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SIRIM Link

Driving innovation through technology and quality

GETTING TO THE HEART OF MATTER

Nanotechnologists at SIRIM's Advanced Materials Research Centre explore the big world of small matter.

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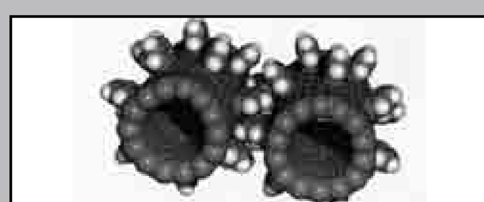
MOLECULAR MANUFACTURING

Nanoscale manufacturing: the next step in industrial miniaturisation.

NANOPARTICLE SYNTHESIS

The synthesis and processing of nanoparticles.

CARBON NANOTUBES



The wonderful possibilities of carbon nanotubes.

SIRIMLink

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NO SMALL CHALLENGE

2009 WAS A VERY IMPORTANT year for SIRIM and the country. We made significant inroads in terms of research and development. In both the local and international scene, we again proved our worth as the country's premier scientific institute. And yet for all that, the biggest – or should I say the smallest – challenges are yet to come.

I am speaking about nanotechnology, of course: "the engineering of functional systems at the molecular scale." It is a subject that has gained notoriety both good and bad. Unfortunately, with nano-fact and nano-fiction all mixed up into one, it is easy to forget that the world is on the cusp of one of the most exciting eras in the history of science and man.

In this issue of SIRIMLink, we asked the team on the Nanomaterials Programme at the Advanced Materials Research Centre (AMREC) in Kulim to help us separate fact from fiction. I am happy to report that the team is doing everything it can to prepare the nation for the nanoindustrial revolution, and that SIRIM is well prepared to face the enormous – or rather, tiny – challenges ahead. SIRIM has also been given the task of developing the National Nanometrology Laboratory, and our metrologists have already taken the necessary steps to ensure that the industry is ready to be supported when the time comes.

SIRIM is also proud to play host to the International Conference on Nanotechnology-Research and Commercialisation (ICONT), which will bring together the world's leading scientists, academics and industry specialists. I hope the delegates have a fruitful and productive time at the conference, and wish them a safe journey home.

I would also like to take this opportunity to wish you a Happy New Year 2010. May you have a productive year ahead.

Nor Rashid Ismail
Vice President
Corporate Division

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Shahrul Nizam Md Salleh, a researcher at AMREC takes a close look at a nanoscale element through an X-Ray Photospectroscopy machine.

The International Conference on Nanotechnology-Research and Commercialisation

Aligning nanotechnology industry and research.

President and Chief Executive of SIRIM Berhad, Ir. Hj. Yahaya Ahmad.

NANOTECHNOLOGY has dominated the headlines of academic journals and magazines around the world. Recognising the need for both researchers and the industry to align their objectives, SIRIM Berhad is organising a four-day conference on nanotechnology research and commercialisation in line with SIRIM's effort to position itself as a Centre of Excellence in the area of Nanotechnology

The International Conference on Nanotechnology-Research and Commercialisation will bring together the world's leading scientists, academics and industry specialists and will serve as a platform for them to exchange and align their ideas.

"Over two hundred people have registered for the programme, so we are very confident that it will be a success," says YBhg. Ir. Hj. Yahaya Ahmad, President and Chief Executive of SIRIM Berhad. "The exhibition will be very interesting and will feature nanotechnology-related equipment and tools."

The conference will be held at the Bayview Hotel and Resort in Langkawi Island from 14-17 December 2009. Registration will be on 14 December 2009, followed by two days of technical sessions, from 15-16 December. On the 17th of December, the doors to the industrial talk will open and the conference will focus on the commercialisation efforts and successes made by scientists so far. It will also take a peek into future commercialisation possibilities.

Among the parties that have confirmed their attendance are Samsung and Park Systems from Korea, Agilent Technologies from the United States, industry analyst Frost & Sullivan as well as leading academics and researchers from Japan, India and Malaysia. Iran is also expected to make a big impact at the conference as representatives from the Nano Initiative Council talk about the country's experiences and challenges in the field.

"Considering that nanotechnology is a field dominated by the traditional world powers, Iran is doing remarkably well for itself," says Ir. Hj. Yahaya. "The country can boast of quite a few successes with nanotechnology-based products."

The keynote speakers include two-time winner of IBC England's "Outstanding Scientists of 21 Century Professor" award Professor Hanjo Lim from Ajou University, Korea and Professor Guozhong Cao, a Boeing-Steiner Endowed Professor from the University of Washington, U.S. Dr Koji Takeuchi, Deputy Director of Japan's National Institute of Advanced Industrial Science and Technology (AIST) is also scheduled to give a talk. Iran's Nano Initiative Council will be represented by its President, Dr Saeed Sarkar.

Hydrostone ceramic products to become new source of income to Port Dickson community

SIRIM Berhad to train local entrepreneurs on Plaster-of-Paris production techniques.

YB Datuk Seri Dr. Maximus Johnity Ongkili hand painting a ceramic handicraft while SIRIM Berhad Chairman YBhg Datuk Jamaliah Kamis (far left) looks on.

THE LOCAL community in Port Dickson, Negeri Sembilan can soon look forward to building another source of income as SIRIM Berhad spearheads a ceramic product development project for decoration using the Hydrostone method, also known as Plaster-of-Paris (PoP).

The programme is aimed to support the tourism industry in Port Dickson, which is famous for its sandy beaches and beautiful scenery. The cooperation between SIRIM Berhad and the local community through the Village Development and Safety Committee, Kampung Baru Si Rusa, Port Dickson was sealed at a ceremony in Port Dickson on Monday, 5 October.

The exchange of documents was witnessed by the Minister of Science, Technology and Innovation, YB Datuk Seri Dr. Maximus Johnity Ongkili. SIRIM Berhad was represented by the President and Chief Executive, Ir. Hj. Yahaya Ahmad while the Kg. Baru Si Rusa Committee was represented by its Chairman, Tusiran Pesan.

Plaster-of-Paris (PoP) is used in a variety of industries. It's fine, white and easily-hardened characteristics make it an ideal material for decorative craft products such as miniatures and figurines. The material is also widely used in orthopedic surgery and its applications.

Under the programme, SIRIM Berhad will provide the necessary consultancy and technology expertise to local entrepreneurs interested in pursuing a business in hydrostone ceramics. They will be given the opportunity to learn about the important factors in product development such as the raw materials needed, designing, modeling and moulding, casting methods and product decoration.

In his speech, YB Datuk Seri Dr. Maximus said, "Local entrepreneurs who want to compete globally must meet world quality and standards and yet remain attractively packaged and branded. Many local products still lack these criteria. Through agencies such as SIRIM Berhad, MOSTI is committed to supporting and assisting these local industries."

The Chairman of the Kg. Baru Si Rusa Committee said the project would be able to provide the local community a new source of income. In addition, the handicraft products that are produced could also become a part of the tourism identity of Port Dickson.

"We are proud to be given the chance by MOSTI and SIRIM to carry out this project," added Tusiran. "It is high time that Port Dickson produced goods with the town's own tourism identity. By purchasing these souvenirs, tourists will always be reminded of their time here when they leave."

SIRIM to help build multi-billion ringgit LED lighting industry

Local partner Avenion Greentech will collaborate with SIRIM Berhad to develop industry.

Ir. Hj. Yahaya, President and Chief Executive of SIRIM Berhad (left) exchanging documents with Dr. Izmi Che Ismail, President and CEO of Avenion Greentech (right).

SIRIM BERHAD INTENDS TO turn Malaysia into a key international player in the light-emitting diode (LED) business.

The company signed a Memorandum of Understanding with Avenion Greentech Sdn. Bhd. to collaborate in the R&D and commercialisation of LED lighting. Under public-private sector agreement, the parties will work closely in the areas of product development, standards benchmarking and project commercialisation. The joint project aims to create a RM25 billion LED industry within twelve years.

"To achieve our aim of turning Malaysia into a key player in the international LED market, we had to choose a local partner that was already producing and marketing high quality LED products," said Ir. Hj. Yahaya Ahmad, President and Chief Executive of SIRIM Berhad at the signing ceremony. "Avenion Greentech has been in the LED business for a long time and their quality standards are world-class."

Avenion Greentech and its sister companies are involved in projects in Malaysia and Japan. The group supplies LEDs to end customers like Toyota, Mercedes, BMW and Audi. According to Dr. Izmi Che Ismail, Avenion Greentech's President and CEO, the company's Optomas brand of LED lighting will soon see its way into internal and external building lighting, as well as outdoor lighting in the near future.

"We benchmark ourselves against the highest market standards and are constantly audited by our customers," added Dr. Izmi. "Naturally we are excited about this development. In SIRIM we find the right level of competencies and expertise to help us move forward internationally."

As a pilot project, one of SIRIM's facilities will be retrofitted with Optomas LED lights. This will provide a benchmark in ascertaining the right working platform between the two parties. It will also provide the impetus for the commercialisation style necessary to help build the foundations for SMEs interested in entering the LED industry.

