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THE MAGAZINE FOR **SMALL SCIENCE**

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Military Applications of Nanotechnology

NANO magazine explores the elephant in the room

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Nano-enhancement for the soldier of the future

Nanotechnology in the US

Past, present and future goals

Unintended Nanoparticles – the Most Dangerous Yet?

Investigating the causes of wartime syndromes

Military Nanotechnology – New Issues for Ethical Assessment

Is a new framework for arms control needed?

NEMS – the Next Revolution in Miniaturization

From nanolasers to nanoassembly, does nano make everything possible?

Interview: Victor Castaño

From nail varnishes to dental coatings – is there no end to this man's ingenuity?

Perspectives on Nanotechnologies in Mexico

Will a lack of planning damage Mexico's nanotechnology industry?

NANO FOR THE MILITARY

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In the next issue – due out 1 February 2010: Applications of Nanomaterials to Sustainable Technologies, Nanotechnology in Japan, Nanomedicine, Investor's Corner. **Plus:** What's new in nano…
and lots more

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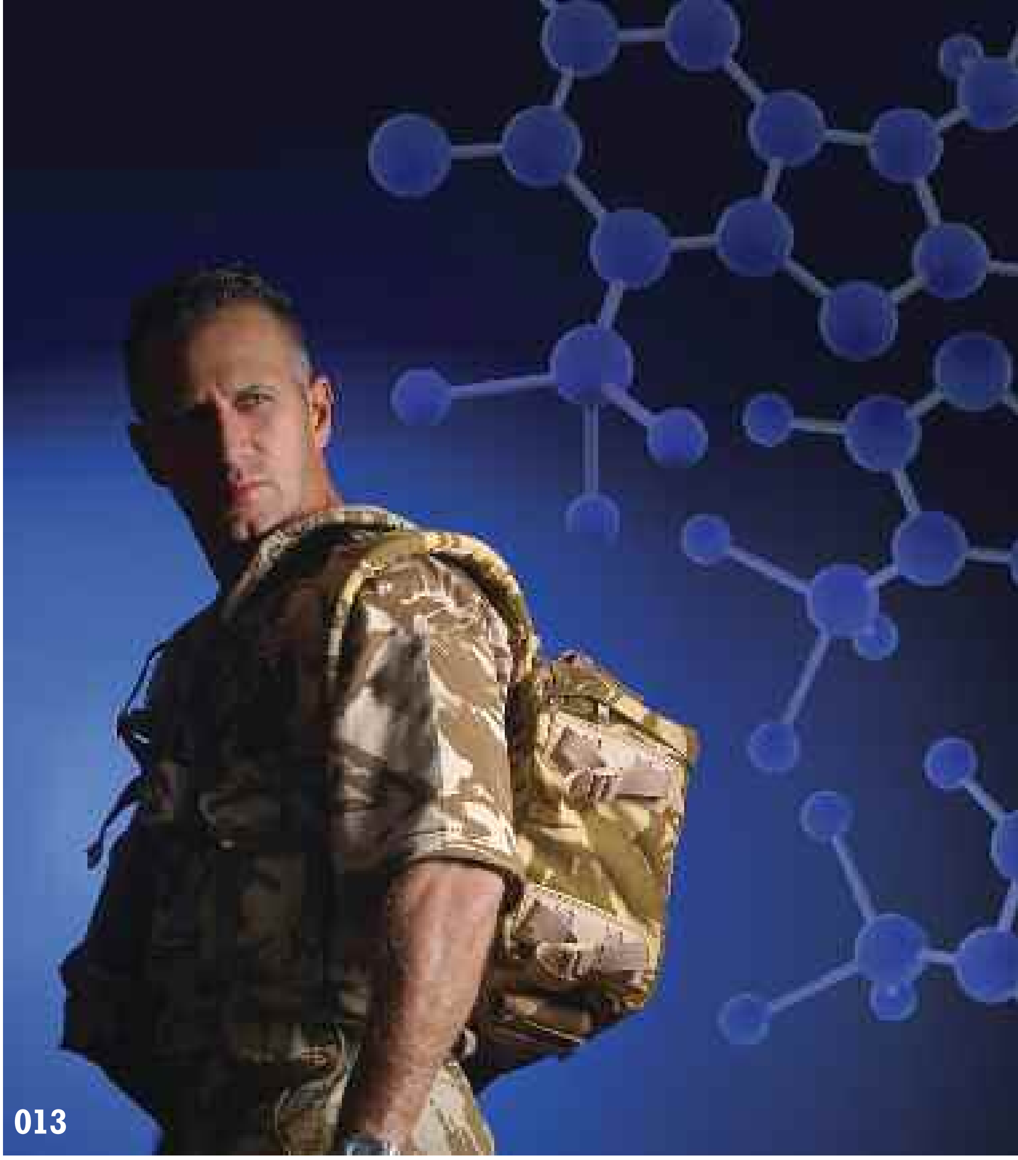
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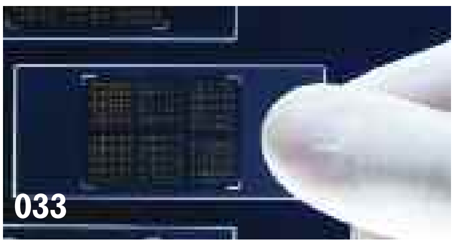
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COUNTRY PROFILE

INTERVIEW

MEDICINE

REGULARS

Nano and the Military


Ottilia Saxl, Director, NANO Magazine

The aim of NANO Magazine is to debate, discuss and inform our readership about nanotechnology and its applications. However, there are several of what might be termed, 'dark corners', where nanotechnology research and development is not openly discussed, especially by those who are intimately involved. This may be for a variety of reasons, including misrepresentation by the media. NANO magazine aims to shine a light into these corners.

One such 'dark corner' is in the area of food and drink, which was the subject of a recent issue (August 2009) of NANO Magazine. The message came across that many companies were in fact researching and developing nanotechnology applications in this area, to meet the demands of a growing population for foods offering new taste experiences, improved nutritional qualities, and less fat.

Another 'dark corner' is nanotechnology for military applications. This is by far and away the most controversial area of nanotechnology research and development - for two reasons. Firstly, the military budget for nanoscale research is probably greater by a factor of two than for any other area; and secondly, although there is some information available, we do not know exactly where the money is being spent, the research themes are not subject to public scrutiny and there is no accountability. Although ethical and moral questions may be asked and issues raised – they may not necessarily be answered or addressed.

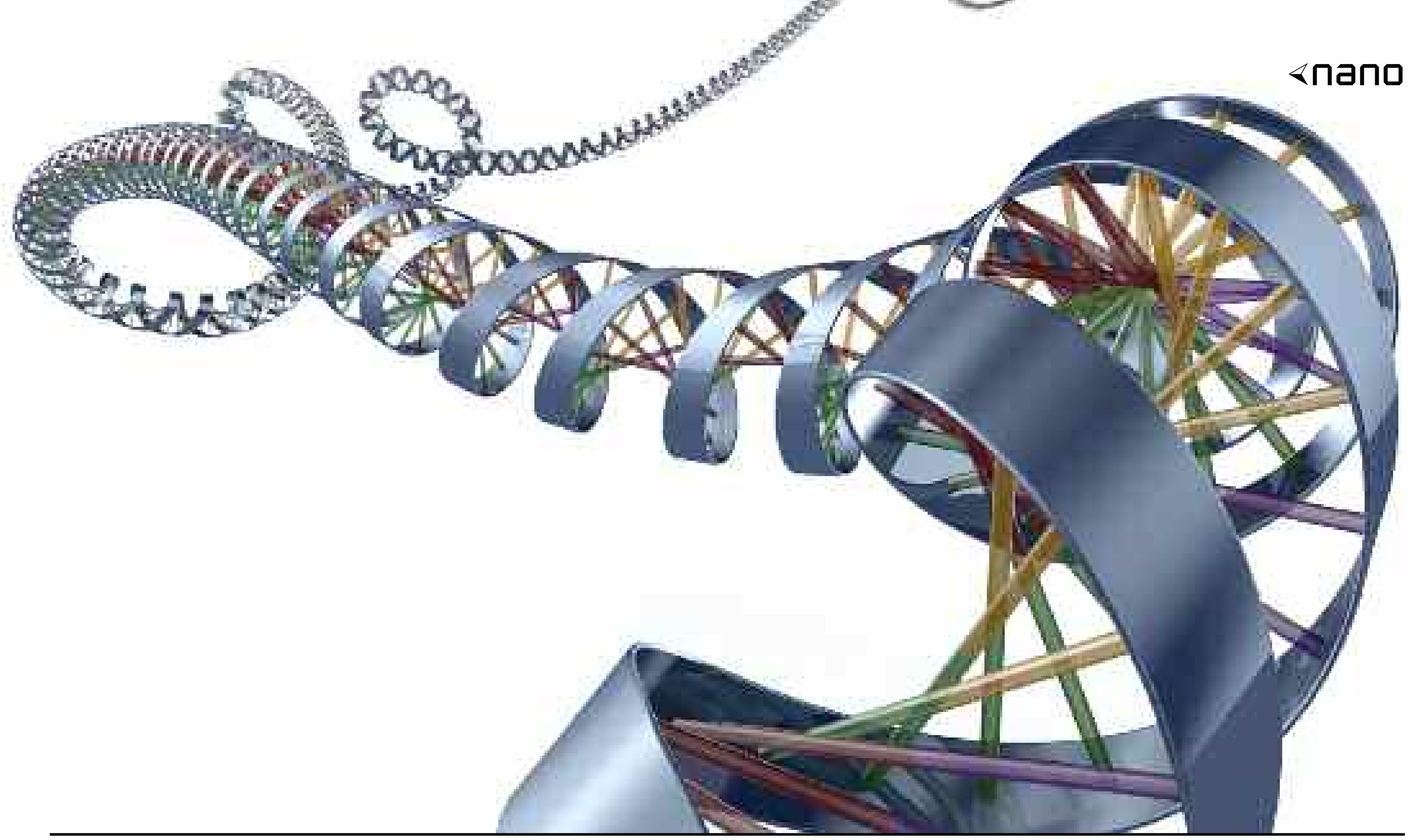
It seems particularly apposite at this time that the money being spent on military research, and the uses it is being put to, forms part of a wider debate. The global population is indeed on the cusp of a war, and it is not about dog fights between nations, but a war of survival to which our politicians should be turning their attention. Global warming, access to food and water, problems of over-population, asymmetric overuse of resources should be where our funding and attention need to be concentrated. Our leaders need to be coaxed away from the Midas school of thought, which exalts commandeering and securing a resource that no one can eat or drink.

In essence, this issue of NANO Magazine aims to demonstrate what can be achieved when there is a powerful and compelling vision. It begs the question - can this vision be redirected for the benefit of humanity, rather than its destruction. And when?

In this Issue

It is interesting to note that more money is being spent on investigating nanotechnology for military applications than for any other use. The military were quick off the mark to appreciate the performance-enhancing potential of this new field for the creation of smaller, smarter, faster, lighter and more effective devices capable of performing more intelligent operations, and using less energy and materials. NANO Magazine examines the aims of the military in terms of technological supremacy in areas such as soldier protection, surveillance, enemy destruction and detection avoidance, and how nanotechnologies is leading to the realisation of these aims.

On an individual level, nanotechnology is being applied increasingly to enhancing soldier survivability. Solutions to the great problems of the battlefield: heavy kit, sleep deprivation, injury and advanced weaponry may be improved through the use of



nanotechnology. In his article, **Daniel Moore** looks at the history of the advancement of soldier technologies, and the current inroads being made towards using nanotechnology to create the 'perfect' soldier.

The USA is one of the biggest spenders on nanotechnology research and development. What have been the outcomes of this spend? How have research priorities changed over nearly a decade of influence by the groundbreaking National Nanotechnology Initiative? NANO Magazine looks at the past, present and future goals for nanotechnology in the USA.

Far from only endangering soldiers in the short term, the effects of modern battle can be seen long after a soldier has left the theatre of war. Gulf War Syndrome, which affected thousands of the soldiers involved in the conflict, has left a legacy of dehabilitating symptoms. These have been investigated at length by **Antonietta Gatti and Stefano Montanari**. Their work in nanopathology examines the possible links between the nanoparticles created by the technologies of modern warfare and illnesses, which affect soldiers and the environment, long after the conflict.

The concept of ethics in war seemed to be an oxymoron until Henri Dunant's experiences at Solferino led to the establishment of the Geneva Conventions, the Red Cross and Red Crescent. In his article, **Jürgen Altmann** discusses whether nanotechnology is raising further issues that need new frameworks for ethical assessment from the angles of 'just' or 'fair' wars, and in the suitability of new weapon technologies in preventative arms control. He argues that whilst some nanotechnologies may appear to be beneficial (sensors for helping with treaty verification, anti-terrorist measures), others pose a distinct threat to existing stability and may lead to a revolutionary change in arms control agreements worldwide.

In his article, reprinted here by courtesy of DARPA, **Dr. Dennis Polla**, Program Manager, Microsystems Technology Office ranges through some of the potential of nanoelectromechanical systems for detection, including miniaturized optoelectronic structures to systems small enough to analyse the state of a single cell; the fast and accurate detection of environmental pathogens and chemical and biological agents, and the potential for nanoassembly of systems and components in situ.

Our Regular features.
In this issue, Ottilia Saxl interviews **Victor Castaño**, a leading Mexican researcher and entrepreneur who seems to have a limitless ability in spotting where nanotechnologies can make a difference. To date, his innovations have spanned anti-graffiti coatings, anti-corrosion coatings, better bullet-proof vests, anti-scratch dental coatings, additives that reduce UV effects in polymer coatings for brass and copper - and even better nail varnishes! Professor Castano has invented many technologies that help Mexican companies stay ahead in a global market place, but simplifying the transfer of these technologies from university to industry is in some ways the real challenge!

Mexico is the country under the spotlight in this issue. **Guillermo Folladori and Edgar Zayago** investigate the structure of the nanotechnology community in Mexico. One of the most advanced Latin American countries in terms of nanotechnology research and development, Mexico is yet to develop an industry around this research and risks missing out on realising the results. Folladori and Zayago call now for a decisive plan that will link academic centres with industry, to ensure Mexican manufacturing companies maintain their competitiveness, in an increasingly aggressive global marketplace.

Catherine Berry, at the Centre for Cell Engineering, University of Glasgow, describes her work on magnetic nanoparticles, which offer great promise for the treatment and diagnosis of many diseases, including cancers. Her aim is to develop multifunctional, magnetic nanoparticles. These Starship Enterprise nanoparticles will be able to locate the site of a given disease and lock onto it, enabling the extent of the disease to be accurately imaged. The particles will also carry a therapeutic 'payload' which can be offloaded exactly where needed. This kind of 21st century treatment holds the promise of better cures with dramatically less side effects than conventional treatments.

Our NanoArt in this issue 'Fly Away' comes from **Eva Mutoro** from the Institute of Physical Chemistry at the Justus-Liebig-University Giessenand serves to graphically illustrate the close link between technology of the macro world, and nature in the nano world.

Events Calendar

EVERY MONTH WE HIGHLIGHT THE LEADING CONFERENCES AND SUMMITS WHERE INDUSTRY EXPERTS, ACADEMICS AND POLICY MAKERS CONVENE.

