tackle the global energy and environmental pollution crises. Conventional photocatalysts, such as TiO_2 , CdS or ZnS, possess excellent activity and stability but only absorb near-ultraviolet light – which accounts for only 4 per cent of the solar spectrum. Expensive noble metal co-catalysts, such as platinum can be added to increase their absorption range but this increases their cost.

Now, Mietek Jaroniec from Kent State University, Ohio, and Jiaguo Yu from Wuhan University of Technology, have made mixed zinc-



cadmium sulfide complexes doped with cadmium sulfide quantum dots (CdS QDs) that show high photocatalytic activity under visible light, without the need for noble metal additives.

‘The high H_2 -production activity of the CdS quantum dot-sensitised material under visible light can be attributed to the facilitated electron transfer from CdS QDs,’ says Jaroniec. The team made the mixed solid solution using a simple hydrothermal method to

CdS quantum dots increase the absorption range of the photocatalyst

Reference
J-G Yu, J Zhang, and M Jaroniec, *Green Chem.*, 2010, DOI: 10.1039/c0gc00236d

combine ZnS nanoparticles and $\text{Cd}(\text{NO}_3)_2$ salt. Followed by the thermodynamically favourable replacement of Zn^{2+} ions by Cd^{2+} ions using cation exchange.

Quantitative analysis shows that the photocatalytic H_2 -production of the new material is more than 50 times greater than CdS on its own, as well as being significantly better than platinum-doped ZnS under UV and visible light.

Max Lu, an expert in clean energy and environmental technologies at the University of Queensland, Australia, says, ‘the results are quite exciting, and the CdS quantum dots are shown to be powerful in facilitating photocatalytic water splitting even without the use of Pt. If the stability is proven to be good, this system should offer the opportunity to substantially lift the rate of hydrogen production under visible light irradiation.’

Next, the team plans to find other quantum dot-based materials, which could be used to enhance hydrogen generation.

Jennifer Newton

Hot science

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I Urban *et al*, *Chem. Commun.*, 2010, **46**, 4583, DOI: 10.1039/b925933c

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Z Yu *et al*, *J. Mater. Chem.*, 2010, DOI: 10.1039/c0jm00400f

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I F Nata *et al*, *Green Chem.*, 2010, DOI: 10.1039/c003479g

Development of safe and scalable continuous-flow methods for palladium-catalyzed aerobic oxidation reactions

X Ye *et al*, *Green Chem.*, 2010, DOI: 10.1039/c0gc00106f

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KA Lynn *et al*, *Analyst*, 2010, DOI: 10.1039/c0an00096e

Continuous two-phase flow miniaturised bioreactor for monitoring anaerobic biocatalysis by pentaerythritol tetranitrate reductase

S Mohr *et al*, *Lab Chip*, 2010, DOI: 10.1039/c003561k

Graphite screen printed electrodes for the electrochemical sensing of chromium(vi)

PM Hallam *et al*, *Analyst*, 2010, DOI: 10.1039/c0an00228c

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R. Busquim e Silva *et al*, *Energy Environ. Sci.*, 2010, DOI: 10.1039/b926784k

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Interview

Great expectations

Zhenan Bao is tipped to be one of the great innovators of the 21st century. Joanne Thomson caught up with her in Atlanta to find out what inspires her to succeed



Zhenan Bao

Zhenan Bao is associate professor at Stanford University, US, where she uses chemical and chemical engineering approaches to make functional nano- and microstructures with novel electronic and photonic properties. Her work has gained her international recognition, including the RSC Beilby Medal and Prize in 2009.

What inspired you to become a scientist?

I always had a very inquisitive nature and liked to ask 'why?' a lot. My parents were both scientists – one a chemist, one a physicist – and I was inspired by their careers. My father in particular instilled in me a curiosity for why things happened. He once bought me a popsicle ice lolly and asked if I thought it would sink or float in water. I said it would sink because it was solid so he threw it in the lake and said he would buy me another if we lost it. I was very surprised when it floated and, of course, wanted to learn why.

Your work focuses on organic electronics. Why did you decide to specialise in this area?

Around the time of my graduate studies in Chicago, Francis Garnier reported the first printed transistor, which really inspired me. After my PhD, I joined Bell Labs (Lucent Technologies). They had already started some work in printed electronics and with my background in synthesis I thought I could immediately contribute. When I started as an assistant professor I was given a lab and told to think about what I wanted to do and make a start. Organic electronics is an area with many useful applications and one where I felt I could make a real difference.

Your work is multidisciplinary, combining chemistry, materials science, physics and various types of engineering. How do you coordinate such a diverse research group and stay on top of all the literature?

I find it very stimulating to have a group of students and post docs coming from very different backgrounds. We have nine chemists, 10 chemical engineers, four electrical engineers, three physicists and several materials scientists. They all bring into the group different expertise. They learn from me and I learn from them – we are learning together. It is hard to keep on top of all the literature but if the students see some exciting work somewhere, they will let me and the whole group know so that helps a lot. I find the journal highlights very useful. They give me an idea of the current exciting work going on without having to read every issue of the journal.

What are you working on at the moment?