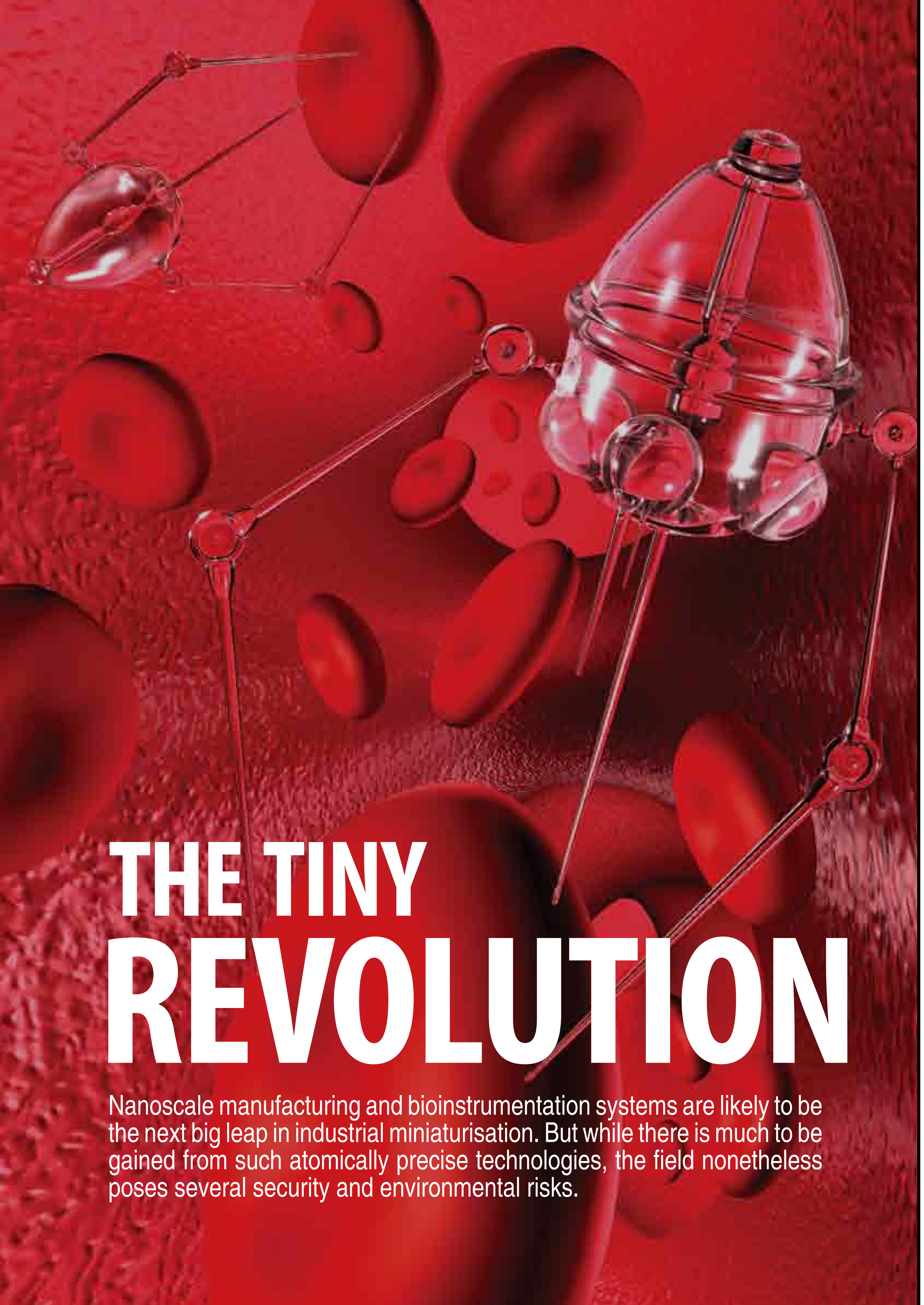
"We will exploit the potential on LED lighting retrofitting at potential areas including government offices, street lamps and places of public interest such as the new Kuching Waterfront," added Ir. Hj. Yahaya.

A GLOBAL ROADMAP FOR NANOTECHNOLOGY

What the future holds for the world's most exciting field of research.

	WHERE SCIENTISTS ARE NOW	WHERE SCIENTISTS WILL BE SOON	WHERE SCIENTISTS WILL BE IN THE FUTURE
Development Area	**Horizon I**	**Horizon II**	**Horizon III**
Atomically Precise Fabrication and Synthesis Methods	• Bio-based productive nanosystems (ribosomes, DNA polymerases) • Atomically precise molecular self-assembly • Tip-directed (STM, AFM) surface modification • Advanced organic and inorganic synthesis	• Artificial productive nanosystems in solvents • Mechanically directed solution phase synthesis • Directed and conventional self-assembly • Crystal growth on tip-built surface patterns • Coupled-catalyst systems	• Scalable productive subsystems in machine-phase environments • Machine-phase synthesis of exotic structures • Multi-scale assembly • Single-product, high-throughput molecular assembly lines
Atomically Precise Components and Subsystems	• Biomolecules (DNA- and protein-based objects) • Surface structures formed by tip-directed operations • Structural and functional nanoparticles, fibers, organic molecules, etc.	• Composite structures of ceramics, metals, and semiconductors • Tailored graphene, nanotube structures • Intricate, 10-nm scale functional devices	• Nearly reversible spintronic logic • Microscale 1 MW/cm^3 engines and motors • Complex electro-mechanical subsystems • Adaptive supermaterials
Atomically Precise Systems and Frameworks	• 3D DNA frameworks, 1000 addressable binding sites • Composite systems of the above, patterned by DNA-binding protein adapters • Systems organized by tip-built surface patterns	• Casings, "circuit boards" to support, link components • 100-nm scale, 1000-component systems • Molecular motors, actuators, controllers • Digital logic systems	• Complex systems of advanced components, micron to meter+ scale • 100 GHz, 1 GByte, 1 µm-scale, sub-µW processors • Ultra-light, super-strength, fracture-tough structures
Applications	• Multifunctional biosensors • Anti-viral, -cancer agents • 5-nm-scale logic elements • Nano-enabled fuel cells and solar photovoltaics, • High-value nanomaterials • Artificial productive nanosystems	• Artificial immune systems • Post-silicon extension of Moore's Law growth • Petabit RAM • Quantum-wire solar photovoltaics • Next-generation productive nanosystems	• Artificial organ systems • Exaflop laptop computers • Efficient, integrated, solar-based fuel production • Removal of greenhouse gases from atmosphere • Manufacturing based on productive nanosystems

Nanotechnology Roadmap by the Foresight Institute. www.foresight.org.



THE TINY REVOLUTION

Nanoscale manufacturing and bioinstrumentation systems are likely to be the next big leap in industrial miniaturisation. But while there is much to be gained from such atomically precise technologies, the field nonetheless poses several security and environmental risks.

WHEN THE GREEK philosopher Leukippos first posited that the entire universe was made up of tiny, indivisible particles he called *atomos*, very few people took him seriously. Nonetheless, his theory of atomism fuelled the imagination of scientists for centuries, until John Dalton finally proved him right with a series of experiments in the early 19th century. Soon, scientists all over the planet were not only studying the sub-atomic world, but were experimenting with it, too. The most famous example of these experiments is, of course, the splitting of the atom.

Nuclear fission taught both scientists and governments to think twice before playing with powerful technologies they know nothing about, and thankfully, the world has since come to regard the atomic world with a healthy mixture of awe and respect. Scientists are no longer obsessed with smashing up atoms. Instead, researchers around the world are using atomically precise technologies to put atoms together.

This field of research – the ability to do things on the scale of atoms and molecules – is called nanotechnology: a term so loosely used these days that it has nearly lost its lustre. It seems that everything from cosmetics to spacesuits appears poised to gain from nanotechnology. Researchers everywhere, from Proctor & Gamble to NASA, are all equally excited about the potential of nanomaterials, nanoparticles, nanolithography and nanorobotics.

SUPER, DUPER NANOMATERIALS

Before we can start building super-light cars and elevators to the moon, however, we need a steady supply of raw nanomaterials such as fullerenes, nanotubes and nanoparticles. Research suggests that the global market for such nanomaterials will reach USD4.2 billion by 2011, and most research in nanotechnology these days is centred around discovering ways of mass producing them. It should therefore come as no surprise that nanomaterials are also at the core of SIRIM's nanotechnology programme.

Dr Abdul Kadir Masrom, Head of the Nanomaterials Programme at the Advanced Materials Research Centre (AMREC)

"We are looking at two things when it comes to these nanomaterials: how to make them, and how to apply them," says Dr Abdul Kadir Masrom, Head of the Nanomaterials Programme at SIRIM's Advanced Materials Research Centre (AMREC) in Kulim. "We are researching several methods to synthesise nanomaterials including the sonochemical process, the sol-gel method and chemical reduction."

The reason nanomaterials are so interesting to SIRIM is simple: they work. Some very ordinary elements possess startlingly unique properties when reduced to the nanoscale. Aluminium becomes combustible. Gold will change colour and turn to liquid at a temperature 500 degrees lower its normal melting temperature. Add to that the fact that silver, copper, and aluminium also possess potent anti-bacterial properties, and what you have are a lot of useful elements just waiting to be put together.

“Our research remains very relevant to the needs of the industry,” explains Dr Abdul Kadir. “We focus on medical applications, environmental applications and energy applications.”

SIRIM’s research into drug delivery systems and cancer diagnostics and treatment processes has already had some promising preliminary results, and Dr Abdul Kadir also sees a lot of potential in water and air cleaning systems. AMREC’s multi-disciplinary team have also started experimenting with organic photovoltaic solar cells, a market that is estimated to be worth USD3.9 billion in 2013.

THE MIRACLE OF MOLECULAR MANUFACTURING

The ultimate vision of nanotechnology enthusiasts, however, is a world in which self-assembling, nanobot-powered factories will build everything from anti-bacterial pasta strainers to thin-film batteries in synthetic, molecular manufacturing environments. Smaller nanobots will build bigger nanomachines to do the heavier work, much like the smaller robots in today’s assembly lines make the larger machines that build today’s automobiles. And, when they become obsolete, these nanobots will self-destruct and donate their atoms toward building newer, more advanced nanobots.

“Fourth-generation nanotechnology – molecular manufacturing – will radically transform the world and the people of the early twenty-first century,” prophesies Dr Abdul Kadir, Head of the Nanomaterials Programme at SIRIM’s Advanced Materials Research Centre (AMREC). “Our vision is a world in which molecular manufacturing is widely used for productive and beneficial purposes, and where dangerous uses are limited.”