December 5-6, 2009
Nanotech Business Summit, Egypt
The world's first nano event just for the booming Middle Eastern markets. Leading scientists, analysts, and financiers will converge on Cairo to seek out potential business partnerships and discuss nanotechnology's regional prospects and applications.
www.nanobus.sabrycorp.com

December 6-10
11th Pacific Polymer Conference
A comprehensive program, including modern polymerization methodologies, living free radical polymerization, complex polymer architectures, functional polymers, nano-composites, traditional composites, electro- and optico active polymers, polymers in biology and medicine, naturally-derived polymers, polymers at interfaces and surfaces, polymer engineering, polymer rheology, polymer processing, mechanical properties and polymer characterization.
www.polymer.org.au/ppc11/2009/

December 7-9
The 3rd International Conference on One-dimensional Nanomaterials
This conference will cover the forefront research and inventions in rational synthesis, structure and property characterizations, device fabrication, system assembly and novel applications of 1D nanomaterials in nanoelectronics, nano-optoelectronics, nanophotonics, biomedical sciences, sensors, nano-enabled energy technology (solar cell, thermoelectric, piezoelectric nanogenerator, energy storage), nanopiezotronics, and environmental sciences.
www.mse.gatech.edu/News_Events/Conferences/ICON2009/icon2009.html

December 7-9
FuSeM 2009, Thailand
The International Conference on Functionalized and Sensing Materials will bring together scientists, engineers, and industry leaders interested in the very latest research on smart materials and their applications. Attendees can expect to share their own expertise while forging profitable international connections.
www.fusem2009.su.ac.th

December 8-9
Fuel Cells Durability & Performance, USA
An interdisciplinary discussion forum for developers, manufacturers, and suppliers in the areas of fuel cells materials, stacks, system design, fabrication, and testing. The conference's focus will be a series of presentations on the technical, research-driven and commercial sectors of the fuel cell industry.
www.knowledgefoundation.com/indexkf.php

December 9-11
ICANN-2009, India
Organized by the Indian Institute of Technology at Guwahati, the International Conference on Advanced Nanomaterials and Nanotechnology will highlight recent advances in nanoengineering, as well as the latest in nanotechnology theory, research, and applications from India, Taiwan, Australia, Germany, the US, and beyond.
www.iitg.ernet.in/icann2009

December 13-14
The 14th Israel Materials Conference, Israel
It will cover a broad range of topics, including nanomaterials, biomaterials, materials for energy systems and cleantech, advanced characterization techniques, etc. New topical sessions, such as materials for aerospace applications and archaeomaterials, are included in the program.
www.eng.tau.ac.il/imec14/index.html

December 13-18
The 5th International Conference of the African Materials Research Society (5th IC-AMRS) & 8th Nigerian Materials Congress (NIMACON 2009), Nigeria
The African Materials Research Society and the Nigerian Materials Congress are joining forces to host a gathering of materials scientists from Africa and the diaspora. The aim of this year's conference will be to discuss the possibilities for improvement of current R&D networks and practices, as well as Africa's potential for future development of nanotechnology and advanced materials manufacture.
www.africamrs.org/

December 14-17
ICONT 2009, Malaysia
The conference aim to develop critical assessment of existing work and future directions in nanotechnology research including nanomaterials and fabrications, nanoelectronics, nanophotonics, devices, and integration. There will be a special focus on materials, applications and devices. They will highlight the challenges facing scientists and engineers in the manufacture of nanoparticles and nanomaterials.
www.icont2009.sirim.my/

December 15
FramingNano, Belgium
Businesses, NGOs, researchers, and regulators involved or interested in the nano industry are invited to the final international conference on the FramingNano FP7 project, the aim of which is to develop a sustainable nanotechnology governance framework.
www.framingnano.eu

December 19 - 22
21th IEEE technically co-sponsored International Conference on Microelectronics ICM'09, Morocco
ICM' 09 is held in cooperation with École Mohammadia d'Ingénieurs and the University of Waterloo. Topics to be addressed include Advances in biomedical circuits and systems. Technologies addressing Emerging Market Needs and CAD Tools for Advanced SoCs.
www.ieee-icm.com

Jan 3-8, 2010
2010 3rd International Nanoelectronics Conference (INEC)
INEC2010 will feature plenary and invited talks by famous scientists in nanofabrication, nanoelectronics, nanophotonics, and nanobiology. A special symposium on nanoscience and nanotechnology in China featuring all invited talks by academicians of the Chinese Academy of

Sciences, Chinese Academy of Engineering, and Academia Sinica will be held during the conference.
www.cityu.edu.hk/ieeeinec/index.htm

January 4-9, 2010
Winter Conference on Plasma Spectrochemistry, USA
Presented by UMass' authoritative ICP Information Newsletter, and motivated by the growing importance of plasma in atomic spectroscopy and mass spectrochemistry across the sciences, this informal gathering of scientists will focus on development in plasma spectrochemical analysis.
www.icpinformation.org/2010_Winter_Conference.html

January 7
The Second Regional Nano/Biotechnology Conference, Iran
Hosted by the Islamic Azad University, this conference will review the progress of Iranian nanotechnology and biotechnology research and innovation in the fields of industrial engineering, agriculture, and medicine.
www.jouybariau.ac.ir/ (Persian)

January 23-28
MOEMS-MEMS, USA
Eight conferences in one revolving around the latest research into micro- and nanofabricated electromechanical and optical components, MOEMS-MEMS will offer professional courses on micro- and nanofluidics, micromachining, and reliability systems and present over 225 papers on micro and nanofabrication.
www.spie.org/moems-mems.xml

February 17-19
Nano Tech 2010, Japan
Now in its ninth year, the world's largest nanotechnology exhibition will present five specialized conferences spanning the entire nano market: Nano Bio Expo (biotechnology, nanotechnology, and business); ASTEC2010 & METEC'10 (surface technology); Nano and Neo Functional Material (electronics and printing); and new for this year, InterAqua (water processing and circulation).
www.nanotechexpo.jp/en/

February 17-20
ICONSAT2010, India
The fourth International Conference on Nano Science and Technology will provide opportunities for students, researchers, industry leaders and entrepreneurs to discuss current developments and future trends in a wide range of fields. Featuring prominently in the schedule will be a special one-day workshop on nanotechnology in oncology.
www.iconsat2010.in

February 22-26
ICONN 2010, Australia
The 2010 International Conference on Nanoscience and Nanotechnology will bring together the Australian and international nanoscience and nanotechnology communities to discuss the latest advances in nanostructure growth, synthesis, fabrication, characterization, device design, modeling, testing, and applications.
www.ausnano.net/iconn2010

February 23
What is Nanomedicine? Netherlands
This intensive one-day course will cover how nanotechnology is being applied to: medical imaging, lab-on-a-chip, quantum dots and other novel diagnostic tools, biosensors, regenerative medicine, advanced and "smart" medical materials, drug targeting and delivery systems, nano-bio-electronic interfaces and novel devices. The course will also examine some of the key associated risk, ethical and regulatory issues.
www.nano.org.uk/events/ionevents.htm#whatis

February 24-25
Nanomedicine: Visions for the Future, Netherlands
The Institute of Nanotechnology, in partnership with NanoNed, brings together world-leading researchers and companies in medical diagnostics, drug design and delivery, imaging and regenerative medicine to show how the application of nanoscience and nanotechnologies can contribute towards answering the multifaceted challenges of modern medicine.
www.nano.org.uk/events/ionevents.htm#visions

Saving Antiques

In the past, restoration of paintings and other old artwork often involved the application of acrylic resins to consolidate and protect them. One of the most important tasks for the modern restorers is to remove these layers, because it turns out that acrylic resins not only drastically change the optics of the treated artwork, but in many cases they accelerate their degradation.

Italian researchers working with Piero Baglioni at the University of Florence have now developed a technique to effectively remove such old polymer layers from sensitive historic artworks. As the researchers report in the journal Angewandte Chemie, the new cleaning system involves only a tiny proportion of volatile organic compounds.

"We have demonstrated the first successful application of a water-based system for the removal of an organic layer from artwork," says Baglioni. "In addition, our method is simpler and less invasive than traditional processes."

The scientists use an oil-in-water microemulsion with the organic solvent para-xylene as the oil component. An emulsion is a fine dispersion of droplets of one liquid in another liquid with which the first is not miscible (one example from our daily lives is milk). A microemulsion is an emulsion that forms spontaneously and is stable. It contains substances that act as emulsifiers. Because the individual drops are only nanometer-sized, the microemulsion is not milky and opaque, but clear and transparent.

The Italian researchers embedded their microemulsion in a matrix of a modified type of cellulose – a material used as a thickener for emulsion paints. The matrix makes the cleaning agent viscous, so that it cannot enter very far into the pores of a painting. Its activity is limited to the outer layer, whilst deeper layers of paint do not come into contact with the xylene. The environment is protected as well, because of the very low concentration of volatile solvent, the evaporation of which is further limited by the matrix. The optical transparency of the system also allows the restorer to continuously monitor the cleaning process.

"We successfully cleaned a mural from the 15th century," reports Baglioni. This painting is located in the Santa Maria della Scala Sacristy in Siena. "It was covered with a 35 year old layer of acrylic from a previous restoration. Our new system allowed us to completely remove the undesirable shine. We were also able to clean another art work: a gilt frame from an 18th century painting." n

Source: *University of Florence, www.unifi.it*

Technology to cool down laptops

Does your laptop sometimes get so hot that it could be used to fry eggs? "Nano technology may help cool it down while also giving information technology a unique twist" according to Jairo Sinova, a Texas A&M University physics professor.

As laptops are getting increasingly more powerful, and smaller all the time, so too are they heating up, and dealing with this excessive heat becomes a problem.

"The crux of the problem is the way information is processed," Sinova notes. "Laptops and some other devices use flows of electric charge to process information, but they also produce heat. Theoretically, excessive heat may melt the laptop – as well as wasting a considerable amount of energy."

One solution may be found in Sinova's research – an alternative way to process information.

"Our research looks at the spin of electrons, tiny particles that the naked eye cannot detect" the professor explains. "The directions they spin can be used to record and process information."

"To process information, it is necessary to create information, transmit and read it. The device we designed injects the electrons with spin pointing in a particular direction, according to the information we want to process, and then we transmit the electrons to another place in the device – but with the spin still surviving, and finally we are able to measure the spin direction via the voltage that they produce."

The biggest challenge to creating a spin-based device is the distance that the spins will survive in a particular direction.

"Transmission is no problem. For comparison, old devices could only transmit the information several hundred feet away, but with our device, information can be easily transmitted hundreds of miles away," he says. "It is very efficient."

Talking about its practical application, Sinova is very optimistic. "This new device, as the only all-semiconductor spin-based device for possible information processing, has a lot of real practical potential," he says. "One major advantage is that it is operational at room temperature, which nobody has been able to achieve until now. It may bring in a new and much more efficient way to process information." n

Source: *Texas A&M University www.tamu.edu*

Major research collaboration will improve British athletes' performance on world stage

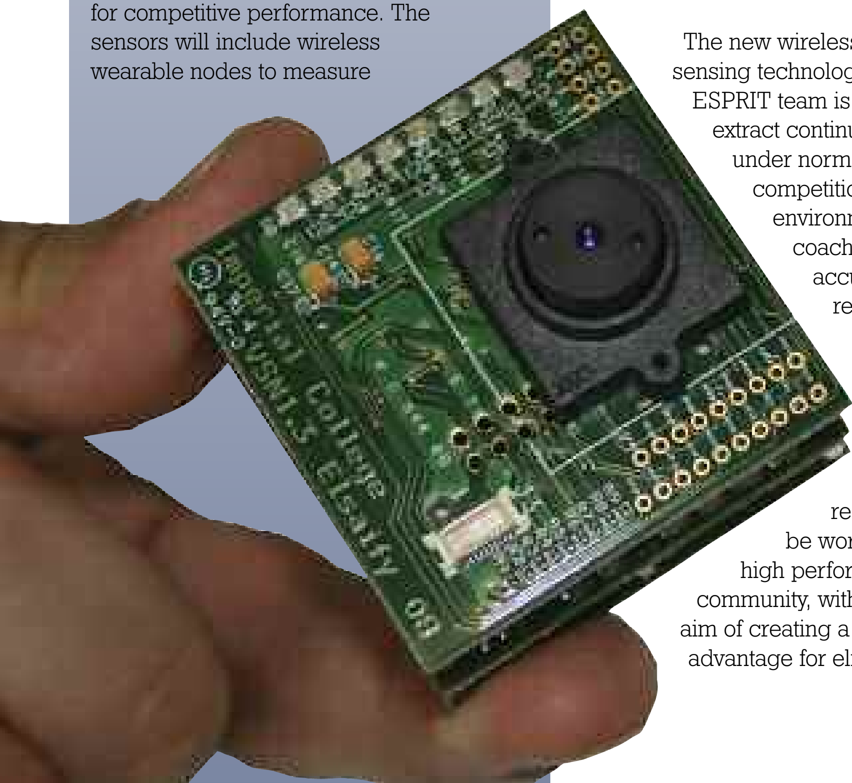
Scientists are developing a range of miniaturised wearable and track-side sensors, computer modelling tools and smart training devices to help British athletes improve their performance on the world stage, as part of a new £8.5 million project that will be officially launched tomorrow (28 October 2009).

The Elite Sport Performance Research in Training with Pervasive Sensing (ESPRIT) project is funded by the EPSRC (Engineering and Physical Sciences Research Council) and is led by Imperial College London in partnership with UK Sport, and supported by Queen Mary University of London and Loughborough University. It involves researchers from the three universities working alongside British athletes via UK Sport's Research and Innovation programme.

The researchers are devising miniature wearable sensors that will monitor different aspects of athletes' physiological performance, in order to optimise training for competitive performance. The sensors will include wireless wearable nodes to measure biochemical information, heart rate, EEG, ECG, muscle activity, joint speed and contact forces. Athletes will be able to use this information to understand how they are progressing with their training.

The team is also developing small track-side sensors for detailed monitoring of an athlete's body movements and location, and the interactions between a team during training.

Sports scientists can currently monitor athletes' performance through controlled experiments in a laboratory setting or, increasingly, via commercially available technologies that can be used in the 'field'. However, the devices used for this are often large and either not suitable for use in the field, or able to measure only one aspect of an athlete's or team's performance. Consequently, the data collected is not realistic enough for sports scientists and coaches to understand how the athletes are performing in a training or competition environment.



The new wireless 'pervasive' sensing technologies that the ESPRIT team is developing will extract continuous information under normal training and competition environments, giving coaches far more accurate and regular feedback about their athlete's performance than is currently possible. The researchers will be working with the high performance sports community, with the ultimate aim of creating a competitive advantage for elite athletes.

Professor Guang-Zhong Yang from Imperial College London, who is the principal investigator and programme director of ESPRIT, says: "We expect that the ESPRIT project will make innovative leaps in biosensor design and allow us to look in really fine detail at the physiological changes that happen to an athlete during training and competition. This means that athletes and their coaches will be able to gain an unprecedented understanding of their performance and use this to develop a crucial competitive edge. The project will also give scientists new insights into how people's bodies work, in order to help them to design devices that improve the health and wellbeing of the general population."