Lots of things! One of the areas I am most excited about is our electronic skin, where we are trying to mimic the chemical, biological and pressure sensing abilities of real skin. We also have really

exciting results on transparent electrodes with carbon nanotubes, where we can achieve really good performance. We are trying to spin off a company from that work. We recently won the MIT Clean Energy Entrepreneurship prize and I am very proud of the students who presented the work. In the solar cell area, we have developed new material design concepts which have started to show promising results.

How does a scientist without a business background go about setting up their own company?

I am still learning! There are other professors who have started companies so there is a lot of help and there are very nice people who are willing to give advice. It is like doing research – when one gets stuck, one goes to the experts in the area.

What is the best part of your job?

It is hard to rank the parts I enjoy the most. I love the interaction with students, meeting people from all over the world, the travel, being able to pursue an idea and see it become reality and also the freedom of being able to decide what to work on, who to work with. There are so many possibilities being a scientist.

You have been selected as both an outstanding young woman scientist who is expected to make a substantial impact in chemistry and one of the top 100 young innovators for this century. What is the secret to your success?

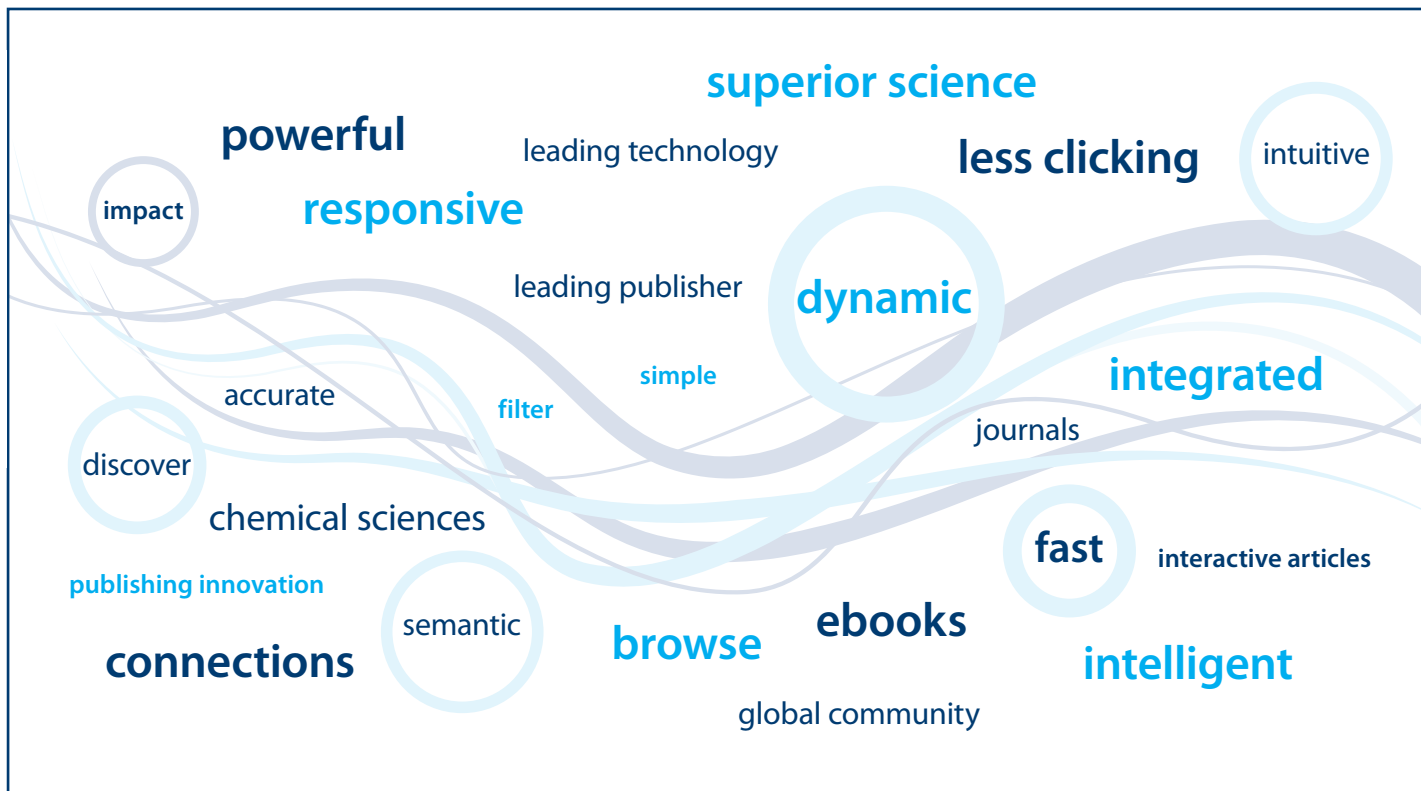
Being curious and asking lots of questions. Also being driven and hard working. Being a scientist is a demanding job but there is no easy job in the world if one wants to be successful.

What is your advice to other young women thinking of embarking on a scientific career?

Women often underestimate their own ability but they must be confident and believe they can do it just as well as anybody else.

What do you do in your spare time?

I don't have much spare time so any that I do have I spend playing with my two kids. I try to inspire them to ask questions and think about everything they do and not take things for granted. I don't know what they will choose to do in the future but I hope that if they develop good problem solving skills they will be successful.



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