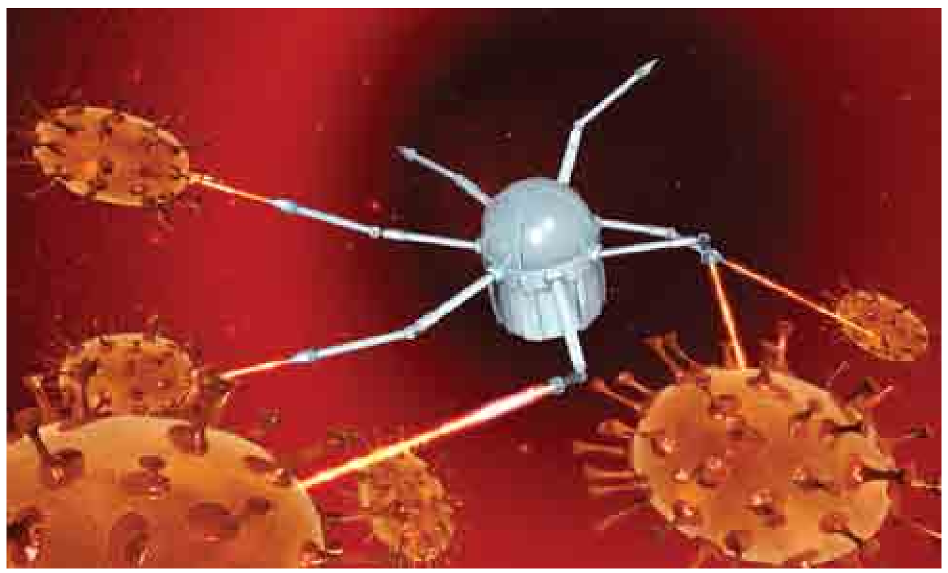
I know, it all sounds like something out of an Isaac Asimov book. But consider this: nanotechnology is not all that new a concept, and neither are self-assembling molecular structures. In fact, Mother Nature has been turning atoms into molecules and molecules into cellular structures ever since the dawn of time. Call it what you want, but this kind of biological nanotechnology is really nothing more than molecular manufacturing at work.

Let’s take a look at a simple leaf, for example. Chloroplasts – the sub-cells responsible for photosynthesis – contain nanoscale power plants called thylakoid disks which convert light and carbon dioxide into chemical energy. That chemical energy is then converted into mechanical work through nanoscale molecular machinery such as motor proteins that make the plant to grow as well as kinesins – the nanoscale conveyor belts used within intra-cellular transport systems. However, the real beauty of these biological nano-systems is that they are almost entirely self-managed, capable of spontaneous assembly, disassembly and reassembly as and when required.

NANOBOTS TO THE RESCUE

Although nanomachines remain a hypothetical concept, researchers are nonetheless experimenting with primitive molecular motors, propellers and wheels. If they can make all of these parts function together as a nanomachine, they say that these nanobots may one day be used to identify cancer cells and destroy them.

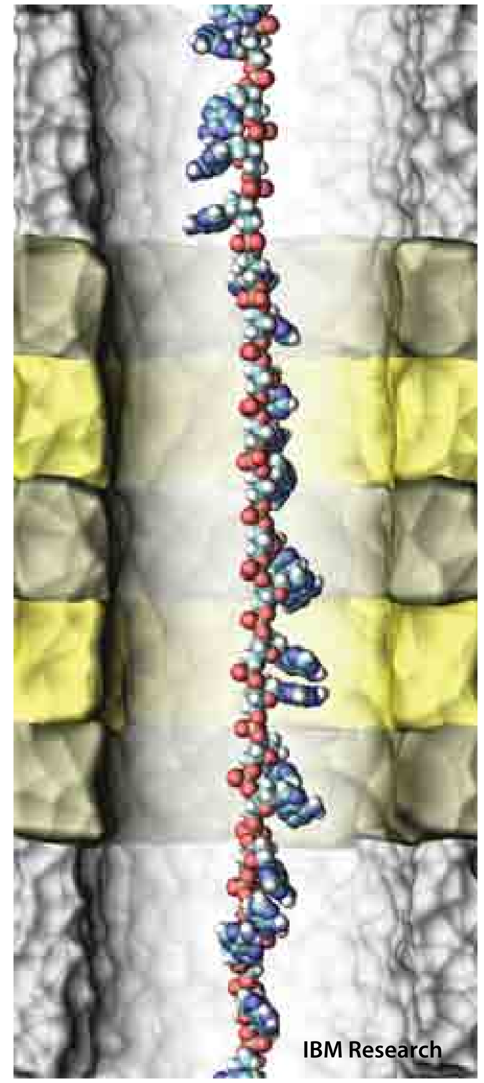
Other scientsist tend be more sceptical. They believe that such nanomachines, if ever built, will probably be used in simpler tasks involving early diagnosis systems, targeted drug delivery, biomedical instrumentation and pharmacokinetics. But will these nanobots be licensed medical practitioners? We’ll wait and see.



Nanotechnology might also be thought of from an industrial production point of view. To make a wooden chair, for example, we chop a large tree down, saw it into smaller components and then nail the pieces all together until we get a chair. Nature operates in a very different way. Rather than cobble different parts together to produce a plant, Mother Nature grows the plant instead. It starts with a very small seed with self-assembling molecules that eventually grow into a full tree.

That’s a pretty neat trick, if you can get it to work, and Mother Nature has had a lot of practice. Synthetic nanotechnology, however, is still many years away from such advanced self-assembly systems. The closest Man has come so far was when researchers at Northwestern University, U.S. used DNA as the blueprint, contractor and construction worker to build a three-dimensional crystalline structure out of gold in early 2008.

Other, smaller advances have been made since then, but nothing that comes close to the mass-manufactured perfection of the living world.Nonetheless, scientists are experimenting with molecular propellers, switches, sensors, tweezers and shuttles. Put all those things together, and it is not hard to imagine synthetic nanobots programmed to swim through our bodies to “fix” broken cells. It is also not hard to picture large-scale molecular manufacturing systems that build tennis balls one molecule at a time.



DNA TRANSISTOR. In an effort to build a nanoscale DNA sequencer, a team of IBM scientists from four fields – nanofabrication, microelectronics, physics and biology – are converging to master a technique that threads a long DNA molecule through a three nanometer wide hole, known as a nanopore, in a silicon chip. This advanced research effort to demonstrate a silicon-based “DNA Transistor” could help pave the way to read human DNA easily and quickly, generating advancements in health condition diagnosis and treatment.

NA-NO-YOUR-BUSINESS

Idealists say that the result of all this nanotechnological wizardry will be a closed, nearly waste-free manufacturing environment that is more efficient and economical than anything we have ever seen. However, such atomically precise manufacturing systems will require programmable controls and fail-safes to protect both the human workers within these manufacturing environments as well as the end-users of the products themselves. What do we do should a rogue nanobot suddenly malfunction due to a programming bug (it happens)? Nanoscale disasters will not be easily detected or contained.

However, rogue nanobots are the least of the scientific community’s worries. There are far more urgent issues at hand: the widespread acceptance of nanotechnology can lead to untraceable weapons of mass destruction, overwhelming nanotoxicology risks and black market.

The ability to play at being Mother Nature comes with an enormous responsibility, because if Man can use nanotechnology to create, Man

THE TINY REVOLUTION

can also use it to destroy. We have to manage this power responsibly.

The biggest worry of policy makers around the world is in how they can make the playing field more level between the haves and have-nots. As it stands, only the developed world has the resources necessary to properly exploit nanotechnology research and applications. Unless developing countries catch up soon, they may find themselves thrown back into third-world status as their old-world patents and products become even more inferior to the developed world's nanotechnology-inspired products.

"You can do almost anything with nanotechnology, and you can do it better than ever before," explains Dr Abdul Kadir. "Developing countries are only just beginning to produce things that are of equal quality to products from developed countries. However, if these countries do not harness nanotechnology quickly, then they will soon find themselves thirty or forty years behind the West again."

Indeed, without a nanotechnology-equipped industry, some economies may collapse altogether. Nanotechnology clearly holds much promise for the future and will likely spark the next industrial revolution. Countries ignore it at their peril. And yet, the economics of nanotechnology is the least of scientists' concern.

A CLEAR AND PRESENT DANGER

The biggest concern with the widespread use of nanotechnology is safety. Nanoparticles can be fifty times more toxic than ordinary materials, and when released, they will likely remain in a state of suspension in the air for quite a while. Some scientists believe that these nanoparticles will quickly bond with other elements and be rendered harmless as soon as they are released. However, there is another group of scientists who think that these nanoparticles may float around indefinitely and wind up in the lungs of unsuspecting lab workers.

"Once nanoparticles have been safely assembled into a product, they pose minimal or no risk," Dr Abdul Kadir explains. "But what about the workers handling the nanoparticles *before* they are assembled? That is why the OECD is working towards establishing new safety standards for workers within nanotechnology manufacturing environments."

Existing lab safety standards generally rate harmful exposure of substances according to weight and time. Thus, a substance with a limit of eight hours of 100 mg/m^3 means that workers should not be exposed to a concentration of the substance of 100 mg/m^3 for more than eight hours. With nanoparticles, however, the safety standard would have to measure the surface area of the nanoparticle rather than its weight. This is because the toxicology of 1 mg of lead nanoparticles might be as dangerous as 100 mg of regular lead.