For their first project, the ESPRIT team has created prototype networks of miniature video camera sensors, called Vision Sensor Networks (VSNs), which coaches can use to monitor an athlete's movements and assess their strategies while training. The scientists are already trialling the VSNs with athletes in training for Britain's summer and winter Olympic sports.

Dr Scott Drawer, co-chair of ESPRIT and Head of Research and Innovation at UK Sport, adds: "At the highest level of elite sport, we know that medals are won and lost within the tiniest margins. Our job at UK Sport is to ensure our athletes reach the start line knowing they are the best prepared and best equipped in the world.

"We hope our work will not only benefit British athletes in the build up to our home Olympic and Paralympic Games in 2012, but also revolutionise the application of, science, medicine and engineering in sport for years to come."

Source: *Imperial College London, www.imperial.ac.uk*

Pittsburgh-led researchers fend off Jack Frost with nanoparticle coating

Preventing the havoc wrought when freezing rain collects on roads, power lines, and aircrafts could be only a few nanometers away. A University of Pittsburgh-led team demonstrated a nanoparticle-based coating developed in the lab of Professor Di Gao, a chemical and petroleum engineering from the Swanson School of Engineering, that thwarts the buildup of ice on solid surfaces and can be easily applied.

The paper in the Nov. 3 edition of Langmuir., by Professor Di Gao and Pitt doctoral student Liangliang Cao, presents the first evidence of anti-icing properties for a burgeoning class of water repellants known as superhydrophobic coatings. These thin films mimic the rutted surface of lotus leaves by creating microscopic ridges that reduce the surface area to which water can adhere. Cao's coauthors include Gao, Jianzhong Wu, a chemical engineering professor at the University of California at Riverside, and Andrew Jones and Vinod Sikka of Ross Technology Corporation of Leola, Pa.

The authors note that because ice behaves differently than water, the ability to repulse water cannot be readily applied to ice inhibition, so the superhydrophobic coatings must be specifically formulated to ward off ice buildup. Gao and his team created different batches made of a silicone resin-solution combined with nanoparticles of silica ranging in size from 20 nanometers to 20 micrometers, at the largest. They applied each variant to aluminum plates then exposed the plates to supercooled water (-20 degrees Celsius) to simulate freezing rain.

Cao writes that while each compound containing silica particles of 10-or-fewer micrometers deflected water, only those with silica particles less than 50 nanometers in size completely prevented icing. The minute surface area of the smaller fragments means they make minimal contact with the water. Instead, the water mostly touches the air pockets between the particles and falls away without freezing. Though not all superhydrophobic coatings follow the Pittsburgh recipe, the researchers conclude that every type will have a different particle-scale for repelling ice than for repelling water.

Gao tested the coating with 50-nanometer particles outdoors in freezing rain to determine its real-world potential. He painted one side of an aluminum plate and left the other side untreated. The treated side had very little ice, while the untreated side was completely covered. He produced similar results on a commercial satellite dish where the glossed half of the dish had no ice, but the other half was encrusted.

Source: *Pittsburgh University, www.pitt.edu*

Washing out the risks

Scientists in Switzerland are reporting results of one of the first studies on the release of silver nanoparticles from laundering the anti-odour, anti-bacterial socks already on the market. Their findings may suggest ways that manufacturers and consumers can minimize the release of these particles to the environment, where they could be harmful.

Clothing manufacturers favour silver nanoparticles because of their antibacterial action, which slows the growth of odour-causing bacteria. In the study, Bernd Nowack and colleagues note that the widespread use of silver nanoparticles in consumer products, especially textiles, is likely to result in the release of nanoparticles to lakes and streams. The scientists studied the release of nanoparticles from laundry water from nine different textiles, including different brands of commercially available anti-odour socks. Previous studies had laundered socks, but only using pure distilled water.

They found that most of the released particles were relatively large and that most came out of the fabrics during the first wash. The total amount of particles released varied from 1.3 to 35 percent of the total nanosilver in the fabric. Bleach generally did not affect the amount released. "These results have important implications for the risk assessment of silver-impregnated textiles and also for studies on the environmental fate of nanosilver, because they show that under certain conditions relevant to washing, primarily coarser silver-containing particles are released," the paper says.

Source: *American Chemical Society www.acs.org*

Tiny injector to speed development of new, safer, cheaper drugs

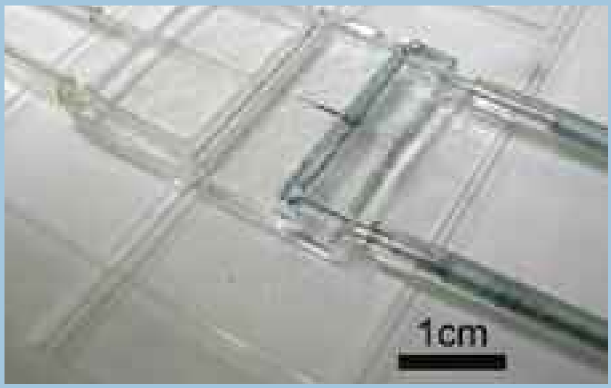
Engineering researchers at McMaster University have fabricated a palm-sized, automated, micro-injector that can insert proteins, DNA and other biomolecules into individual cells at volumes exponentially higher than current procedures, and at a fraction of the cost. This will allow scientists to vastly increase preclinical trials for drug development and genetic engineering, and provide greater control of the process.

The researchers have constructed a microfluidic micro-injector, which achieved an almost 80 per cent success rate in injecting Zebrafish embryos.

"This device is to drug discovery what the assembly line was to the automobile, or the silicon chip to information technology," enthused Ravi Selvaganapathy, assistant professor of mechanical engineering at McMaster and lead author of the research. "It turns what was a complex, resource-intensive process available to a few, into an automated, predictable, reliable, and low-cost system accessible to almost anyone."

The micro-injector has a cell-wide channel, cast on a silicon chip, that guides cells and embryos to the injection site. A similar channel guides the injection reagent to a needle only 10 micrometers in diameter. The researchers can drive the needle through a cell's pliable outer membrane accurately and to the proper depth. The injection dosage is controlled electrically, as is monitoring of the needle's position.

Notably absent is the need for a microscope or optical magnification to conduct the process. The microfluidic device also allows easy integration of post-processing operations, including cell sorting and the testing of cell viability.



The micro-injectors can be run in parallel and allow scientists to test far greater combinations of materials in a much shorter time than is possible using current processes.

The micro-injector also holds great promise for in-vitro fertilization as it provides far greater accuracy and control than current manual injections procedures.

Source: *McMaster University, www.mcmaster.ca*

Bioengineering of nerve-muscle connection could improve hand use for wounded soldiers

Modern tissue engineering techniques developed at the University of Michigan could improve the function of prosthetic hands and possibly restore the sense of touch for injured patients. Researchers presented their findings at the 95th annual Clinical Congress of the American College of Surgeons on the 14th October 2009. The research project, which was funded by the Department of Defense, arose from a need for better prosthetic devices for troops wounded in Afghanistan and Iraq.

"Most of these individuals are typically using a prosthesis design that was developed decades ago," says Paul S. Cederna, M.D., a plastic and reconstructive surgeon at U-M Health System and associate professor of surgery at the U-M Medical School. "This effort is to make a prosthesis that moves like a normal hand."

When a hand is amputated, the nerve endings in the arm continue to sprout branches, growing a mass of nerve fibers that send flawed signals back to the brain. The researchers created what they called an "artificial neuromuscular junction" composed of muscle cells and a nano-sized polymer placed on a biological scaffold. Neuromuscular junctions are the body's own nerve-muscle connections that enable the brain to control muscle movement.

That bioengineered scaffold was placed over the severed nerve endings like a sleeve. The muscle cells on the scaffold and in the body bonded and the body's native nerve sprouts fed electrical impulses into the tissue, creating a stable nerve-muscle connection. In laboratory rats, the bioengineered interface relayed both motor and sensory electrical impulses and created a target for the nerve endings to grow properly.

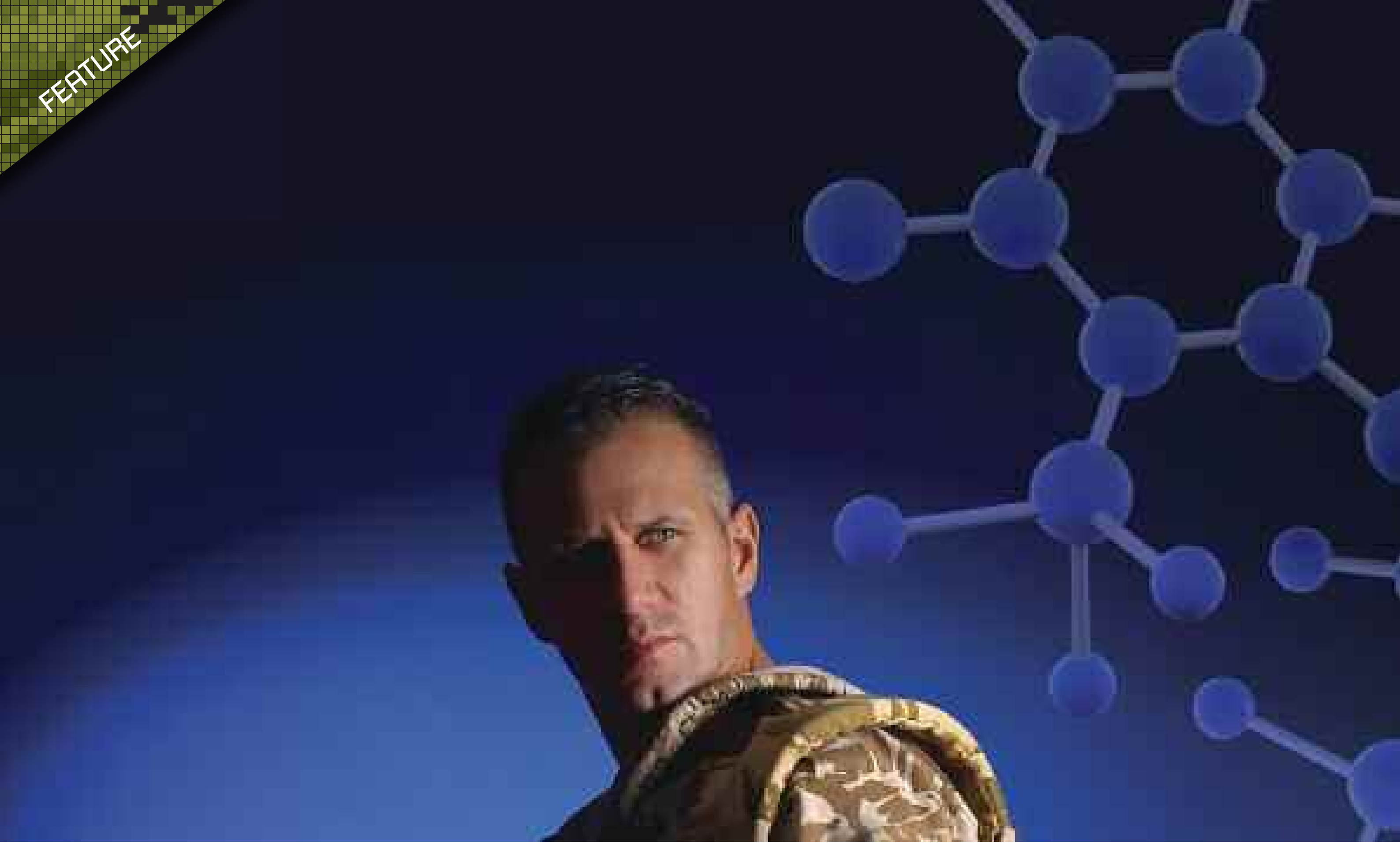
The studies indicate the interface may not only improve fine motor control of prostheses, but can also relay sensory perceptions such as touch and temperature back to the brain. "Laboratory rats with the interface responded to tickling of feet with appropriate motor signals to move the limb." noted Dr Cederna.

Source: *University of Michigan. www.umich.edu*

Military Applications of Nanotechnology

THE MILITARY HAVE BEEN QUICKER THAN MOST TO APPRECIATE THE POTENTIAL OF NANOTECHNOLOGY. MORE MONEY IS BEING SPENT ON NANOTECHNOLOGY RESEARCH FOR MILITARY APPLICATIONS THAN FOR ANY OTHER AREA. THE IDEA THAT NANOTECHNOLOGY COULD LEAD TO LIGHTER WEIGHT, SMARTER DEVICES FOR SOLDIERS IN THE FIELD, UNIFORMS THAT OFFER BALLISTIC AND OTHER PROTECTION, AND MORE DEADLY WEAPONRY, HAS PROVED IRRESISTIBLE. THIS ARTICLE EXAMINES SOME OF THE MILITARY PROBLEMS FOR WHICH NANOTECHNOLOGIES ARE OFFERING NEW SOLUTIONS.

Over the last 20 years or so, governments and industry have invested substantial amounts of money into nanoscience and nanotechnology, investigating what happens to matter at the molecular and atomic scales. The military have been quick to appreciate the performance enhancing potential of this new field for the creation of smaller, smarter, faster, lighter and more effective devices capable of performing more intelligent operations, and using less energy and materials.



Nanotechnologies for military applications include such concepts as micro radar for personnel use and for unmanned miniaturized vehicles, thermal IR sensors with enhanced sensitivity, portable and/or wearable inertial and position, motion and acceleration sensors, miniaturised and highly sensitive vision camera systems, biochemical sensors (remotely operated or hand-held), health monitoring sensors (embedded, continuous or intelligent), ongoing condition monitoring of equipment and munitions, distributed sensors and reporting systems, wireless secured RF-links between sensor(s) and autonomous equipment.

In the US over 1.4 billion dollars was spent on nanotechnology in 2008. Europe, by comparison, spent 0.91 billion Euro (1.3 billion dollars). It is suggested that funding for research into the military applications of nanotechnology in the US outweighs all other research by a factor of two.

In essence, the objectives of scientific research for military applications can be summarised as follows:

- to ensure leadership in technological capability
- to minimise battlefield casualties (soldier protection)
- to enable the acquisition of knowledge on all aspects of the enemy's activities.
- to efficiently immobilise/destroy the enemy
- to limit access by the enemy to resources that may result in re-mobilisation

Technological capability

The lesson from history is that the better equipped an army is, the more likely their chances of winning in battle. Although less true today, it is still the reason why so much is invested in gaining technical superiority. For example, nanotechnology is underpinning the development of new nanomaterials called nanocomposities that are lighter and stronger than their conventional counterparts. The ability to create lower-weight materials, while not compromising on strength and ruggedness, is ideal for the development of more manoeuvrable aircraft and missiles with extended ranges. With the addition of new nanocoatings that enhance 'stealth' capabilities, the latest aircraft and missiles can now travel further whilst reducing the likelihood of detection by an enemy.

Aircraft and missiles are also improved by new on-board sensors. Nanotechnology has inspired a revolution in sensor technology. The new generation of sensors, characterised by their tiny size and weight, are enabling, amongst other things, the 'health' monitoring of aircraft and spacecraft structure systems in real-time.

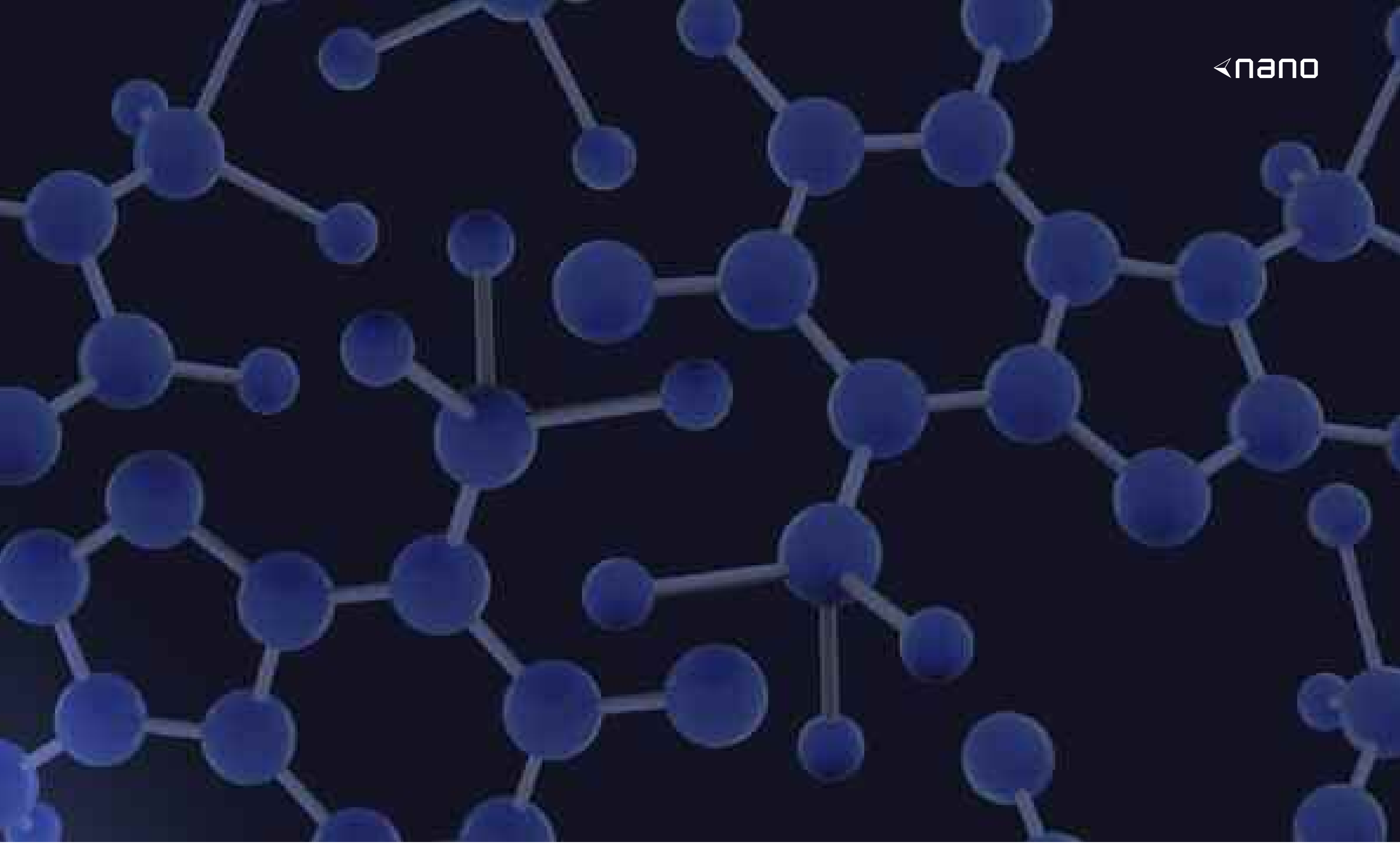
With regard to infrared sensors used for night-vision, and which operate at very cold or cryogenic temperatures, nanomaterials offer a reduction in the cooling needs of these sensors. With reduced cooling requirements, a new generation of infrared sensors can now be used more widely than their predecessors, enhancing their potential for extended surveillance missions.

Nano for Human Enhancement

The development of nanoelectronics and a better understanding of brain physiology have led to the idea of brain implants, accounts of which are found in many science-fiction novels, particularly Arthur C. Clarke's '3001 - The Final Odyssey'. The notion of being able to programme or reprogramme the human brain is not lost on the military. The US and other nations have been funding the development of brain implant chips for some time now, as a possible means of downloading new information and control systems and uploading surveillance and location information.

More recently, the idea of 'augmented cognition' has taken root. Work on the human-silicon chip interface has the express aim of 'transcending the traditional boundaries of the slowly evolving human mind and body, by artificially augmenting functions such as perception, comprehension, insight, and memory.'

Other applications of brain chips have been speculated on at length – including battalions of 'cyborgs', created by



implanting captured enemy soldiers – or even by implanting monkeys. DARPA's Brain Machine Interface project of a few years ago was also said to be developing technology that "promises to directly read thoughts from a living brain – and even instil thoughts as well."

A newspaper article of 2004 describes how a neuroscience professor in the US implanted a chip into a rhesus macaque monkey's motor cortex, establishing "a brain/machine interface" that allowed the animal to control a computer cursor using nothing more than its thoughts. The researcher explained: "We had a monkey playing a video game, using its hand to control a mouse to play the video game. Then we disconnected the mouse and ran it straight out of his brain, so that the control signal to the computer was its brain." This research was in a large part funded by a US Defense Department grant. Military uses for this technology are said to vary from military uniform-embedded health sensors to remote-controlled animals.

Less noteworthy, but a real step towards the making of bionic soldiers, has been the routine procedure in the UK to improve night vision in fighter pilots, using advanced laser techniques and cornea mapping. The surface cells of the cornea are rolled up and laser pulses applied to smooth out its surface, then the surface cells are rolled back again. These treatments are sought by pilots on night fighter missions, or by those attached to aircraft carriers, where night landings are a frequent occurrence.

Nano for Detection Avoidance

Apart from designer nanoparticles to enhance the performance of coatings, which can make surfaces harder, smoother and less liable to corrode, nanotechnologies offer the potential for both 'stealth' coatings that minimise the likelihood of radar detection, and coatings that can change colour in order to maintain camouflage in different environments. It is likely that camouflage paint schemes of the near future, applied on vehicles as 'smart' coatings, could be altered with an electrical impulse as simply as changing pixel colours on a screen.

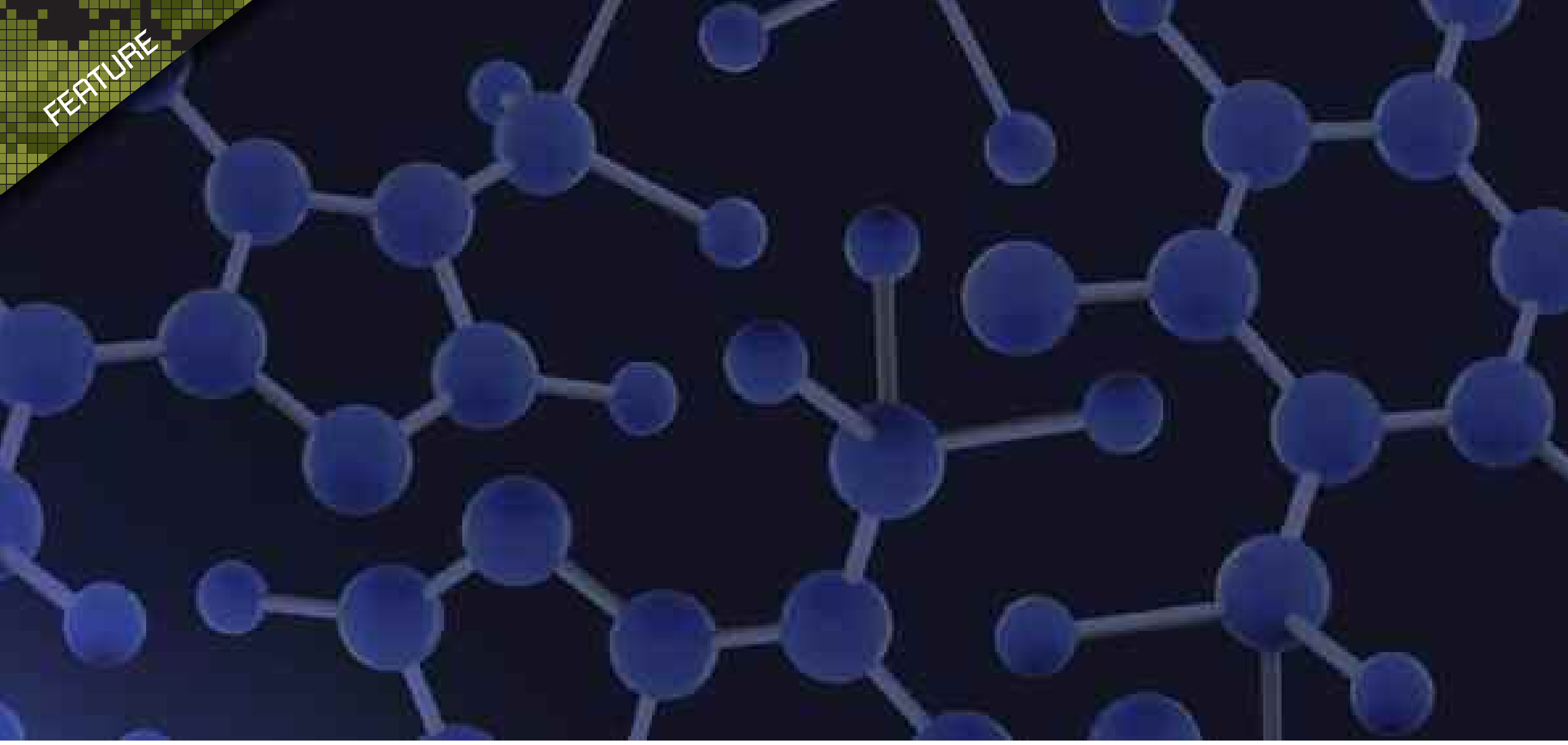
The idea of 'invisibility cloaks' has been much publicised through the Harry Potter stories. Far from mere fantasy, these 'cloaks' can be created relatively simply by projecting what is behind an object onto its surface – to all intents and purposes, making it disappear.

However, this year (2009) there has been a real breakthrough in advancing this technology, based on a theory first described by John Pendry from Imperial College in 2008. Researchers in California, using this theory, have developed a material that can bend light around 3D objects making them 'disappear'. These materials are termed 'metamaterials' and have smaller features than would occur naturally, but have been created on a nano scale. Light is neither absorbed nor reflected by the material, which passes "like water flowing around a rock." As a result, only the light from behind the object can be seen. Applications are still very limited at this stage, as the metamaterial can only be produced in small quantities.

Soldier Protection

A military uniform today needs to perform a variety of tasks, such as providing ballistic protection; the ability to autonomously gather and transmit information, assist in the healing process if a soldier is wounded and protect its wearer from extreme environments such as heat and cold and the threat of biological warfare. It needs to be lightweight yet strong and, of course, cheap to produce.

Critical to many of these textile applications are carbon nanotubes, a new 'super material', possessing some extraordinary properties. For example, carbon nanotubes have a similar tensile modulus to the current best carbon fibres, but are nearly 20 times stronger! Similarly remarkable properties are true for their electrical and thermal conductivity. Combined with another important phenomenon, that nano-particles below the diffraction limit of light are invisible to the naked eye, carbon nanotubes can therefore impart properties to their host matrix, unseen, whether it is an increase in strength, or electrical and thermal conductivity.



New ways of sensing can also be achieved with networks of nanotubes embedded within a polymer matrix that can also form part of battle fatigues. These networks can be distorted by external stimuli, thus creating flexible sensors. Since most polymers are insulators, any distortion of the conductive network of the nanotubes will cause an increase in electrical resistance. Thus the carbon nanotube network become an integrated analogue switch, whose on/off characteristics will be a function of the host polymer. For example, a stimulus could be swelling of the polymer in the presence of water, a solvent or gas, or mechanical strain. In this way, nanotube networks enable the creation of smart, responsive textiles when incorporated in a polymer fibre.

Knowledge Building

The military has always been fascinated by the idea of undetectable surveillance. In the time of the Cold War, phone tapping and miniature cameras were the technologies of the day. Now, listening, imaging and information processing devices are tinier and more efficient than could ever have been imagined in the past. Nanotechnology is enabling new forms of almost 'invisible' surveillance through the incorporation and integration of different technologies with IT, otherwise called ubiquitous computing, including radio frequency identification chips (RFIDs), integrated circuits, quantum dot tags, minute (bio) sensors, intelligent fabrics, films and smart surfaces.

Because surveillance techniques can be miniaturised so effectively, the idea of using live insects ('spy' bees) or creating tiny winged robots that emulate insects to be flown into an enemy situation to record data, has formed the basis of several research projects.

Apart from 'spy' bees (and it might be said there is a greater need today for 'normal' bees), one of the great fears regarding nanotechnology is that it will herald in a world where computing and communication power is so cheap and sensors so ubiquitous that all freedom of the individual will be curtailed. Worries about this are articulated by a senior nanoscientist, George Whitesides, who says "…the most serious risk of nanotechnology comes, not from hypothetical revolutionary materials or systems, but from the uses of evolutionary nanotechnologies… for Universal surveillance – the observation of everyone and everything, in real time, everywhere." Of course, this is close to being a reality already, as can be inferred from the 'Smarter Intelligence' video on IBM's Smarter Planet website, which predicts that by 2010 there will be 1bn transistors per human, 2bn people on the web, and 30bn RFID chips produced annually across the globe.

Efficient Destruction and Resource Immobilisation

In 2009, a patent was granted for an improved plasma method for producing ultrafine refractory metal and ceramic nanopowders. The process is said to be particularly applicable to tungsten, molybdenum, rhenium, tungsten carbide, molybdenum carbide and other related materials. This is an important patent, as nanocrystalline and ultra fine bulk tungsten is attractive to the military for its enhanced dynamic deformation behaviour. Consequently, ultrafine and nanostructured tungsten, when used as a kinetic energy device, outperforms depleted uranium.

Applications of these ultrafine and nano metal materials also include superior weapon systems for armour and anti-armour applications, high kinetic energy penetrators in tank ammunitions, armour plating, and scatter grenades, counterweights in tanks, non-eroding rocket nozzles and jet vanes and welding electrodes, crucibles, nuclear power, propulsion components (high-powered electrical, beamed energy, and nuclear), cartridges, X-ray targets and heat pipes.

Metal nanoparticles have also been shown to be efficient fuels for unmanned vehicles and battlefield power sources. Like hydrogen, metal fuels such as iron, aluminum, and boron burn cleanly; but unlike hydrogen, these metal fuels possess a higher energy content per unit volume, they can be stored and transported at ambient temperatures and pressures, reach combustion at high efficiency in a heat engine and avoid the high costs of fuel cells.

If one was to look back and see when nanotechnology was first embraced by the military, it could be argued that it arrived a few decades ago – in nuclear weapons laboratories. The main impetus then was the need for safe arming and triggering mechanisms for nuclear weapons, such as atomic artillery shells. A further impetus was the drive towards miniaturisation of nuclear weapons, and the related quest for very low yield nuclear explosives which could also be used as a source of nuclear energy in the form of controlled microexplosions.