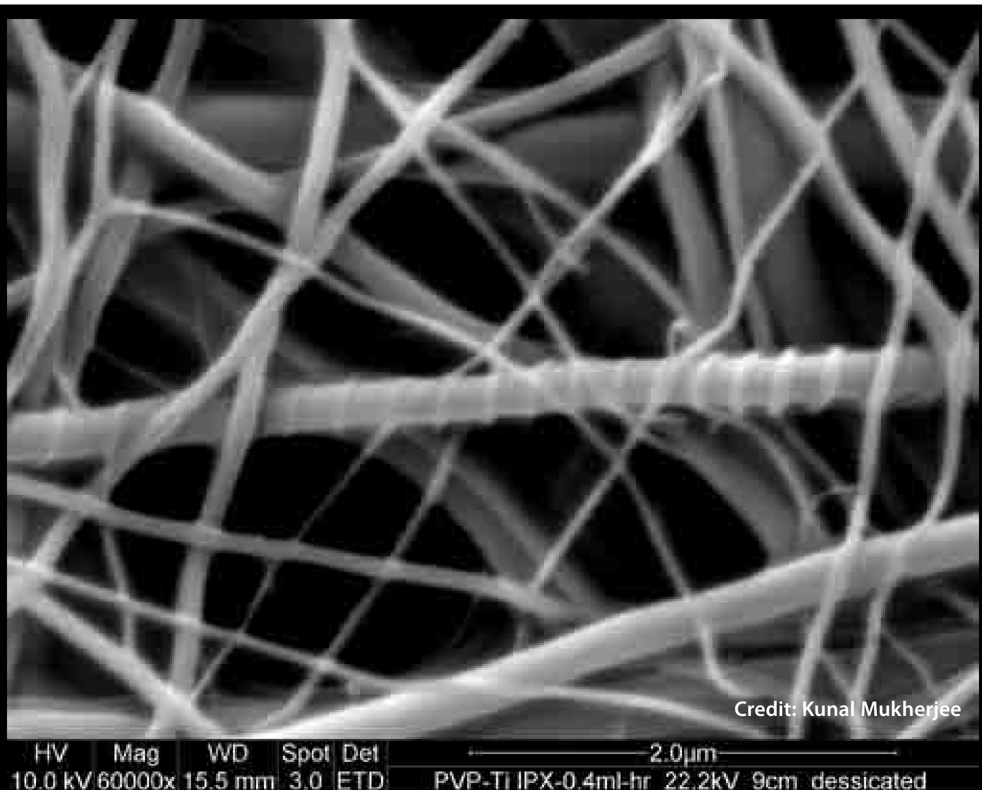
"The rules of measuring safety standards are very different in a nanotechnology environment," says Dr Abdul Kadir. "Nanometrology is very important to this field and SIRIM researchers are equipping themselves to face these future challenges. We have to quickly agree on how to measure the nanoworld so that we can start drawing up safety guidelines for working within it."

As it stands, everyone has their own ways of referring to aspects of the nanoworld. There is no clear, globally accepted definition of words like 'nanoparticles' or 'nanosized'. In fact, the world appears to be divided upon the eschewed benefits of nanotechnology.

"Asian consumers gravitate towards products with the word 'nano' on their labels, but in Europe, consumers are extremely wary of nanotechnology," explains Dr Abdul Kadir. "Use the word 'nano' with your product and no one will buy it!"

In the next Malaysian Plan, SIRIM plans to put forth a proposal to establish a research programme with regards to nanotoxicology and ecotoxicology in an effort to safeguard the Malaysian population as well as promote safe use of nanotechnology.

"I reckon that will be a positive step forward for the industry as a whole," Dr Abdul Kadir adds.



Credit: Kunal Mukherjee

TOXIC NANOFIBRES?

A study by a team of scientists at Arizona State University suggests that nanomaterials may be dangerous to the human digestive system.

In the study, the research team exposed a layer of colon cells to titanium dioxide (left), a nanomaterial commonly used as white pigment. The TiO_2 dramatically broke down the cellular layer, indicating that the nanomaterial either killed the cells or weakened the cellular junctions.

However, principal researcher Paul Westerhoff cautioned against drawing conclusions from these preliminary results, saying that they are in no way conclusive.

THIN-FILM POWER

One very exciting area of nanomaterial research is in nanostructured thin-films – ultra-fine material films measuring anywhere between fractions of a nanometre to mere micrometres thick. Thin-films are already widely used in electronic semiconductor devices and optical coating applications around the world. At SIRIM's Advanced Materials Research Centre, Suffian Saad is hard at working developing thin film batteries: a market that is estimated to be worth USD98 million worldwide by 2013.

A normal battery consists of an anode, cathode, current collector and electrolyte. In a thin film battery, however, all these parts are built using what is known as the sputtering technique: a process in which atoms are knocked around by high-energy ions until the surface is perfectly flat, like a thin-film.

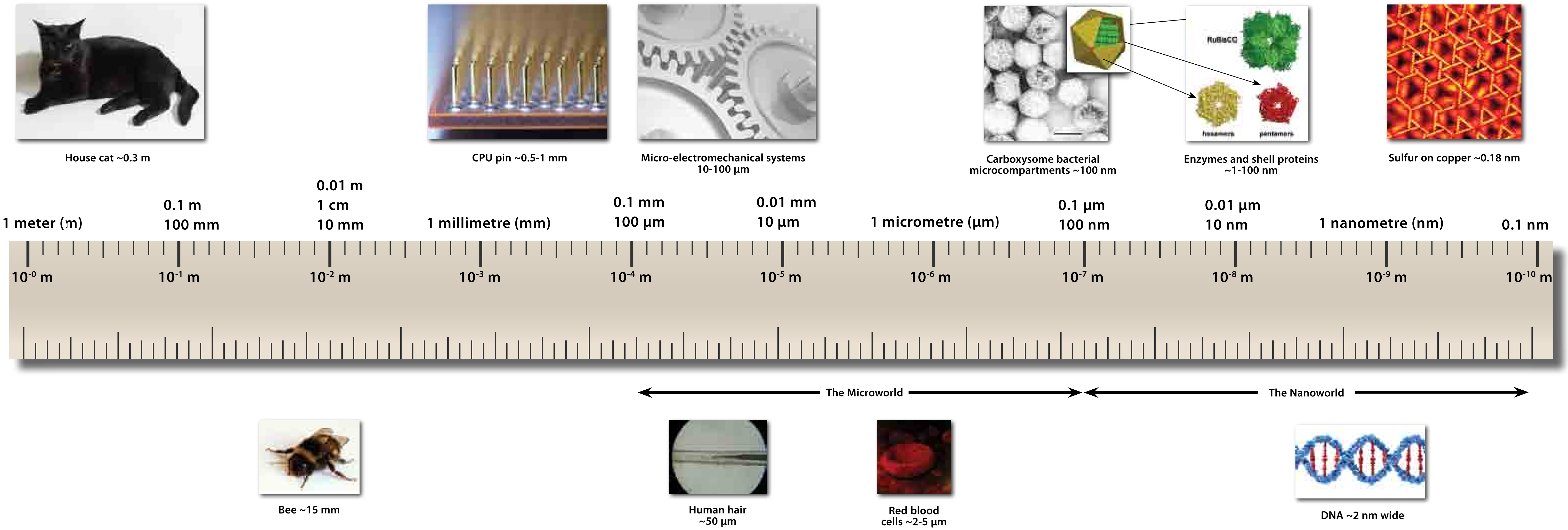
"First, a current collector surface is laid down, followed by a cathode surface, an electrolyte surface and finally another current collector surface," explains Suffian. "The result is a battery that is only microns thick, suitable for high-end applications in sophisticated devices like biosensors and electrically-powered RFID tags and smart cards."

Another advantage to thin-film batteries is that they can be constructed in any shape or dimension and can be literally coated onto any surface, including spheres and polyhedrons. As such, they are proving to be a popular area of experimentation among gadget manufacturers obsessed with making things smaller and lighter.

Suffian Saad showing the thin-film target materials of his experiments.

Thin-film batteries will also likely be used in active RFID tags to boost the range of their transmission. As things stand right now, passive RFID tags must be in very close proximity to scanners in order to be detected. Thin-film-cell powered RFID tags, however, will have a considerably greater transmission range. This will improve security and speed things up at ports around the world.

"Thin-films are also used as protective surface coatings, reflective and anti-reflective glass, transparent conductive coatings and photovoltaic solar cells," Suffian enthuses. "The market is huge, and it can only get bigger. Nanotechnology is changing everything."



NANOSCALE CHALLENGE

As industries around the world move into nanoscale territory, metrologists find themselves face-to-face with their most difficult challenge yet.

THEY SAY A GOOD METROLOGIST can split any scale by ten and is able to imagine the divisibles along any dimension, be it temperature, distance, electrical current, frequency or mass. This is a good thing, because as nanotechnology environments become increasingly more pervasive within industry, our present micrometre devices will soon become obsolete. We need the imaginations of metrologists to help chart our way through nanoscale dimensions too small for the naked eye to perceive.

We also need them to lay down some rules for a world gone loopy on the hype of nanotechnology.

SMALL, SMALLER, SMALLEST

The metric convention for what constitutes a nanometre is anything between 0.1 micrometres (100 nanometres) and 0.001 micrometres (1 nanometre). As it stands, many so-called products of nanotechnology are not really nano-sized at all, such as titanium dioxide nanofibres (200 nm) and biotinylated molecules (300 nm). These products actually fall squarely in the realm of 'microtechnology'. Unfortunately, that word does not sound nearly as exciting as 'nanotechnology', thus the tendency for the world's scientists and media to use the latter label instead of the former.

Sadly, metrologists lead a rather thankless existence. They work behind the scenes and help the gamut of industry to operate upon the same standards of measurement, from high-technology computer chip manufacturers to downtown cloth merchants. A metre is not a metre unless a metrologist says it is, yet few people realise just how important that job is.

Let's take a manufacturer of a metric ruler, for example. Unless his cutting machine is regularly calibrated by a skilled metrologist with high-precision equipment, how can the manufacturer be absolutely sure that the centimetre and millimetre marks etched on his products are precisely spaced? How will he know whether his products are accurate to 0.5 mm or 0.1 mm?

Now, imagine that this manufacturer wanted to make a ruler at the nanoscale, and you'll have an idea of the challenge facing metrologists today. Of course, such a nanoruler would not be used by the common man. But in the realm of nanotechnology, it would be indispensable. After all, how can a nanoindustry exist without a nanoruler to measure its products?

"Just as one would not use a standard metre to make microcomputer chips, one cannot use a standard micrometre to make nanocomputer chips," explains En Abdul Rashid Zainal Abidin, Senior General Manager of the National Metrology Laboratory of SIRIM Berhad (NML-SIRIM). "You'd need a nanoscale device, which is what nanometrology is all about. Without a precise understanding and definition of the nanoworld, there can be no harmony within the nanoindustry."

En Abdul Rashid Zainal Abidin, Senior General Manager, National Metrology Laboratory (NML-SIRIM).

FIT FOR THE PURPOSE

The general rule of thumb is that the scale used to measure and calibrate something should have a much higher resolution and accuracy than the dimensions being measured. Thus you need precise measurement with well-defined measurement uncertainty.