Nanotechnology is also recognised as a way of meeting the growing demand for novel materials with specific characteristics for improving weaponry. For example, materials for improved insulators to increase the storage capacity of capacitors used in detonators, nano-engineered, high-explosives for advanced weaponry, and nano-engineered components for extreme precision applications.

Be All You Can Be: The Nano-Enhanced Army

NANOTECHNOLOGY IS JUST THE LATEST POTENTIAL TOOL IN THE QUEST TO PRODUCE THE 'PERFECT SOLDIER'. HERE, DANIEL MOORE DISCUSSES THE HISTORY OF HUMAN ENHANCEMENT AND THE MILITARY, FOCUSSING ON HOW NANOTECHNOLOGY COULD NOW BE UTILISED AS A SOLUTION TO LONGSTANDING BATTLEFIELD PROBLEMS.

In 2002, the US Army established an interdepartmental research center at the Massachusetts Institute of Technology called the Institute for Soldier Nanotechnologies (ISN). ISN was charged with developing ways to substantially improve the survival and performance of US soldiers through the use of nanotechnology. This technology would have a point of use in individual soldiers. That is, the technology acts on, affects, or is implanted by an individual.

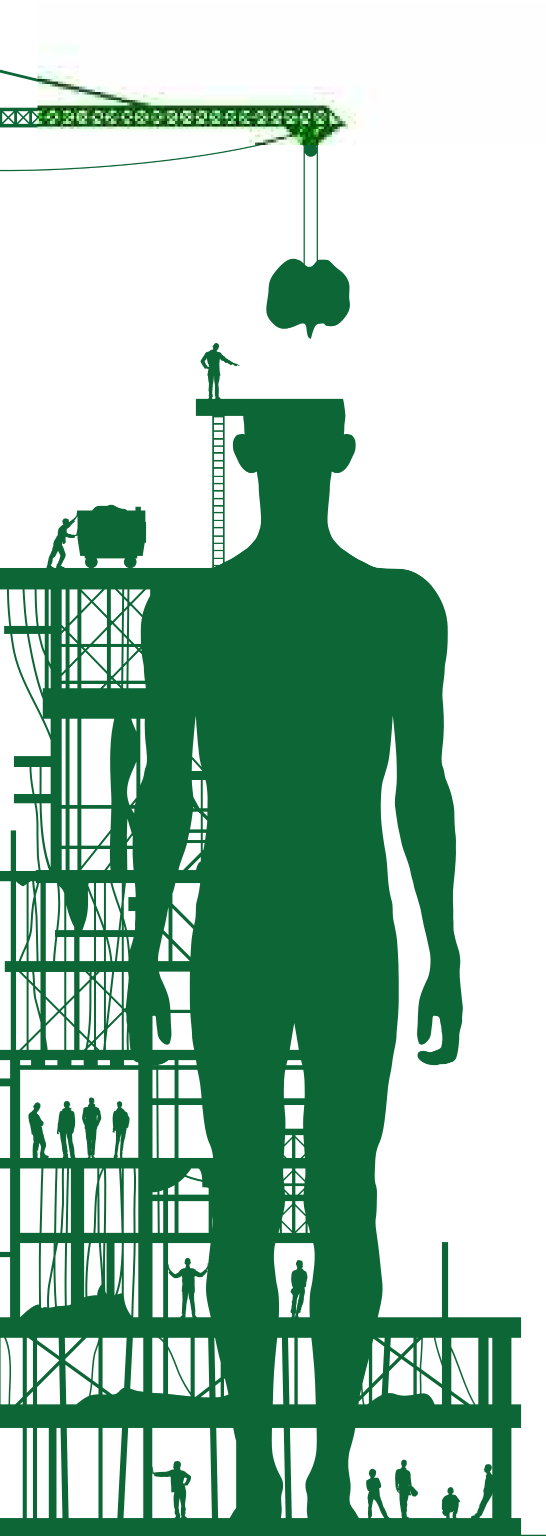
Much of the activation of the technology occurs automatically, without any conscious input from the soldier at all. This can be accomplished with environmental, biochemical, and other sensors that trigger a response from the technology. All of these goals seem to be looking for a way to enhance the individual soldier in a way that enables the soldier to go beyond the limitations of natural human action.

Why enhance?

Enhancing humanity beyond its natural limitations is the basic raison d'etre of technology – that is, all technology adds or enhances what humans can do either individually or collectively. Contra to the Leonardo da Vinci image, Vitruvian Man, as the ideal human state, you can make the argument that enhancing ourselves through technology is what humans, as a species, do. In fact, existing without any technology, in our bare form, is typically considered somewhat inhuman. The military has for a long time been a catalyst for technological development / human enhancement. The typically clearly defined goals of military action and the drive for constant improvement on those goals have long interlocked the military with technology.

Individual and group enhancement, making the soldier and larger units "better," has been a key part of military strategy for as long as we can look back. For example, the Greek Hoplite realizes that his hand and fingernails aren't effective enough in punching and stabbing his enemy, so he enhances the power of his hand with a sword. However, he also realizes that holding up his hands to protect his body

SUPPOSE A HUMAN COULD BE ENGINEERED WHO SLEPT FOR THE SAME AMOUNT OF TIME AS A GIRAFFE (1.9 HOURS PER NIGHT). THIS WOULD LEAD TO AN APPROXIMATELY TWOFOLD DECREASE IN CASUALTY RATE



against other swords isn't good enough, so he extends the blocking ability of his arm with a shield. Then, he thinks that it might be useful to begin the attack when he is farther away from the enemy, so he equips himself with a spear. Furthermore, the shield might not provide the ultimate protection – either because it can't reach his back or because he will be blindsided by an attack – so he enhances the toughness of his skin with body armour. And so on.

We can shift ahead a few centuries and look at the Medieval Knight and Longbowman. Sometimes, military technology development leads to specialization. With the Medieval Knight, the body armour enhancement has led to the development of chain and plate mail that covers the entire body, a better sword and a better shield. These enhancements provide protection, but less mobility, making the knight a powerful shock weapon. The longbow has also been developed, allowing for the inexpensive deployment of a large number of missile troops. Protected by distance, the longbowman does not require as extensive a body armour as the knight.

Another few centuries later, we can look at the British soldier. The development and use of missile weapons powered by gunpowder, such as the rifle, led to the obsolescence of medieval knights and drastically reduced fighting with melee weapons (though the bayonet still provides for close up fighting). The more modern U.S. soldier has much more powerful missile weapons at his disposal (and grenades of various types). Body armour is also much more sophisticated. Other types of enhancements have also entered into general military use – including enhanced eyesight providing the ability to see better at night and to see/enhance different wavelengths of light.

The point is that all technologies provide an enhancement to humanity. But all of these aren't what we mean by "human enhancement." It is a difficult line to draw, probably because there isn't a line at all but a continuum upon which the technologies lie. We can look at different ways to distinguish military technologies: purpose of use (defensive or offensive), level of use / impact (civilization or individual), type of use (shock or missile), amount of control required (human controlled or autonomous system), duration of use and/or impact (temporary or permanent), and the locus of use (internal or external). This isn't a comprehensive list, but it represents several ways of analyzing military technologies that are relevant to a discussion of human enhancement (and to comparing different types of technology). For example, a pistol is an offensive weapon that acts on an individual, whereas a protective wall is defensive and protects on the civilization level. Automated defence shields are missile weapons requiring minimal human input, and swords are shock weapons that require extensive human input. Battlefield medicine is a temporary fix that acts internally to the body, while traditional limb replacement can be seen as a permanent fix that is external to the body.

How and why nanotechnologies are being deployed

When talking about nanotechnology, human enhancement and the military, it is also important to understand what uses the military might have for technology. After all, technologies are not created in a vacuum. They are created to solve problems and enhance capabilities. This is also true for military technologies. Some of the "problems" that exist in the military and are related to human enhancement are:

- **Soldiers need more effective tools to accomplish their goals;**
- **Soldiers carry a heavy load, averaging just under 100 lbs in combat operations;**
- **Threats to soldiers can come unexpectedly, suddenly, and can cause injuries that cannot be healed quickly;**
- **Sleep deprivation hurts soldier performance.**

It should be noted that none of these is a new challenge to the military. Many of the technologies described earlier were developed in attempts to provide a novel solution to these problems. Different times and cultures have developed different technologies that solve these challenges to different degrees and with different methods. Furthermore, major advances in technological solutions to these problems have shown the ability to create major changes in battlefield outcomes, tactics, and situations. As

mentioned, the longbow is a perfect example of this. Developed in Wales, it introduced a new form of artillery fire and contributed significantly to the removal of armoured knights from the battlefield.

As we will see, nanotechnology offers a significant number of technological avenues towards human enhancement. It allows for the creation of tools that enable more permanent effects and that are continuous or always on/available. Nanotechnology also enables technologies to move towards more internal use and impact because of its small scale and capabilities. It also leads to technologies that are relatively ubiquitous. Nanotechnology offers new and transformative directions in military technology because it leads to enhancement in humans that is more permanent and more internal. It helps to make strong inroads into previously difficult to directly address problems, such as the managing of individual mental states. If we look at the list of problems above and examine what nanotechnology based solutions might look like, then we can begin to develop a picture of a nanotechnology enhanced military.

More Effective Tools

Soldiers need more effective tools to accomplish their goals, that is, they need more effective weaponry. A specific example of nanoscale materials showing their impact in weaponry is nanoaluminium. Bulk-scale aluminium contains aluminium atoms that cover roughly one-tenth of 1 percent of the surface area. Nanostructured aluminium contains aluminium atoms that cover roughly 50 percent. More atoms on the surface create more sites for chemical reactions to occur. This is used in conjunction with metal oxides such as iron oxide to create superthermites, which increase the chemical reaction time by three orders of magnitude. Therefore, greater amounts of energy can be released, creating more powerful conventional explosives and faster moving missiles and torpedoes (so fast, in fact, that they can bypass evasive actions).

Reducing Load Weight

Soldiers typically carry a heavy load during combat operations. Historically, load size has been a severe limiter of army mobility. For example, Hannibal had more than 2000 head of cattle to support his army of 30,000 men. By simply making devices smaller and lighter, the soldier can be made more mobile and have a smaller logistical footprint, allowing for far greater supply lines. The average present-day soldier carries in excess of 100 pounds of equipment while on assignment. Much of this weight is due to the electronic equipment (including communication equipment) and power supplies (usually batteries) used to power them. Through the use of smaller, lighter equipment, this weight could be reduced dramatically without a sacrifice in functionality; the soldier could therefore move more quickly and/or further (in the same amount of time). Much of this weight reduction can be accomplished by reducing the scale of the power generators that the soldiers have to carry. For example, nanoscale power generation has been recently demonstrated by utilizing an array of piezoelectric nanowires. By converting mechanical, vibrational, or hydraulic energy into electricity, these “nanogenerators” can be used to power the electrical systems carried by the soldiers.

Sudden threats, and battlefield injuries

Threats to soldiers can come unexpectedly, suddenly, and can cause injuries that cannot be healed quickly. Traditionally, shields and body armour have been the solution to providing direct protection to soldiers. Nanoscale materials can be made out of flexible polymers and nanocomposites to form nanoscale trusses. Woven into a battle suit, these materials would provide light weight flexible body armour. This would provide ample protection without significant loss of performance due to weight. For example, recently, GE has demonstrated a SiC matrix with nanoscale SiC fibers capable of stopping a bullet. Furthermore, nanotechnology allows for more direct and immediate detection and treatment of injuries. Using designed nanoscale polymers that have an electrorheological response, mechanical actuators could transform a material from flexible and pliant to nonpliant and armour-like almost instantaneously. This could be used to automatically form a cast or tourniquet to treat injuries and wounds. This same material response could be used to give CPR, if necessary, with little to no human input. This mechanically active exo-skeleton could have more uses than just injury mitigation and treatment – serving as exomuscles to augment a soldier’s physical strength and movement.

Sleep Deprivation

According to a JASON report, “the most immediate human performance factor in military effectiveness is degradation of performance under stressful conditions, particularly sleep deprivation.” If an opposing force had a significant sleep advantage, this would pose a serious threat… Suppose a human could be engineered who slept for the same amount of time as a giraffe (1.9 hours per night). This would lead to an approximately twofold decrease in the casualty rate.” Human enhancement with nanotechnology can have a major impact here. Even the simple detection of fatigue, lapses in attention, and changes in neurological behavior would allow battlefield commanders to have better knowledge about the forces under their command. Nanoscale sensors can be used to detect this fatigue in individual soldiers. This can be done by monitoring the brainwave patterns, but it can also be done more simply by closely monitoring, in real time, muscle response, eye movement, chemical levels in the body, and other triggers and suggestions of fatigue. DARPA is investing in what it refers to as “metabolically dominant” war-fighters that will “be able to keep their cognitive abilities intact, while not sleeping for weeks. They will be able to endure constant, extreme exertion and take it in stride.” By allowing for targeted drug delivery systems, nanotechnology provides access to chemical methods to enhance and control the mental states of soldiers with minimal side effects.

In conclusion, nanotechnology leads us towards military technology that enhances humans more permanently and more internally. More efficient weaponry, lighter loads and devices that allow increased capability without sacrificing mobility, energy absorbing and electromechanical materials acting as an exoskeleton to help automatically protect the individual, and some management of the mental states of individuals are all made possible by the shrinking size and increasing technological capabilities that nanotechnology provides us with. n

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Perspectives on Nanotechnology in Mexico

A LEADER IN LATIN AMERICA IN TERMS OF RESEARCH AND DEVELOPMENT, MEXICO IS YET TO MATCH THIS ACADEMIC SUCCESS WITH THE CREATION OF A SUSTAINABLE NANOTECHNOLOGY INDUSTRY. A LACK OF A DISTINCT NANOTECHNOLOGY PLAN, COMBINED WITH ISSUES IN FUNDING, PRODUCTION AND AN UNTESTED MARKET, MAY MEAN THE WINDOW FOR A VIABLE PRACTICAL TRANSLATION OF THIS R&D SUCCESS INTO PRODUCTION MAY BE MISSED. GUILLERMO FOLADORI AND ÉDGAR ZÁYAGO DISCUSS.

In Latin America, Mexico is second to Brazil in leading the Research and Development of nanotechnology as measured by the number of scientific papers published and the number of patents registered over the period between 2000 and 2007.

Nanotechnology was identified as a strategic area for Mexico's development in 2002. This was ratified in 2008 in the Special Program on Science and Technology (PECYT) 2008-2012 of the National Council of Science and Technology (CONACYT). However, the PECYT did not articulate specific ideas on the operationalisation of the endeavor.

Nanotechnology R&D has been varied, particularly in universities, as well as in research centers. The country boasts around 56 research and teaching centers with approximately 450 researchers working in the area. Several international collaborative agreements, associations or cooperation between institutions have been signed. It is worth mentioning some of the most ambitious projects.

The Center of Advanced Research Materials (CIMAV), located in Chihuahua, inaugurated in 2008 the National Laboratory of Nanotechnology (NaNoTeCH), with the objective of supporting institutions and Mexican enterprises in all aspects related to nanotechnology. This Laboratory is to be the heart of the National Network of Nanotechnology. Also, the Scientific-Technological Cluster of Nanotechnology in North America was created in partnership with Arizona State University in the U.S.. In addition, CIMAV became, in 2009, the Mexican National Point of Contact for nanotechnology and new materials.