This is not a problem so long as you have good eyesight and are dealing with dimensions that are within the visible spectrum, and so that is exactly what metrologists used to do in the old days. But when the world began moving towards micrometre manufacturing in the early 1970s, it became obvious that the old international standard metre bars would no longer be precise enough for the world's needs.

Metrologists needed a new way to measure distance, and it had to be exceptionally precise and virtually future-proof. Thus, in 1983, the metre was redefined in terms of time and the speed of light: 'the distance travelled by light in vacuum in 1/299,792,458 of a second'.

Some people foresaw that the microtechnologies of the 1970s and 80s were merely precursors to the nanotechnologies scientists are exploring today. Thankfully, the new method for measuring distance is still up to the task. By using the speed light – *c* – to measure distance in relation to time, we can split up a standard metre many billion times over if we need to. A standard nanometre (1×10^{-9}) could therefore be theoretically described as the distance travelled by light in vacuum in $(1/299{,}792{,}458) \times 10^{-9}$ of a second.

"We have to use a standard that is 'fit for the purpose'," says Abdul Rashid.

The 'purpose' in this case is defined by the manufacturer. If a manufacturer wants a product to be regarded as being of superior quality, he must be able to back up his claim by adhering to a specific standard of quality. In order to comply with that

Dr Ahmad Makinudin Dahlan calibrating a high precision glass scale with a laser interferometer at SIRIM's National Metrology Laboratory.

standard, the equipment and instruments used in his production processes must be calibrated and certified by a recognised institute.

"You cannot measure or calibrate nano-products on a scale of micrometres because the micrometre is not fit for the purpose," explains Abdul Rashid. "We need to quickly map out the nanoscale world and agree upon the way we define nanoscale products. The industry depends upon it."

NANO CERTIFIED

Dr Ahmad Makinudin Dahlan, Principal Metrologist at NML-SIRIM takes the nanotechnology industry's current interest in carbon nanotubes as a good case study of why an international standard for the nanoworld is required.

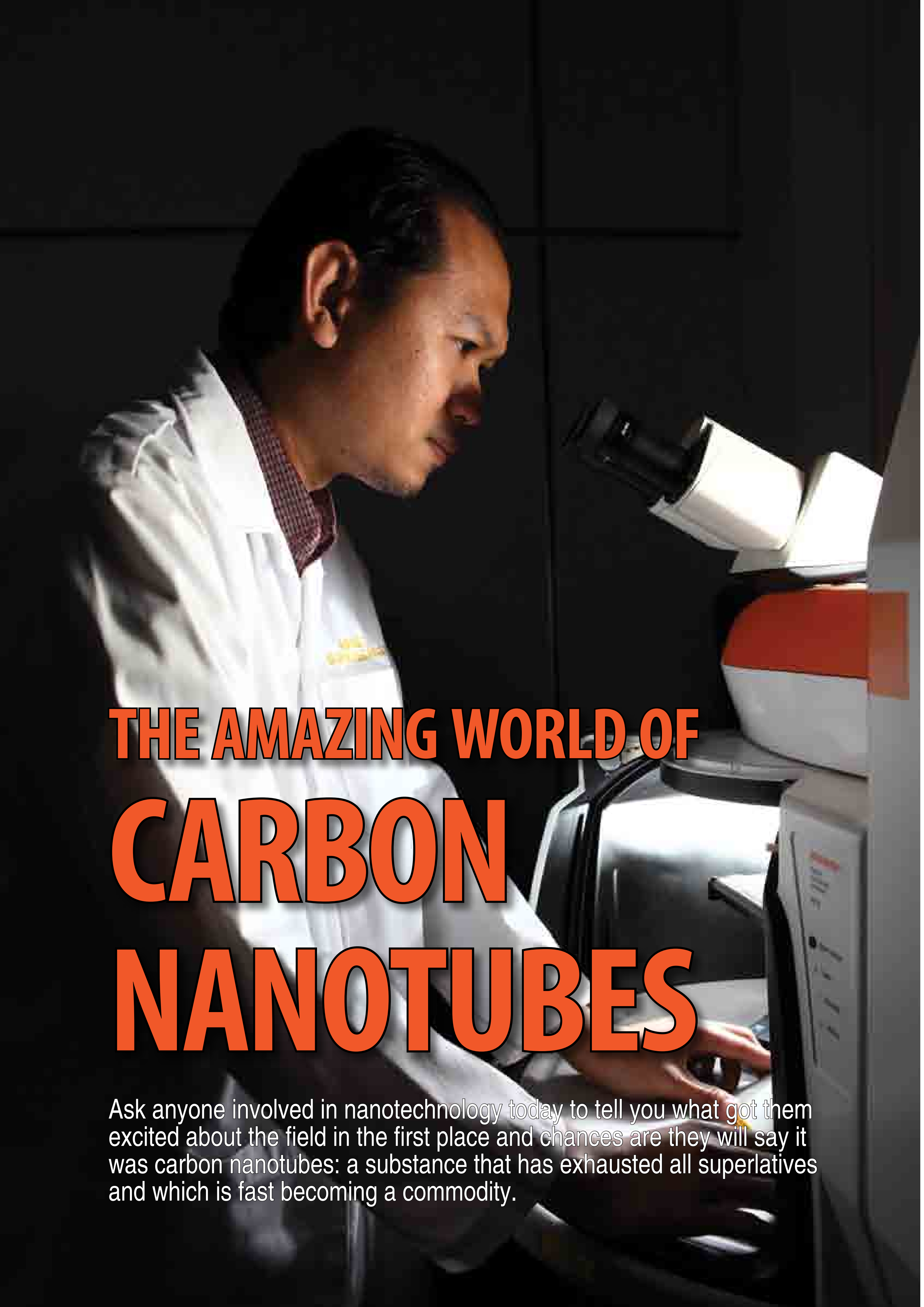
"The world is divided in its methods for exploring and measuring these carbon nanotubes," says Dr Ahmad. "Some scientists use Atomic Force Microscopes (AFMs) while others use Scanning Tunnelling Microscopes (STMs). The result is that everyone has a hard time agreeing with everyone else."

The international community of metrologists has been looking at ways to standardise the methods and techniques used in defining the nano regime. This will eventually lead to greater agreement and interpretation of experimental results.

"We want for everyone to come together and be able to say that yes, this is 0.1 nm, give or take 0.05 nm," explains Abdul Rashid. "That is the ultimate aim of the metrology community."

Taiwan established the world's first "Nano Mark" system for certifying nanotechnology-enhanced products, and other countries are likely to soon follow suit. However, unless all these certification systems can agree upon the same standards, there may soon be an international disagreement. If the Nano Mark from one country is not recognised by another, international trade may suffer.

"Everybody seems to be researching nanoparticles and nanoproducts, but without a commmon reference point, who really knows what is going on?" asks Abdul Rashid. "That is the missing link between nanotechnology and nanoindustry, and that is what we metrologists are trying to solve."



THE AMAZING WORLD OF CARBON NANOTUBES

Ask anyone involved in nanotechnology today to tell you what got them excited about the field in the first place and chances are they will say it was carbon nanotubes: a substance that has exhausted all superlatives and which is fast becoming a commodity.

SCIENTISTS HAVE KNOWN about carbon's unique, multi-purpose properties for a while now. Diamond, for example, is among the hardest materials known to man, while graphite is soft enough to be used in pencils. Carbon fibres are used as reinforcement materials in plastics and in many aerospace structures as a substitute for steel and aluminium. Carbon is also found in almost all organic compounds and is the basis of all life form on earth – in the human body, for example, it is the second most abundant element by mass (about 18.5%) after oxygen.

But carbon nanotubes are really special. True, they are made of the same stuff as carbon fibres, but that is the only thing carbon nanotubes have in common with them. Carbon nanotubes are estimated to be at least a hundred times stronger than carbon fibre and 1,000 times more conductive to electricity than copper. Naturally, they are also expensive. Single-walled nanotubes currently retail at about USD60 per gram – somewhat less than the USD1,500 per gram they cost ten years ago, but still nearly double the price of gold.

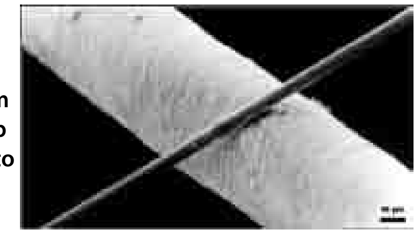
"Carbon fibre is really just black, fluffy graphene sheets spun into a thread about five micrometres thick," explains Shahrul Nizam Md Salleh, a Researcher at SIRIM's Advanced Materials Research Centre in Kulim. "With carbon nanotubes, however, these graphene sheets are instead rolled into tubes little more than one nanometre thick diameter. This unique molecular structure gives them super strength and unique electrical properties."

One piece of on-going research seeks to construct a hydrogen storage technology out of carbon nanotubes that will work very differently from the current technology. Instead of storing hydrogen as a dangerously combustible gas in high-pressure vessels, the hydrogen atoms will instead be chemically bound to the carbon atoms around the nanotubes. They will then be released for burning through an electro-chemical process – a perfectly safe storage facility, in other words.

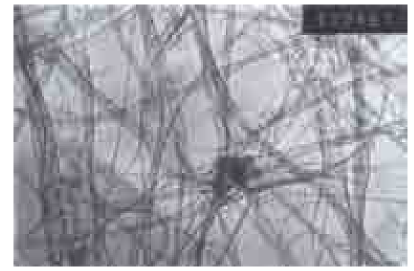
"Carbon nanotube hydrogen storage cells will be much safer than conventional high-pressure vessels because the hydrogen atoms are bonded and grounded to other atoms instead of remaining as an explosive gas," explains Shahrul. "The possible applications of such safe technology within the energy business are practically limitless."

SMALLER AND SMALLER

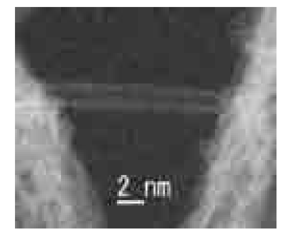
TOP: A 6 µm diameter carbon fibre (from bottom left to top right) compared to a human hair.