The Potosí Scientific and Technological Institute (IPICyT) located in the State of San Luis Potosí, promotes research and training in nanotechnology. A recent development in this institution is the creation of the National Research Laboratory on Nanosciences and Nanotechnology (LINAN). This laboratory has several partners: businesses, universities and research centers, national as well as foreign.

The National Autonomous University of Mexico (UNAM) runs the University Project for Nanotechnology (PUNTA), created in 2004, grouping more than 30 researchers from 8 different centers, mainly in México City. This project focuses on the development of nanostructured materials as catalysts for environmental improvement. Another body is the Research Network Groups on Nanosciences (REGINA), which groups more than 50 researchers in 8 centers of UNAM. In March 2008, the Center for Condensed Matter Sciences (CCMC) of UNAM, located in Ensenada, Baja California, became the Nanoscience and Nanotechnology Center (CNyN).

Other research centers and universities doing R&D in nanotechnology include: the Autonomous University of Nuevo León (UANL), the University of Guadalajara (UdeG), the Technological Institute of Advanced Studies of Monterrey (ITESM), the Research Center of Applied Chemistry (CIQA), the Mexican Institute of Petroleum (IMP), the Center for Research in Optics (CIO), the National Institute of Nuclear Research (ININ), the National Institute of Neurology and Neurosurgery (INNyN).

Mexico's national laboratories and institutions working with nanotechnology are facing challenges due to the decreasing amount of funding channeled to Science and Technology (S&T). The portion of the Gross Domestic Product (GDP) allocated in 2007 was just 0.35%; 0.34% in 2008 and will be around 0.33% in 2009.

The association of Mexican research centers and national laboratories with business groups, both national and foreign, has been another avenue of obtaining additional resources. One example is the National Laboratory of Nanoelectrical Components attached to the National Institute of Astrophysics, Optics and Electronics (INAOE), located in Puebla. This laboratory has a first-class clean room and a complete manufacturing line for integrated circuits thanks to a partnership signed with Motorola. Another important example is the creation of the Research Park for Technology Innovation in Monterrey, Nuevo León, a city that endorses nanotechnology development as a strategy for economic advancement. This park is one fraction of the project called City of Knowledge, which includes the insertion of the CIMAV and its National Laboratory of Nanotechnology (NaNoTeCH). There are also other research centers with nanotechnology projects in different universities throughout México.

Despite the number of research centers, hundreds of researchers, collaborative agreements and projects implemented to develop high-tech parks, nanotechnology developments in Mexico are not promising. There are, at least, three matters of concern.

First, most of the research is conducted with public funding, yet there are no specific resources for nanotechnology R&D. As a consequence, research centers and their projects become dependent on the occasional and under-funded calls that the National Council of Science and Technology (CONACYT) organizes. That is, of course, if they are successful in obtaining the funding. Assuming that the professional competition for funding is positive, long-term projects with uncertain results, such as the ones associated with new technologies, are not likely to advance under the framework of little funding and short-term plans (most of these projects last between one and two years, rarely longer). Even so, there are some funding programs that encourage the collaboration between academia and businesses, but the involvement of the private sector in R&D is still negligible.

The second factor that raises doubts about the future of nanotechnologies in Mexico relates to production. The possibility that research conducted in public centers and labs could translate into real-world applications is unsure unless business fills up all the subsequent stages and commercializes them. There are several high-tech parks being fostered to integrate R&D with production; but the vertical production chains are not fully developed in the case of new products, especially those requiring novel raw materials and different manufacturing procedures. Furthermore, these production chains take longer to expand in unknown markets because they are more susceptible to changes in supply, credit or consumption preferences. The ambiguity does not end there. In fact the manufacturing process in itself has a degree of uncertainty which follows the product until it reaches the market. In order to promote nanotechnology it will be necessary to secure the manufacturing platform, at least while a market is developed and vertical chains of production are properly established. In Mexico, the science and technology (S&T) policy gives an initial push and provides some financial support to develop new technologies, but the continuation of the endeavor relies on the business sector (long term R&D, vertical integration of production and market development). However this is not likely to happen at the national scale and is even less probable in the case of new products, with no experience in manufacturing or in the market. Nevertheless, Mexico has a significant level of expertise both in research and somewhat in production and it could develop a long-term program to support research with state owned enterprises, at least until a market is fully developed.

The third factor that calls into question the future of nanotechnologies in Mexico pertains to the market. Market viability of new products is unknown and as a consequence, businesses are hesitant to attempt entry. Furthermore, there is the problem of the uncertainty of the market associated with the prices of the basic materials, the possibility of acquiring nano-raw material sourced in other countries and the mobility of financial capital that could endorse unexpected manufacturing. Also, we would have to consider the problems associated with labeling, international standardizations and the complicated topic of patents. In addition, there is the matter of risks associated with nanotechnologies, which the Mexican government has ignored as a potential problem. There is no funding to research the risks, and academics are reluctant to commit themselves to research these matters.

There can be exceptions and some public enterprises could appear as important players, however, a country without a plan - and without the articulation of research with production and consumption - cannot be expected to compete. Why not employ the enormous state power in Mexico to promote the development of new technologies by integrating long term R&D with production and consumption? This alternative is not part of the discussion.

Despite the existing infrastructure and prospective developments, to find their full potential, nanotechnologies in Mexico need to have support from the State so as to foster their vertical integration in research, production and consumption. Still, this alone will not be enough to encourage nanotechnologies towards a social oriented development. There is no plan or public policy defining research areas, and neither is there interest in researching political, social, ethical, environmental issues and impacts upon health nor proposals to regulate or normalize labeling and patents, alongside many other problems. This lack of planning for nanotechnology development leads to the creation of spaces in the market that will benefit, sooner or later, foreign counterparts and the market, which will damage and potentially jeopardize Mexico's development. n

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An update on nanotechnology in the US:

The US National Nanotechnology Initiative – past, present and future goals and funding.

THE US NATIONAL NANOTECHNOLOGY INITIATIVE IS PREDICATED ON 'A FUTURE IN WHICH THE ABILITY TO UNDERSTAND AND CONTROL MATTER AT THE NANOSCALE LEADS TO A REVOLUTION IN TECHNOLOGY AND INDUSTRY THAT BENEFITS SOCIETY'. HERE NANO MAGAZINE TAKES A LOOK AT THE GRAND CHALLENGES AND COMPONENT AREAS WHICH HAVE MOTIVATED THE INITIATIVE FOR THE LAST 8 YEARS.

The US National Nanotechnology Initiative was established in 2001 to coordinate nanoscale research and development, and ensure communication, cooperation and collaboration across the participating funding agencies. Twenty-five American agencies are involved in the Initiative, thirteen of which have a Research and Development remit. At its inception, the National Nanotechnology Initiative (NNI) ambitiously identified nine 'Grand Challenges areas for nanotechnology in the United States:

Nanostructured Materials by Design
To increase knowledge, understanding and the ability to control items at the nanoscale, in support of the development of new materials.

Manufacturing at the Nanoscale
The manufacture of nanostructured materials, devices, and systems with precise control over the location of individual atoms and molecules.

Chemical-Biological-Radiological-Explosive Detection and Protection
To focus upon biosensors, decontamination measures, and protective clothing and manufacture of materials.

Nanoscale Instrumentation and Metrology
The improvement and creation of techniques and tools for seeing and working at the nanoscale.

Nano-Electronics, Photonics & Magnetics
To take the miniaturization of microelectronics to an even smaller scale, whilst attempting the dual achievement of increasing functionality while driving costs down through new construction methods.

Healthcare, Therapeutics, and Diagnostics
Assembling far-reaching information about the chemical and physical properties of nanoscale biological structures.

Energy Conversion and Storage
Improving the storage and conservation, transmission and conversion of energy.

Microcraft and Robotics
To combine the miniaturisation of computer systems and machinery to create robotics, vehicles and crafts.

Nanoscale processes for environmental improvement
To reduce, avoid and prevent the impact of pollution which results from manufacturing, which impacts upon both human health and the environment, with a dual focus on both prevention and cure.

Today, these have been streamlined into four overarching goal areas, as follows:

1. The advancement of a world-class nanotechnology research and development program.
2. To foster the transfer of new technologies into products for commercial and public benefit.
3. To develop and sustain educational resources, a skilled workforce, and the supporting infrastructure and tools needed to advance nanotechnology.
4. To support the responsible development of nanotechnology.

As stipulated by the 21st Century Nanotechnology Research and Development Act, the NNI's Strategic Plan in 2004 led to a restructuring of the initiative, putting forward the four goal areas, and replacing the 'Grand Challenges' with updated 'Program Component Areas' (PCAs). There were originally seven of these PCAs, which were extended to eight by the 2007 Strategic Plan. They came to being as a result of a series of NNI-sponsored workshops in which members of the nanotechnology community identified the areas which should be targeted for investment. While the four goals provide the vision and structure of the initiative's strategies, the PCAs define the areas where investment is needed to achieve these goals. As a result, the PCAs are less applications-based than the Challenges had been, and the activities in each area branch into multiple agencies.

The Program Component Areas and their aims are:

Fundamental nanoscale phenomena and processes
To discover and develop knowledge regarding new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale. Elucidation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms.

Nanomaterials
To discover novel nanoscale and nanostructured materials and a comprehensive understanding of the properties of Nanomaterials. The ability to design and synthesize, in a controlled manner, nanostructured materials with targeted properties.

Nanoscale devices and systems
To create novel, or improve existing, devices and systems. The incorporation of nanoscale or nanostructured materials to achieve improved performance or new functionality.

Instrumentation research, metrology, and standards for nanotechnology
To develop tools needed to advance nanotechnology research and comme-rcialization, including next-generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. Develop standards, including standards for nomenclature, materials, characterization and testing, and manufacture.

Nanomanufacturing
To enable scaled-up, reliable, and cost-effective manufacturing of nanoscale materials, structures, devices, and systems.

Major research facilities and instrumentation acquisition
To establish user facilities, acquisition of major instrumentation, and other activities that develop, support, or enhance the Nation's scientific infrastructure.

Environmental, health, and safety
To understand the environmental, health, and safety impacts of nanotechnology development and corresponding risk assessment, management, and mitigation.

Education and societal dimensions
Education-related activities such as development of materials for schools, undergraduate programs, technical training, and public communication. Research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications.

The new addition from the 2007 Strategic Plan was the separation of the "Social Dimensions" PCA into two: Environment, Health and Safety and Education and Social Dimensions, to allow a clearer sense of where investment was targeted by splitting risk management, assessment and mitigation from education-related activities.

NNI 2009 Proposed Budget
The planned share of the NNI's $1.5 billion budget for 2009 each PCA received are shown in the table below.

Program Component Areas	Planned investment 2009 $000,000
Fundamental Phenomena and Processes	550.8
Nanomaterials	227.2
Nanoscale Devices and Systems	327.0
Instrument Research, Metrology and Standards	81.5
Nanomanufacturing	62.1
Major Research Facilities and Instrumentation Acquisition	161.3
Environment, Health and Safety	76.4
Education and Social Dimensions	40.7

Five of the agencies share a high percentage of the total budget for nanotechnology. Of these the Department of Defense leads the way, with a proposed 2009 budget of $431M, this is followed by the National Science Foundation ($397M), Department of Energy ($311M), the Department of Health and Human Services of the National Institutes of Health ($226M) and the National Institute of Standards and Technology ($110M). The other eight agencies involved, which include NASA and the Environmental Protection Agency, share the remaining $52M between them.

The NNI's FY2009 Budget & Highlights describes some of the achievements of the initiative. The infrastructure identified as required for nanotechnology research in the original strategy, is now near completion. This network consists of research centers and user facilities which are being increasingly encouraged to work alongside industry from small scale business up. As sanctioned in the Strategic Plan of 2007, these industry ties should lead to increasing levels of technology transfer, working alongside the electronics, chemical, forestry industries and industrial research management community. Outside the US, the NNI continues to participate in international collaborations including chairing The Organisation for Economic Cooperation and Development (OECD) Working Party on Manufactured Nanomaterials to address health and safety and a second working party for economic impact, education and training and public communication.

The USA's massive commitment to financing nanotechnology to ensure its status as world leader is patent. The next NNI Strategic Plan will be published at the end of 2010 and will no doubt lay out a map to further cement the US position at the top of the food chain. n

Victor Castaño

Professor Victor Castaño is a member of Faculty and the Director of the Center for Applied Physics and Advanced Technology (CFATA) at UNAM (Universidad Nacional Autonoma de Mexico), the most important academic institution in the country. His list of career achievements is long and distinguished, having published over 500 peer reviewed international papers. He has been recognized by numerous national and international awards.

In addition, Professor Castano has attracted more media attention in Mexico than any other scientist through his discoveries and inventions. He has a reputation for solving practical problems and is the holder of several patents. Of particular note is his development of an anti-graffiti paint and a bullet-proof vest, which are original nanotechnology applications and are currently being produced commercially.

OS: Professor Castano, you are a highly respected researcher; and for most academic researchers, their goal is only to produce more and better papers. How did you get involved in the commercial world?

VC: As a youngster I was convinced that knowledge also implies a serious responsibility in a country like Mexico, with all the social problems we face. I dreamed of being able to not only generate original and relevant research, but to apply it to solve specific problems. This personal attitude has been a constant in my career. My dream became reality when the expansion of the economy in the last two decades turned Mexico into a global player, and forced Mexican companies to adopt innovations in order to be competitive. This opened a way for the transfer of the knowledge and ideas of our research group to several companies, both in Mexico and abroad.

Of course, publishing is obviously a must for an academician, but applying knowledge implies an extra challenge, which has always been tempting to me!

OS: Can you describe the journey from having a solution to a problem to getting it to the market place?

VC: Doing the actual research was the easy part. Convincing, negotiating and scaling up the technology to commercial levels took a lot more effort and stamina. This was partly due, in my opinion, to the lack of experience in our group in undertaking projects at that industrial level. Now it is becoming easier with our new projects. Also the lack of experience by Mexican companies in assimilating novel technologies, in spite of the fact that there are some really huge Mexican firms, was another barrier.

OS: What is the environment like in Mexico for individuals who want to commercialize their research?

VC: The government and several universities and institutions are making great efforts to encourage innovation. However, the situation overall is still difficult for those people wanting to impact the market with new technology. This is due, I believe, to the lack of any tradition in this area in our country, which is one of the challenges we face. However, I'm optimistic in that things will improve soon.

OS: What problems have you worked on solving since your first success in anti graffiti coatings? And how are they progressing in terms of bring these solutions to the market? Does it get easier, now that you have more experience?

VC: We have succeeded in commercializing, though under limited conditions, a bullet-proof vest, whose production is now being negotiated with one of the largest global manufacturers, and which we hope will be a worldwide product soon. We have a big contract with a Danish-American-Mexican company for producing diesel from municipal waste (not biomass). We have also concentrated, in recent years, on the biomedical applications of nanotechnology; and three of our developments will hopefully be commercialized by a leading company in this the area in the near future. One is related to chronic diseases, the other to sanitation and the third to the detection of a bacteria which causes a wide-spread disease in the world.

OS: As a professor and entrepreneur; what is it you most enjoy about your working life? What are the benefits and drawbacks about being an academic in Mexico?