MIDDLE: A TEM image of Single-Walled Nanotubes; 90wt% purity; 1-2 nm outer diameter; 5-30 µm length



BOTTOM: Electron micrograph showing a single-walled carbon nanotube suspended between two nanotube bundles.



STRONGER, LIGHTER, BETTER

The real beauty of carbon nanotubes, however, is their high strength-to-weight ratio, which makes them exceptionally well-suited for use in advanced composite materials. The maximum tensile strength of carbon nanotubes achieved so far is 30 GPa with a young modulus of 1.3 TPa. The highest tensile strength that an individual multi-walled carbon nanotube has been tested so far is a staggering 63,000 MPa, which is roughly the equivalent to dangling a six-ton weight on a 1 mm cable. This is why scientists are trying to harness their super-tensile strength by mixing them into composite materials.

Rosli Mohd Ali, Researcher, Advanced Materials Research Centre (AMREC).

Rosli Mohd Ali, a co-researcher with Shahrul Nizam at SIRIM, recently succeeded in increasing one test material's tensile strength by over a hundred percent by anchoring carbon nanotubes on the carbon fibre surface. The team is experimenting with increasing the strength of composite carbon fibre by incorporating carbon nanotubes into the surface and improving the bonding strength between the carbon fibre and the polymer matrix.

"We want to find a way to make carbon composites stronger," explains Rosli. "Say you have a composite with a tensile strength of 90 MPa. By introducing carbon nanotubes into that composite you can increase its tensile strength to 120 MPa. This can open new doors to new applications never considered before."

But before you can start making stronger composites, however, you need a steady supply of carbon nanotubes. The most common commercial method of producing carbon nanotubes right now is known as the 'chemical vapour deposition' technique (CVD), an expensive process that consumes large amounts of energy and which requires specialised equipment. Rosli, however, is experimenting with the 'electrophoritic deposition method', a simple electrochemical synthesis technique very similar to electrolysis.

First, Rosli prepares a suspension of carbon nanotubes with an organic solvent such as ethanol. He then disperses it ultrasonically in order to cut up the carbon nanotubes into smaller pieces so that they will form a more even coat over the target material. After that, he sets up his electrophoritic deposition facility with a filament of carbon fibre as an anode.

"Finally, I turn on the current, submerge both electrodes into the suspension of carbon nanotubes and then manipulate the time and voltage to see what happens," Rosli explains. "We start off with ten volts and gradually increase it to a hundred volts, the highest voltage we've tried so far. We also vary the duration of the process."

Rosli's research is directed to the composites used within the aerospace and high-end automotive markets. Currently, the composites used in these industries are reinforced almost exclusively with carbon fibres. In theory, substituting these carbon fibres with carbon nanotubes will make these high-strength composites much, much lighter.

"You only need a few milligrams of carbon nanotubes to get the same reinforcement benefits as one kilo of carbon fibres," explains Rosli. "These composite materials will therefore become much lighter, making the vehicles they are used in far more fuel-efficient."

UP THE VALUE CHAIN

There are generally two types of carbon nanotubes – single-walled nanotubes and multi-walled nanotubes.

Single-walled nanotubes (SWNTs) are considered to be more useful for electrical applications because of their unique electric properties. This is because SWNTs are excellent

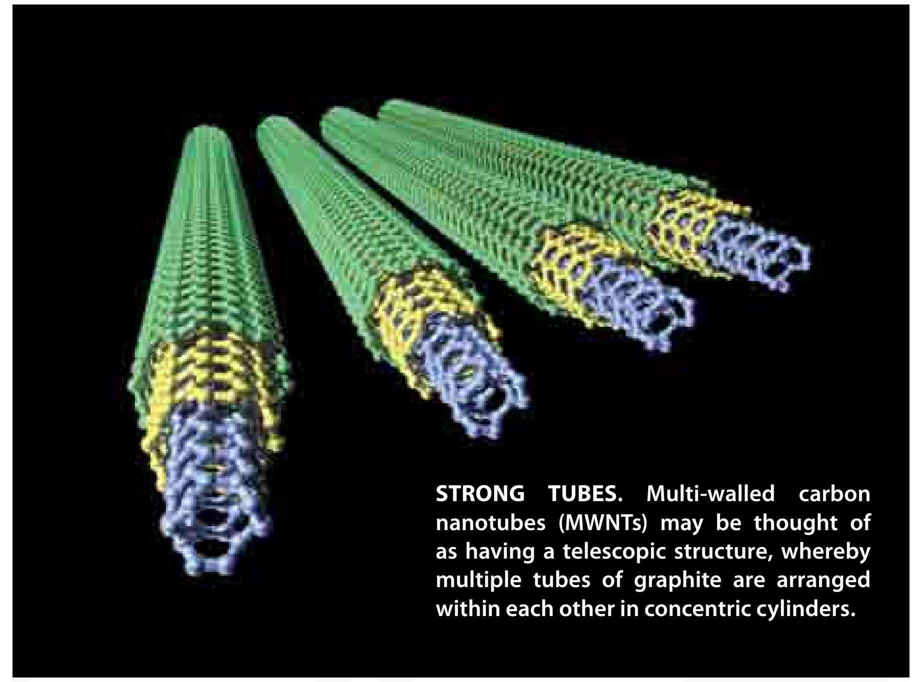
conductors, which would make them very handy in nanoelectronics minitiaturisation projects. Carbon nanotubes are predicted to be able to carry an electrical current density of 1013 A/m^2 – 1,000 times more than copper.

Multi-walled carbon nanotubes (MWNTs), on the other hand, may be more useful in applications that require chemical grafts. The carbon atoms on the outer wall of a nanotube may be bonded to other elements to add new properties to the nanotube (a process called "surface functionalisation") without affecting the integrity of the inner nanotube's structure.

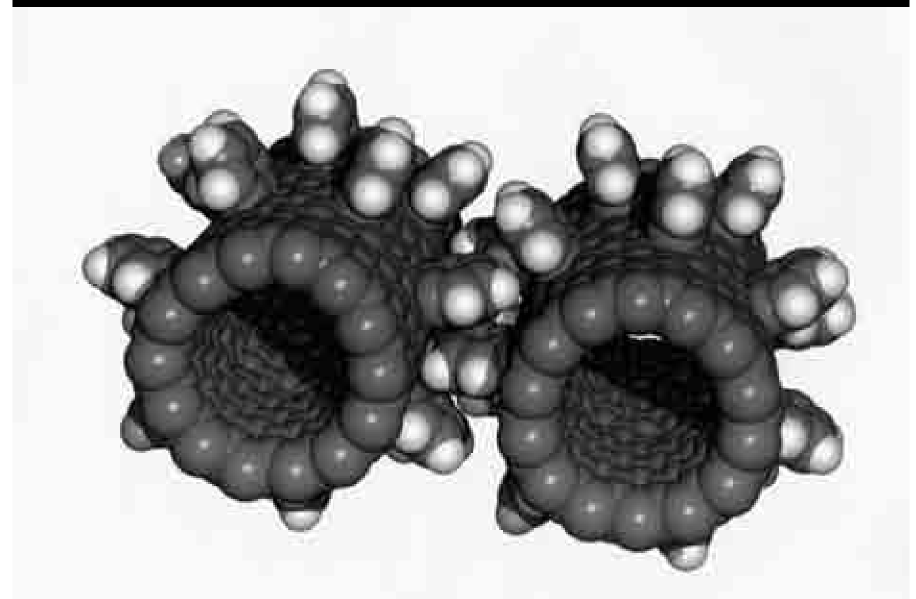
Functionalised carbon nanotubes are substantially more soluble and biocompatible, making them easier to deal with in both laboratory experiments and in industrial applications. As a result, they tend to fetch much higher prices than pure carbon nanotubes, which is what makes them so interesting to Rosli. Pure raw multi-walled carbon nanotubes (MWNTs) generally retail for around USD3 per gram, depending on their purity. Pure Functionalised MWNTs, on the other hand, sell for at least 40% more, and Short Functionalised nanotubes can sell for 300% or more per gram.

"To ensure that we have a steady supply of raw material to be used in our research, SIRIM aims to build a carbon nanotube manufacturing pilot plant with an initial capacity of 8 kg per day," explains Shahrul excitedly. "Once we have that plant in place, we'll be able to move up the value chain and focus our energies on application-specific, functionalised carbon nanotubes instead of merely pure carbon nanotubes."

In doing so, SIRIM will again pave the way forward for an industry fraught with risk and uncertainty.



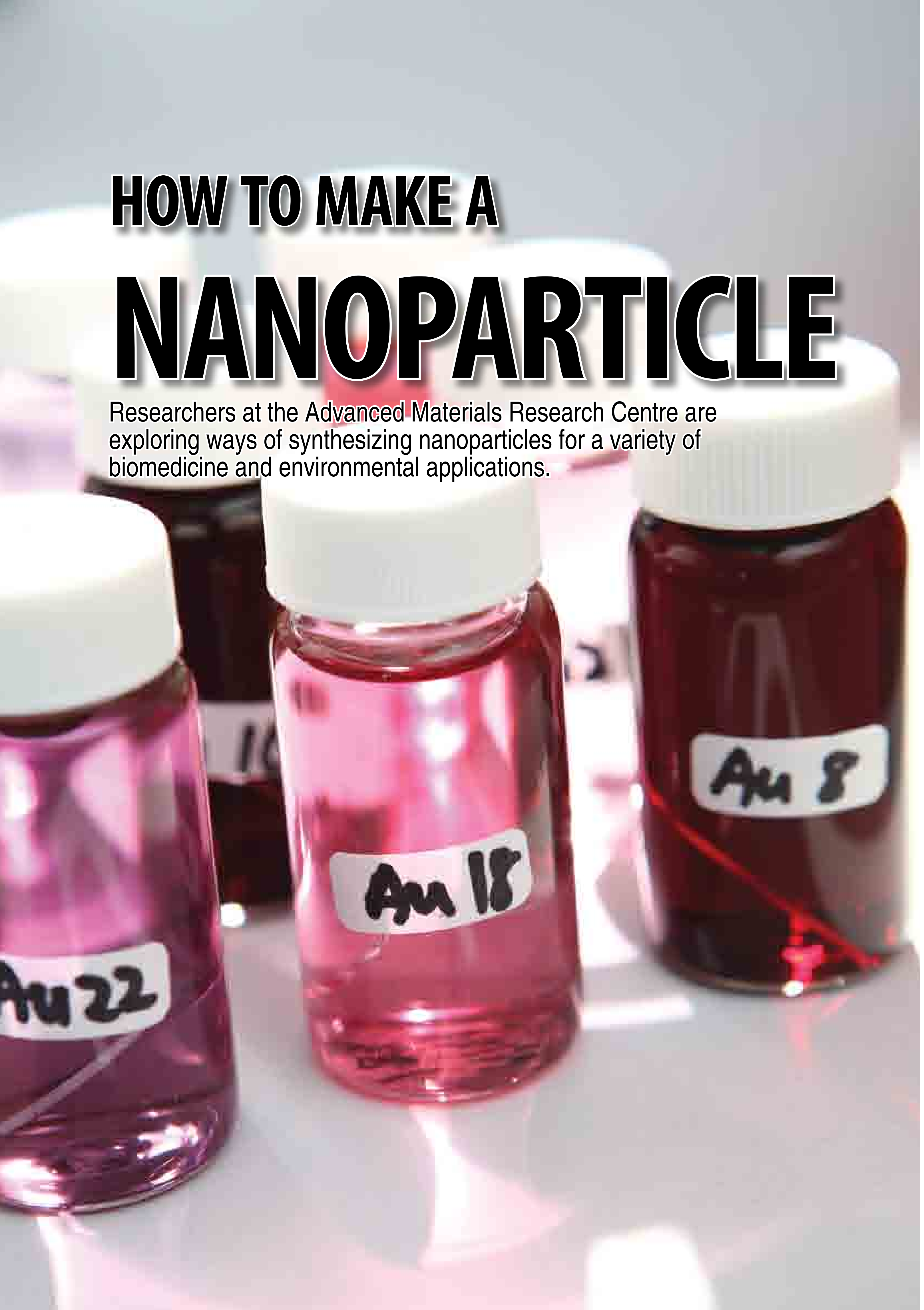
STRONG TUBES. Multi-walled carbon nanotubes (MWNTs) may be thought of as having a telescopic structure, whereby multiple tubes of graphite are arranged within each other in concentric cylinders.



FULLERENE NANO-GEARS. Researchers at NASA have simulated attaching benzyne molecules to the outside of a nanotube to form gear teeth. To "drive" the gears, the supercomputer simulated a laser that served as a motor. The laser creates an electric field around the nanotube. A positively charged atom is placed on one side of the nanotube, and a negatively charged atom on the other side. The electric field drags the nanotube around like a shaft turning. Image courtesy of NASA.

HOW TO MAKE A NANOPARTICLE

Researchers at the Advanced Materials Research Centre are exploring ways of synthesizing nanoparticles for a variety of biomedicine and environmental applications.



ALTHOUGH molecular manufacturing is the ultimate aim for nanotechnologists, the biggest areas of interest within nanotechnology today remain grounded in practical, real-world applications. A lot of this real-world interest is geared toward nanoparticles: particles of matter that measure between 1 and 100 nanometres in diameter.

Research has shown that nanoparticles can be used to enhance or even replace current microscale technologies. Unfortunately, these nanoparticles are not readily available off the shelf, which is why researchers at SIRIM's Advanced Materials Centre (AMREC) in Kulim are studying ways of synthesising, processing and producing them.

"Scientists need a steady supply of nanoparticles for their research, and eventually, industry will need a steady supply of nanoparticles for their products," explains Norhanita Mohd Yusof a researcher at AMREC. "We are trying to identify the optimal chemical formulations and precursor concentrations to be used use in nanoparticle synthesis so that we can start thinking about mass production."

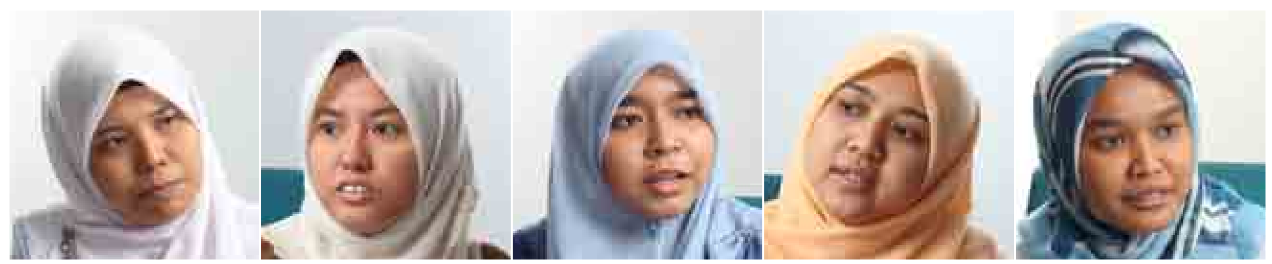
Not all nanoparticles are equal, however. Gold and silver, for example, are both highly toxic to bacteria. But while silver is already used in nanotechnology-hyped antibacterial products such as washing machines and refrigerators, gold is too expensive to be so widely used. However, gold's future appear to lie in medical applications.

"Our process and synthesis programmes are dedicated to nanoparticles that show potential in biomedical and environmental applications," says Dr Abdul Kadir Masrom, Head of the Nanomaterials Programme at AMREC. "Although there are many nanoparticles worth studying, we're only interested in a few specific metals and metal oxides for now."

Nurdina Abd Kadir synthesising magnetic nanoparticles in her lab.

SONIC BOOM

Synthesising nanoparticles is a new and tricky business. At least half a dozen synthesis techniques have been discovered that use both dry and wet chemistry approaches, and each technique can



NANOPARTICLE SYNTHESISERS. From left: Farinaa Md Jamil, Norhanita Mohd Yusof, Nur Izzah Abd Azes, Nurdina Abd Kadir and Suhaina Mohd Ibrahim.

SYNTHESISED NANOPARTICLE	POSSIBLE APPLICATIONS
Gold (Au)	Gold has actually been used in medical applications for centuries, the best examples being gold implants and dentures. Today, gold and cobalt nanoparticles have been successfully tested in cancer therapies that only target the affected cells in the brain or prostate. Unlike chemotherapy, these nanoparticle therapies do not damage the whole body unharmed. Gold nanoparticles are also used in cosmetic formulations and products.
Silver (Ag)	Silver nanoparticles have been tested in several medical applications, including bone cement, surgical instruments, surgical masks and wound dressings. Silver nanoparticles are also used to coat household appliances, ostensible to make them resistant to bacteria growth.
Cobalt (Co)	Cobalt's ferromagnetic properties may see it used to detoxify human exposed to poisonous gases. Functionalised magnetic cobalt nanoparticles administered by injection will bind with the toxin in the body and may then be dragged out of the affected person by magnetic force. Cobalt nanoparticles may also be used in drug delivery and to treat local hyperthermia in the therapy of tumours.
Iron (Fe) and iron oxide	May be employed as a contrast agent to improve magnetic resonance imaging (MRI) results. May also be used in cell and tumour imaging and therapy. In Bangladesh, micron-sized iron particles are already used to treat water systems that have been contaminated by arsenic. Iron nanoparticles, being much smaller and therefore more potent, will be able to treat a much larger body of water. These nanoparticles will also be able to reach underwater nooks and crannies that current iron treatment solutions cannot.
Titanium dioxide ($Ti0_2$)	May be used as a high-performance nanobiophotocatalyst for targeted brain cancer therapy.
Silica ($Si0_2$)	Mesoporous silica may be used in the development of molecular sieves that may be used to diffuse specific hydrocarbon molecules.
Quantum dots	Semiconducting crystals that may be used in transistors, solar cells, LEDs, and diode lasers. They are also being studied as contrast agents in medical imaging.

yield startling different results in terms of the size, shape and properties of the nanoparticles they produce.

"Ideally, you want a synthesis technique that gives you maximum yield at minimum cost and with zero waste," explains Dr Abdul Kadir. "However, some chemical reduction methods require the presence of other chemicals to act as reductants, and that can sometimes result in unwanted by-products."

Take sonochemistry, for example. This method uses ultrasonic radiation to reduce chemical compounds into two or more target elements, a process called "reduction". It does not need a chemical reductant and leaves no unwanted waste behind. With a precursor metal compound such as gold chloride, sonochemistry synthesis results in a safe colloidal suspension of spherical-shaped gold nanoparticles and hydrochloric acid – a substance that is easy to handle and widely used in industrial applications.

In other words, there's no waste.

"Then again, sonochemistry does not have all the answers," cautions Dr Abdul Kadir. "It is ideal for producing spherical-shaped gold nanoparticles, but if you want rod-shaped gold nanoparticles, you have to use another chemical reduction method. It all depends on what you want to do."

MAGNETIC CHARM

Meanwhile, Nurdina Abd Kadir, another researcher at AMREC, is studying the synthesis of magnetic nanoparticles of cobalt, iron and nickel. These nanoparticles posseses unique properties that may make them useful in the defence industry as radar-absorbing materials or as a wall-coating insulation against microwaves. Nurdina's focus is on magnetic nanoparticles of iron oxide, a substance already used in water treatment systems.

"Iron oxide nanoparticles have super-paramagnetic properties that make them ideal for applications within magnetic resonance imaging," explains Nurdina. "When injected into patients, nanoparticles with specific functional groups will attach themselves to the diseased tissue and make it more visible on an MRI machine."