VC: Discovery by itself and the personal satisfaction of seeing your thoughts in action, have been my main driving forces. In Mexico we enjoy an almost complete freedom to decide and pursue the research we want to do, with no limitations, in general, by the funding agencies, provided you are doing reasonable work. The limited number of researchers in the country, given its size, and a certain scepticism from internationally-recognized groups which evaluate and fund projects, are certainly limiting factors, but also interesting challenges to overcome.

OS: Mexico and Brazil are the first countries people tend to think of in relation to nanotechnology in Latin America. Is the Mexican Government doing enough to promote nanotechnology research and development? Could they do more?

VC: There are interesting programs and initiatives by the government related to nanotechnology. However, I do not think they are being as effective as they should be. Personally, I do not consider the problem to be a lack of interest, or lack of resources for that matter, but the need of a general government policy towards science and nanotechnology, which should become a matter of public interest. A unified program for nano R&D would certainly be in order for Mexico.

OS: In what areas do you see that nanotechnologies could offer benefits to the Mexican people? What existing skills / resources do they have that can be built on? (For example, much work on nanotechnology in South Africa is based on the applications of precious metals, such as gold and platinum).

VC: I'm convinced that there are four relevant areas for Mexico in which nanotechnology could play a key role, namely, health (drug delivery, early detection of diseases, sanitation, vaccines); water (purification and treatment); energy (alternatives to petroleum), and construction (cheaper and improved construction materials for buildings, housing and roads). As a country, we need a decisive government policy and targeted programmes, in order to work together towards common goals - the latter perhaps being one of the main challenges for the nano community in Mexico.

OS: Finally, what future ambitions in the nano world do you have for your university, your country and yourself?

VC: I would like to see many products in the global market produced with Mexican nanotechnology. International recognition for Mexican scholars is, doubtless, a matter of national pride, but providing a service to the Mexican people, by producing wealth and solving their urgent needs is my leitmotif, and is what would ultimately legitimate our institutions.

Ballistic nanomaterials

Anti-corrosion coatings

Anti-grafitti coatings

Professor Castaño's best known invention is the unique anti-graffiti paint he developed alongside colleagues at the National Autonomous University of Mexico. Unlike previous anti-graffiti solutions, which require reapplication, this nano innovation is more durable and stands up to continued usage. This paint shows complete oil and water repellency, and is scratch and UV resistant. The coating can be used on a variety of surfaces: brick, mortar, glass, and plastic, protecting all of these from the tools of graffiti art: spray paints and marker pens alike. In doing so they help solve a problem that costs millions a year to counteract, and which is seen to be the first sign of a community becoming susceptible to crime.

The coating is a two-component system, consisting of a high-performance polymeric base, that includes the nanoparticles and oil and water-proof molecules, and a cross linking agent. The system is physicochemically-designed as to induce the segregation of the oil and water-repellent molecules on the surface upon drying, while keeping the nanoparticles evenly distributed throughout the whole film. The coating can range from a few hundred nanometers to a few micrometers thick, depending on the thickness of the base, and can be made to be completely opaque to highly transparent. Commercialised as Deletum 5000, the coating can last up to ten years without needing to be reapplied, and can be used to protect historic buildings without causing harmful side effects to the stone or its appearance.

Other coatings invented by Professor Castaño include an anti-corrosion coating, a water-repellant coating, UV protection for polymers and coatings to prevent the tarnishing of silver and copper. He has even applied the concept of Deletum 5000 to products like nail varnish, creating a long lasting protective nail veneer.

Not content with coatings for inanimate objects, along with other colleagues, Professor Castaño has also developed a protective coating for dental applications. It was found that a novel nanohybrid coating containing an inorganic ceramic and an organic copolymer constituent can be used to cover the surfaces of teeth, dramatically improving their scratch resistance.

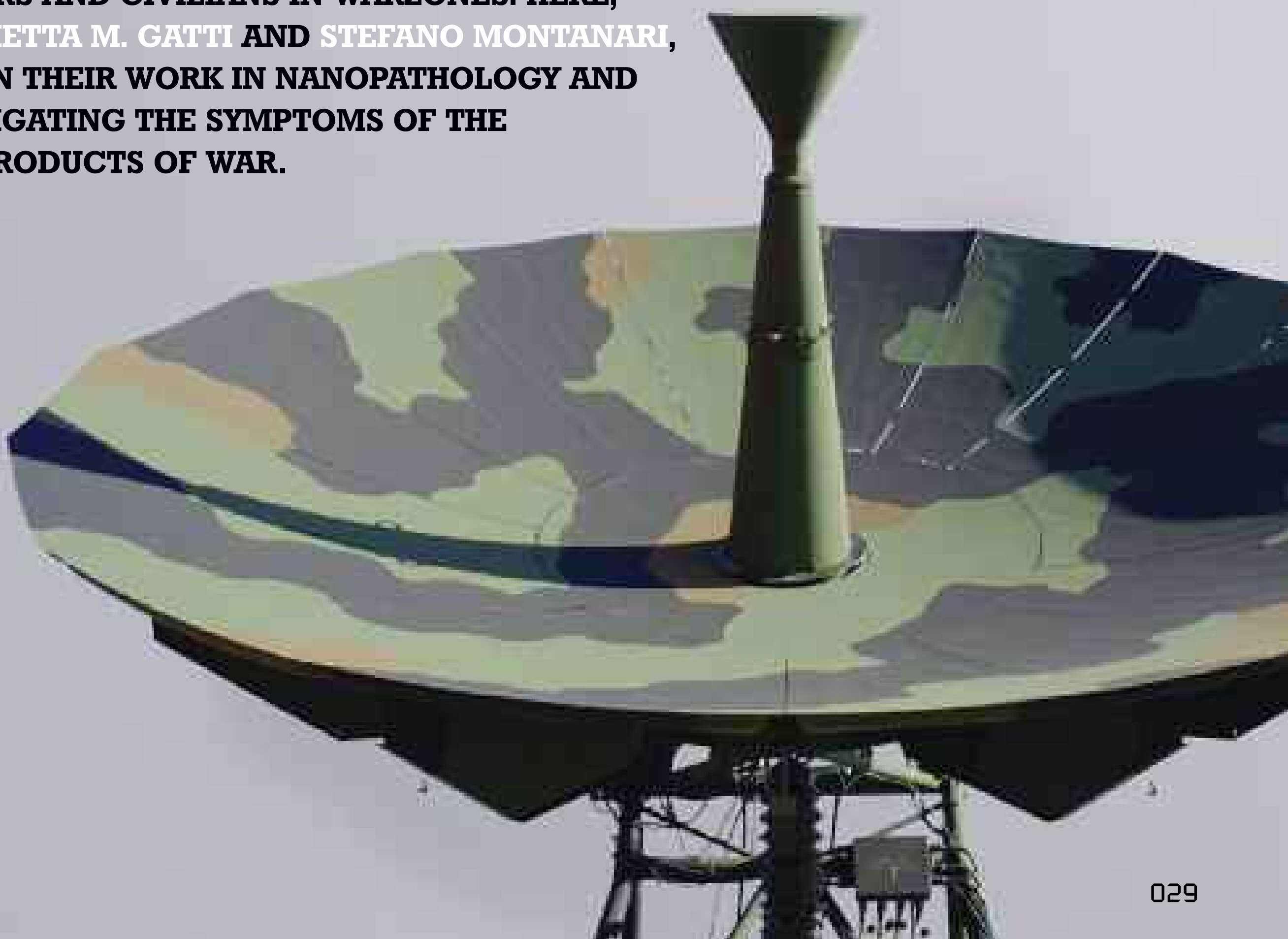
The next application to which Professor Castaño turned his attention to was the improvement of the effectiveness of bullet proof vests. This has been achieved by attaching ceramic nanoparticles to Kevlar fibres, using an organic coupling agent. This allows the added benefit of shielding the material against UV, without any negative effects upon its protective properties.

After anti graffiti, anti corrosion and water repellent coatings, UV protection for silver and copper coatings, better nail varnishes, coatings that provide scratch resistance for teeth – what else that to invent a diamond coating, using tequila? In a uniquely Mexican experiment, Castaño and his fellow researchers Javier Morales and Miguel Apatiga found that they could produce films of synthetic diamond, using tequila. This was achieved using Pulsed Liquid Injection Chemical Vapour Deposition onto silicon and stainless steel at 850˚C. They believe this process could provide a lower cost alternative to existing methods for producing industrial-scale diamond thin films for practical applications.
Cheers! (Or as they say in Mexico – Salud!)

Other nanomaterials and Technologies which Professor Castaño has been involved with include: a fire-resistant nanocomposite made from rice husk. Asphalts modified with rubber, fingerprint recognitions technology, a process for electronic detection of fat pigmentation in cattle, a robot to perform ellipsometry, water and alcohol repellent oven fabrics and micro and nanospheres for water treatment.

Unintended Nanoparticles – the most dangerous yet?

EVEN BEFORE ROADS WERE MADE TOWARDS USING NANOTECHNOLOGY FOR MILITARY APPLICATIONS, WARFARE HAS PRODUCED NANOPARTICLES AS A SIDE-EFFECT, POSING EXTRA RISKS TO BOTH SOLDIERS AND CIVILIANS IN WARZONES. HERE, ANTONIETTA M. GATTI AND STEFANO MONTANARI, EXPLAIN THEIR WORK IN NANOPATHOLOGY AND INVESTIGATING THE SYMPTOMS OF THE NANOPRODUCTS OF WAR.



Military Problems and Nanotechnology Solutions

Military organizations are attracted to the possibility of creating innovative, invincible, technological weapons that can be levelled against less technologically-advanced enemies, and to provide their soldiers with the most modern technologies to improve their comfort and safety in warfare. Other applications of nanotechnologies include the possibility of having lenses that are always clean, clothes that do not need frequent washing, uniforms equipped with sensors for real-time health monitoring, or miniaturised diagnostic assays for use in theatres of war, etc. All such items can help soldiers in the battlefield or during war missions.

The U.S. Army's interests in nanotechnologies started in 2003 when the Institute for Soldier Nanotechnologies (ISN) was founded, with an investment of $50 million and a staff of 150 people. The main goal was to enhance the soldiers' protection and survivability under the headings "threat detection, threat neutralization, automated medical treatment, concealment, enhanced human performance and reduced logistical footprints". Nanotechnologies indeed have the potential to offer innovative solutions to these problems. For instance, taking advantage of the incredible properties that materials exhibit at the nanoscale; the size and weight of devices that are necessary for a soldiers' daily life can be decreased from the present 100 pounds to 45 pounds. Such an advantage can dramatically improve a soldiers' performance in the battlefield.

Nanotechnology-based materials offer unprecedented possibilities for developing protective light-weight uniforms; uniforms that change colour to provide environmental camouflage; clothes that change their rigidity in case of need (for instance, the leg of as soldier's uniform can become a rigid cast for a fractured limb); physiological sensing of soldiers' condition from sensors embedded in the fabric; miniature self-powering radio tools for communications; drug dispensers embedded in clothing that can be administered automatically by a geographically distant medical doctor via radio waves; uniform, helmet and gloves that can offer highly effective protection against chemical and biological and physical agents; and so on. The applications of these novel technologies should be able to transform fatigue uniforms into battlesuits that make the soldiers all but invincible!

Other military applications can include new fuels where nanoaluminium is the catalyst rather than costly platinum; improved protective materials for tanks, airplanes, submarines or car armour plating; coatings that make vehicles invisible to radar scanning; nanocoatings for night-vision goggles; batteries that are rechargeable in a matter of a few minutes - which means a lesser quantity need be carried in the battlefield; portable laboratories; electricity supplied by nanoscale hybrid photovoltaic cells and, last but not least, in the military field, more powerful ammunition.

New "invincible munitions" are the dream of every nation for offence and defence purposes, and nanotechnology-based weapons can supply innovative solutions, but since every medal has also a reverse side, new risks may be posed by their use, not only for the soldiers themselves and the workers involved in their manufacture, but mostly for civilians and the environment. Some direct and indirect effects of these weapons are already visible, but not always universally understood.

Symptoms of the nano products of war

Presently, in the Gaza Strip, medical doctors are taking care of civilians with strange lesions due to the explosion of new "bombs". The wounded present missing lower parts of their body with sharp resections, parallel to the ground, and the cross sections of the wounds show already-cauterized vessels and flesh. The geometry of these lesions requires new solutions for their surgical treatment and ensuing prosthesization. Medicine can take advantage of these new situations by being forced to contrive innovative solutions and new treatments, but the situations themselves are not something desirable for people or the environment.

A possible explanation for these never-experienced-before lesions is that a "dense fire wall" with sharp borders is generated during the bomb blast and propagated at high speed and pressure. Matter touched by this "ball of fire" is promptly sublimated and aerosolized. This effect can be generated by having a depleted uranium or tungsten ball explode, generating nanoparticles. Other innovative weapons used in current conflicts can theoretically be identified, if you look for the effects they produce. A trace, even if just at nanoscale level, can always be determined and recognized.

Nanopathology – the study of the effects of nanoparticles formed by high temperature

If engineered nanoparticles and nanotechnological tools are in the spotlight, the non-engineered ones, though much more numerous and with little-known consequences on health, lie in the shadows. Nanosized particles, unintentionally released by high combustion processes, are already present in the environment, as well as in the bodies of living creatures, including humans. A new word for this situation "Nanopathology" was invented in 2002 to describe the harmful effects brought about by the interaction of micrometric and nanometric particles with organs, tissues and cells.

To briefly explain the effects of those particles, it must be realized that they are extremely fine and light and, because of that, they behave very much like a

gas. For that reason, they are inhaled along with air, and can reach the pulmonary alveoli and enter the blood stream in about one minute. A similar situation exists with particles ingested with the vegetables they fall upon. Once that particulate matter is in the blood, it can trigger an abnormal coagulation phenomenon and form thrombi that embolize in the lung circulation, if all that takes place in the veins; or migrate virtually to any organ where they cause infarction, if within the arterial circulation. Unfortunately, most inorganic particles cannot be biodegraded or eliminated by the organ they have reached, so they stay there forever and, after having concentrated, induce granulation of the tissue that may possibly grow into a cancer. Inorganic, non degradable particles are also known to be endocrine disruptors.

The first group of patients already recognized as affected by nanopathological symptoms are soldiers. As soldiers are subject to health checks before being sent to fight or engage in peace-keeping missions, it is possible to demonstrate their state of health, exposure to "war pollution" and the onset of the symptoms while they served, or immediately after being repatriated. The symptom evolution can be different depending on concentration, size, chemical composition, and uptake velocity of the particulate pollutants.

Gulf War and Balkan Syndromes

In 1991, during the first Gulf War, a few soldiers, who apparently did not suffer from visible wounds, returned home after just a 6-month mission and started to die. At the beginning, the symptoms were not severe and not clearly understood. The analysis of the symptoms did not help in diagnosing a single, clear pathology. A new phrase was invented for this: Gulf War Syndrome. After a while, another new phrase was coined: The Balkan Syndrome, to describe a new collection of symptoms that affected some of the soldiers who were deployed in the Balkans during the recent war. Also in that case, the symptoms, although not severe in the beginning stages, grew in severity with time, and were inexplicable.

As a rule, soldiers left in perfect health, a condition certified by the clinical files concerning the examinations performed before the mission - and, in any case, a soldier on active service must be in good health. But, after a comparatively short time in the battlefield or in a bombed environment, they may start to show symptoms, sometimes trivial, but growing more and more serious and, after a few years, may even prove fatal.