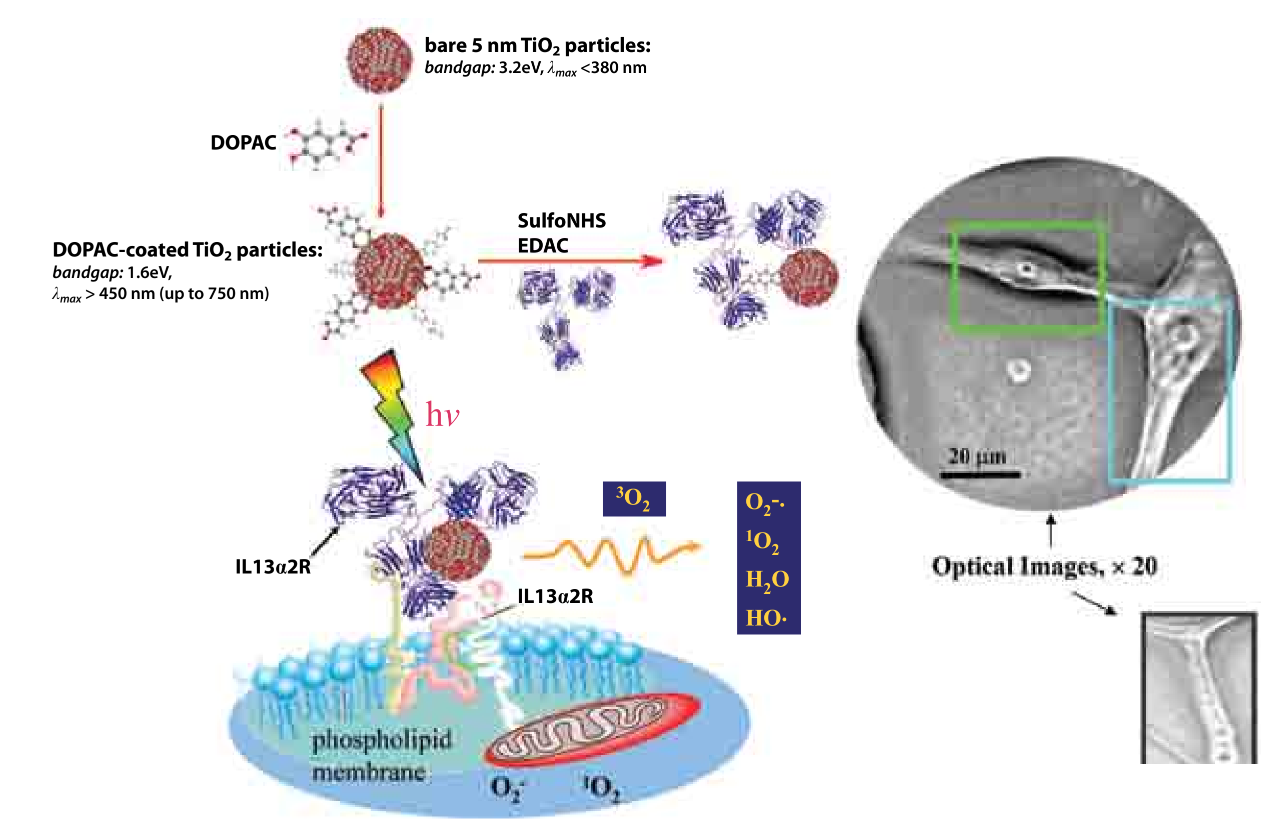
Current MRI technology only allows for tumours to be detected at later stages of development. Typically, patients have to suffer months of chemotherapy afterwards without even knowing whether it will be successful. Scientists hope that by using iron oxide nanoparticles, doctors will be able to detect these tumours when they are still in their early stages of development.

To further develop this technology, AMREC is working closely with researchers in Iran. AMREC researchers prepare the material and then go to Iran to use their mice labs and MRI facility.

"Nanotechnology is a very multi-disciplinary field," says Dr Abdul Kadir. "In the study of medicine especially, chemists and physicists often have to work side-by-side with biologists and radiologists."

Unsurprisingly, nanoparticles sometimes also need to be specially treated, depending on their intended application.

"We not only look at how to produce nanoparticles, but also how to tailor them for a specific function," explains Nurdina. "We have to make the nanoparticles biocompatible by using some other biological or organic coating with them, depending on what cell you want to target".



CANCER KILLER. Argonne scientist Elena Rozhkova, along with researchers from the University of Chicago, have developed a way to attach an antibody to nanomaterial titanium dioxide and kill brain cancer cells.

The bare titianium dioxide nanoparticle bonds with an antibody and attaches itself to brain cancer cells. When exposed to concentrated white light, the titanium dioxide creates free radicals of oxygen that cause the cancer cells to die. The image here (right) shows an X-ray fluorescent imaging of the TiO_2-mAb binding to the single brain cancer cells.

Image courtesy Argonne National Laboratory, U.S..

10 September 2009 – SIRIM's clients from the automotive industry taking part in the Tech Tarik Session with the Automotive Industry at the Holiday Inn, Glenmarie, an effort by SIRIM to gauge their feedback on its services and requirements on the automotive technology whilst updating them on SIRIM's latest development in the field.

12 October 2009 – Deputy Minister of International Trade and Industry, YB Datuk Jacob Dungau Sagan (second from left) being briefed on the testing facilities during his visit to SIRIM QAS International Sdn Bhd whilst Managing Director of SIRIM QAS International, YBhg. Dato' Mariani Mohammad (second from right) looks on.

14 October 2009 – Participants of the WAITRO-ISESCO-SIRIM Joint Cooperation Programme 2009 at a photography session during the opening ceremony. The programme, a cooperation between WAITRO, Islamic Educational, Scientific and Cultural Organisation (ISESCO) and SIRIM Berhad is to introduce scientists and researchers in the early stages of their careers to research opportunities abroad.

9 September 2009 – President and Chief Executive of SIRIM Berhad, YBhg. Ir. Hj. Yahaya Ahmad (right) exchanging documents with Chief Executive Officer of Global Environment Management Solutions Sdn Bhd, Syed Ali Syed Alwi (left) to promote cooperation in the research and development of Quantum Persistent Reflection and Multi Sustainable Concepts Technology at the Technology Park Malaysia, Bukit Jalil.

6 October 2009 - President and Chief Executive of SIRIM Berhad, YBhg. Ir. Hj. Yahaya Ahmad (left) and Executive Director of Robotics Arts Creative Education Sdn Bhd, Tengku Soraya Tunku Dato' Ahmad Nerang Putra (right) signing a Memorandum of Understanding to encourage, create awareness and promote robotics technology through ROBOFEST, an annual technology festival organised by SIRIM.

5 October 2009 – Representatives from the iron and steel industry being briefed on the latest updates on importation procedures for iron and steel products due to the review of steel policy by the Government.

MY DARLING TiO_2

With so many applications going for it, its no wonder that titanium dioxide has become the darling of industrial scientists.

ONE OF THE MOST KEENLY researched nanoparticles in the world is titanium dioxide, also known by its chemical name, $Ti0_2$. Despite its many merits, titanium dioxide has become rather controversial in light of its widespread application within the cosmetics business. Titanium dioxide nanoparticles, however, may soon save it from its fall from grace.

Already used extensively as a photocatalyst and in many antibacterial and air-purification applications, researchers are now trying to find ways of using titanium dioxide thin-films to produce self-cleaning glass. This glass has already gained acceptance within the construction and automotive industries, and theoretically, the thin film technology may also be used on other surfaces such as fabric and ceramic tiles in lavatories and kitchens.

Suhaina Mohd Ibrahim holds up the results of her experiments so far: self-cleaning glass coated with titanium dioxide nanoparticles.

"So far, we've been successful in preparing the films and coating the glass, but the films are not transparent enough," says Suhaina Mohd Ibrahim, a researcher at AMREC.

Suhaina reckons that the glass needs to be at least 98% transparent before her experiments are ready for the next step.

Researchers at AMREC are also interested in making $Ti0_2$ nanoparticles more reactive to visible light, thereby making them more flexible in water treatment applications.

"Currently, titanium dioxide nanoparticles only get excited under high ultraviolet radiation, but we're trying to dope them with vanadium and other types of metals to make the TiO_2 sensitive enough to get excited under ordinary visible light," explains Suhaina. "By modifying their surface with vanadium metal, we can make them more reactive and hence improve their effectiveness in water treatment applications."

Another way to make titanium dioxide nanoparticles more reactive is to increase their surface area. One method being explored is to develop mesoporous nanoparticles with 'nanopores' of between 2 nm and 50 nm in diameter. These mesoporous nanoparticles have nearly double the surface area of regular nanoparticles and therefore, double the reactivity.

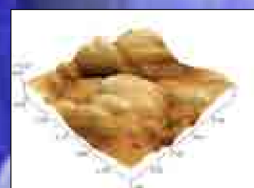
"The mesoporous quality of titanium dioxide nanoparticles is largely determined by the humidity and temperature used during the drying process," says Suhaina. "It is not easy to do, which is why so few researchers around the world are studying it."

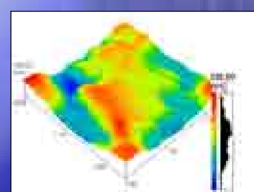
INTERNATIONAL CONFERENCE ON NANOTECHNOLOGY-RESEARCH & COMMERCIALISATION (ICONT 2009)

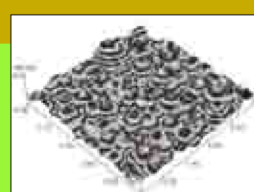
14-17 DECEMBER 2009, BAYVIEW HOTEL LANGKAWI ISLAND, MALAYSIA

“EMERGING NANOTECHNOLOGY ENABLING SCIENTIFIC DISCOVERIES AND INNOVATIONS FOR WEALTH CREATION”

image source:“nano rings” by Dr Andreas Fuhrer. ETH Zürich, Switzerland. http://www.icmm.csic.es/spmage/







SCIENTIFIC TOPIC

- Nanomaterials: Nanoparticles, Nanowires, Carbon Nanotubes, Funtionalized Polymers, etc
- Nanodevices, Nanoelectronic and Nanophotonics
- Nanobiotecnology, Nanomedicine and Drug Delivery Systems
- Nanofabrication and Self-organising System
- Nanotechnology Application including in Energy, Environment and Health
- Nanotechnology Standardisation
- Nanoparticles Toxicology, Health and Safety
- Societal and Environmental Impacts and other related topic including initiative and policy

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