Gulf and Balkan Syndromes do show some differences, and this is particularly important as a clue, because it means that, though the activities undertaken were unquestionably similar, there was something that made them somehow different. In the case of the Balkan Syndrome, the media blamed the depleted uranium used in the weapons and its radioactivity as the cause of the illnesses or, at least, an aggravating agent, but that was only a superficial analysis that could never be proved in a scientific way. Something more serious and logical occurs in environments devastated by bombing.

According to the Nuclear Regulatory Commission, Depleted Uranium (DU) ammunition contains less than 0.711% of Uranium-235, and its radioactivity is very low. Even if the global quantity of DU weapons released was far from negligible, radioactivity was spread across a wide territory and, except in some restricted areas, there was no cumulative effect, as the United Nations Environment Programme showed in their reports after a campaign of investigation in the territory after the war. So, another explanation must be looked for.

Some nations tried to explain the mysterious diseases considering different possible agents like, for example, multiple vaccinations, sprays of various chemicals in tents, and drugs against the effects of biological weapons, but no proof was ever found to support such hypotheses; also because many patients, mostly civilians but also soldiers, did not receive any vaccination nor lived in tents nor took any such drugs.

Investigating the causes

At the initial stages of our study into these diseases, we developed an innovative investigation technique, performed directly on the soldiers' pathological samples. We wanted to detect and identify the DU debris, starting from a practical hypothesis that only if the radioactive particulate matter was inside the body, could it trigger the disease. As a matter of fact, we never found DU particles in the pathological tissues, but, instead, found something else: micro and nanosized particles with chemical compositions that we had reason to correlate with the effects of explosions of high-technology DU and tungsten-based weapons.

When a projectile is launched, its pointed penetrator can pierce relatively thick armour plates or virtually any other target, and the ensuing explosion results in part of the material involved being vaporized, as the temperature induced is in the range 3,036 – 3,063 °C. After sublimation, everything present in the vapour gives rise to an aerosol rather than to condensation dust, and because of the very high temperature, is often of nanometric size. The chemical composition of those particles is the result of the fortuitous combination of the elements present in the occasional crucible represented by the target and, on a much smaller scale, by the bomb itself. This effect was clearly investigated by researchers of the Military Base of Eglin (Florida) in a report dated November 1978. They measured submicronic particles

(0.3-0.5 micron sized - at that time the word nanoparticle was unknown) and even more than 30 years ago the researchers involved expressed concerns about these airborne particles and their possible inhalability.

The main factor affecting the size of that particulate matter (sometimes within the order of magnitude of the tens of nanometres) is temperature; and, as a general rule, the higher the temperature, the smaller the particles. As a consequence, the particles generated close to the core of the explosion will be smaller than those formed in a more peripheral area. Similar results occur when a great quantity of conventional ammunition is used, an event common when weapons are disposed of, and that is done by setting them off, or when an accidental explosion occurs in an arsenal.

It is reasonable to think that the chemistry of the airborne pollution changes from place to place, and is mostly related to the material the target is made of. The evidence we found consistently in the pathological tissue specimens of more than 150 cases of ill soldiers that were studied (also from the Second Gulf War in Iraq) is the most irrefutable demonstration of this theory.

Particles, mostly round-shaped (i.e. typical of high-temperature formation), of heavy metals and combinations of them, but also of ceramic materials like silicates, zirconia, etc., were found. Also found was debris of lead and tin, zinc-iron-titanium, bismuth, lead-bismuth, tin-silver, iron-copper-zinc, titanium-iron, silicon-zirconium, strontium-sulphur, cadmium-silicon and also, exceptionally, silicon-uranium-thorium. A new kind of environmental pollution is generated by the explosion of high-temperature weapons like those based on DU or tungsten, which never existed before as to size and composition. This pollution can be inhaled or ingested (along with polluted food) by soldiers, civilians, NGO members, journalists, animals and their fate is greatly unknown.

War and the effects of war, have been known for ever, but now one of the main differences between today's and yesterday's warfare is the submicronic-sized matter generated by the very high blast temperature of new weapons. The nanosized particles have the potential to negotiate all the physiological barriers and so reach the most intimate parts of the organism including glands, brain and gonads. Among many other effects, it means that nanoparticles can even contaminate seminal fluid that and consequently contaminate partners. A further sexual disease that can be correlated to the War Syndromes is the so-called "Burning Semen Disease" of the soldiers' wives and partners. Soldiers carry with them, to their homes, the effects of the war they fought in.

Conclusion

Novel 'nano products' resulting from new weapons of war are posing real risks that are already with us. Even if governments seem to be unaware of them, society must take a stand against the many "boomerang" effects related to the serious side effects of military technologies.

In 1962, the Nobel Prize Laureate John Steinbeck said that "The ability to think differently today from yesterday distinguishes the wise man from the stubborn". We hope governments will "recognize" the pervasive and ongoing effects of new weapons and protect their people, as more harm may come about from their use than posed by the 'enemy' themselves.

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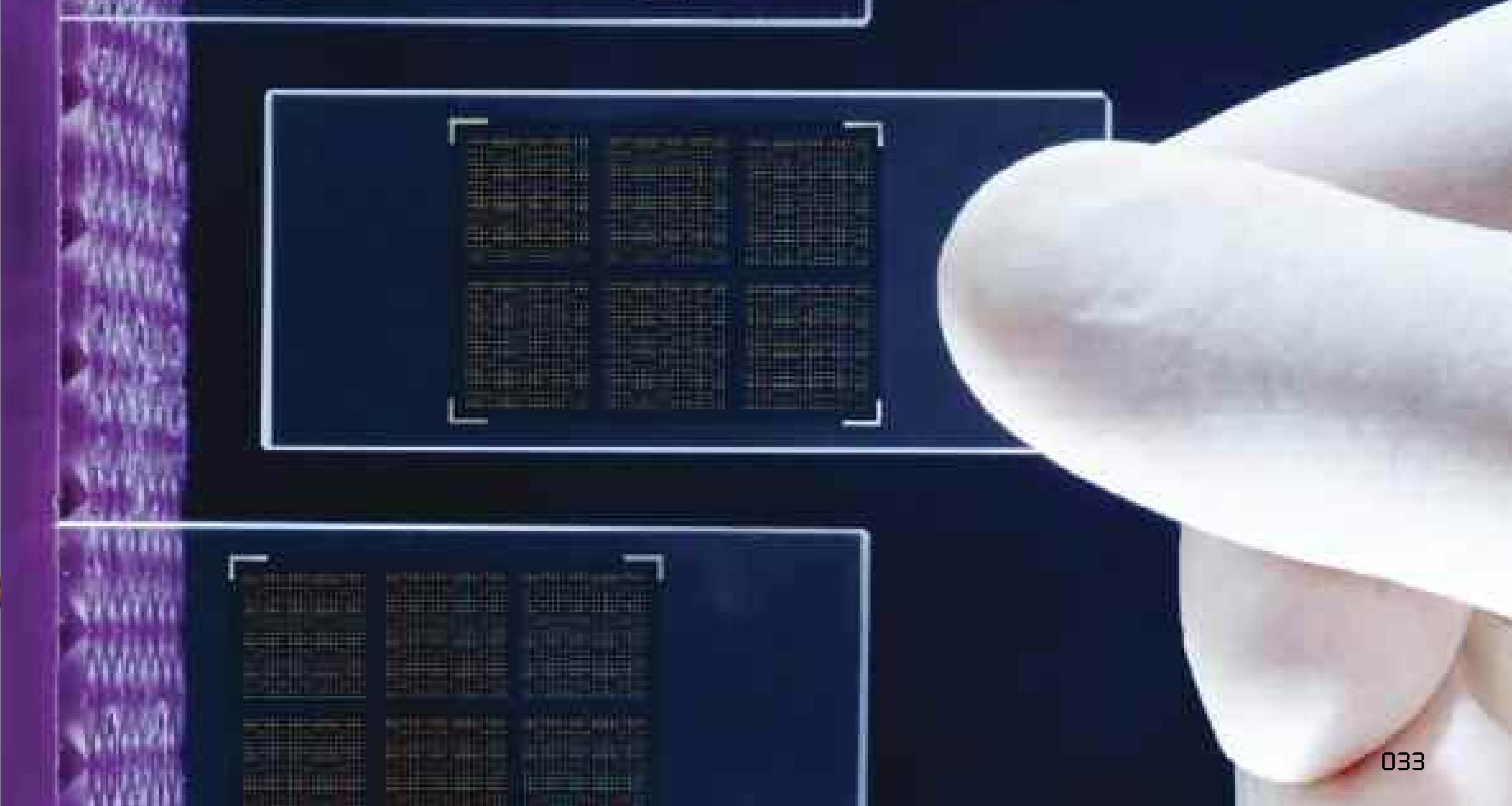
THE FIRST GROUP OF PATIENTS ALREADY RECOGNIZED AS AFFECTED BY NANOPATHOLOGICAL SYMPTOMS ARE SOLDIERS. AS SOLDIERS ARE SUBJECT TO HEALTH CHECKS BEFORE BEING SENT TO FIGHT OR ENGAGE IN PEACE-KEEPING MISSIONS, IT IS POSSIBLE TO DEMONSTRATE THEIR STATE OF HEALTH, EXPOSURE TO "WAR POLLUTION" AND THE ONSET OF THE SYMPTOMS WHILE THEY SERVED, OR IMMEDIATELY AFTER BEING REPATRIATED.

NEMS – the next revolution in miniaturization

THIS PRESENTATION ORIGINALLY DELIVERED AT A DEFENSE ADVANCED RESEARCH PROJECTS AGENCY MEETING IS PRINTED HERE, AS IT ENCAPSULATES THE HOPES VESTED IN NEMS-ENABLED TECHNOLOGIES FOR NEW SOLUTIONS TO TECHNOLOGICALLY COMPLEX MILITARY PROBLEMS.

Imagine it's just around sunset in a city in the Middle East. Daytime visibility has ended and a lone Soldier is just becoming aware of the uncertainties that darkness brings. Now imagine the Soldier blinks his eye, activating a special contact lens that allows him to see a crystal clear image of the surroundings behind him. A second blink and he sees what's ahead of him, and so on.



> WE ARE AT THE BEGINNING OF AN EXCITING NEW TECHNOLOGY ERA, THE AGE OF NEMS, AND I WOULD LIKE TO HAVE YOU THINK OF NEMS AS THE FUSION OF MEMS AND NANOTECHNOLOGY, ENABLING THE REALIZATION OF MEANINGFUL ULTRA-SMALL SYSTEMS, OR NANOSYSTEMS

A contact lens, yes, a contact lens that looks, feels, and flexes like an ordinary contact lens. But embedded within it is an invisible, high-density, nanowire display formed by an array of nanoLEDs and a set of wireless communication electronics. The contact lens is in constant communication with a dispersed network of ground-based imagers, sensors, and the Soldier's command center.

Imagine a thousand dispersed microcameras bluetoothing information to the contact lens. Now imagine yet another type of plastic-like display, one slightly larger than the period at the end of a sentence that is covertly sewn inside the eye – a vital communication display device that the Soldier knows will always stay with him even if he is captured by the enemy. This becomes a communication device that will always keep him informed of the information he needs and will let him know help is on the way.

How is this possible? It's possible because of NEMS – Nanoelectromechanical Systems, powerful integrated systems that contain nanotechnology-enabled components – components or sub-systems so small, so broadly capable, and so reliable that we dare imagine the almost impossible. NEMS is an emerging technology with the potential to dramatically alter many facets of our daily lives and will profoundly impact future military operations. It is the dawn of a new age.

The Achievements of Microelectromechanical Systems (MEMS)

DARPA is extremely pleased to have helped to create many diverse microtechnologies, the identification of new materials, and the development of processing and manufacturing methodologies critical to the development and maturation of MEMS – MicroElectroMechanical Systems. These technological advances are now being exploited or are under serious consideration for numerous applications. Among them are new or improved capabilities in a wide range of military systems, as well as in many consumer products we use every day.

In order to imagine the future, let's go back to three basic truths DARPA has learned over the last decade:

1. **MEMS enable performance**
2. **Smaller is better**
3. **MEMS are reliable**

Let's start with performance. Accelerometers, inertial guidance devices, and uncooled infrared detector arrays are outstanding examples of the controlled multi-functional integration of mechanics and electronics on a single chip. With MEMS technology, parasitic losses can be significantly reduced by closely locating a sensor and its first-stage preamplifier on the same chip. Additional bonding and attachment of these chips to other electronic and photonic building blocks – known as heterogeneous integration – enables additional performance enhancement and improves packaging. There has been progress in replacing macroscale laser ring gyroscopes with MEMS Inertial Measurement Units (IMUs). These IMUs provide significant improvements in bias stability and reduction of noise. In addition, they significantly reduce cost and have reduced physical volume. These advantages enable new applications such as personal navigation, location, and tracking for individual Soldiers.

Second, smaller is better. This has successfully exploited in the form of miniaturized systems such as chip-scale atomic clocks. And it plays out in other unexpected ways. The Micro Gas Analyzer demonstrates what can be achieved by shrinking the various types of devices associated with common instrumentation such as chemical gas analyzers. Specifically, ultra-miniaturization allows extremely high surface-to-volume ratios that afford us the unprecedented ability to preconcentrate, separate, and detect the chemical constituents in an unknown gas mixture. Potentially hazardous substances can be separated from a background of multiple inert and benign interferents at the level of parts per trillion with no ambiguity.

Not only do MEMS components such as accelerometers, navigational units, and RF switches offer significant advantages with respect to size, weight, and power consumption over their macroscale counterparts, they are also more reliable. The physical fatigue and failure mechanisms that govern mechanical behavior in macroscale materials don't seem to be as prominent in MEMS devices. Indeed, some of these devices have been cycled up and down 10^{16} times without failure! Have you ever tried to flex the tab on a beer can 10^{16} times?

Third, MEMS are reliable. The RF switches for radar applications are based on movable electrical contacts that have demonstrated reliable switching operation over 100 billion times. As Dr. John Evans in our MTO office has noted, "this is like flipping a light switch on and off once a second for over 3,000 years."

Defining NEMS

We are at the beginning of an exciting new technology era, the Age of NEMS, and I would like to have you think of NEMS as the fusion of MEMS and Nanotechnology, enabling the realization of meaningful ultra-small systems, or nanosystems. Forget the various definitions of MEMS and nanotechnology you might have heard before. If the system has a key enabling mechanical component or structure less than 1 micrometer in size and can be integrated with other dissimilar components – it's NEMS.

I would like to further define NEMS as including the integration of sensors, actuators, electronics, photonics, energy, fluidics, chemistry, and biology into a meaningful system enabled by submicrometer science and engineering precision. We also need to think about scaling. For example, what happens when the electrical domain is scaled down in size? And how do we address the challenges associated with ultrafine scaling in the mechanical, optical, chemical, fluidic, and biological domains?

The Promise of the Age of NEMS

Let's explore some of the exciting new opportunities in NEMS. The Age of NEMS and its products are surely unpredictable, but let me mention five exciting and compelling potential applications.

Nanowire enabled optoelectronic structures. First, nanowires such as nanoLED arrays might enable a new class of nanodisplays. But consider fabricating nanowires out of dissimilar materials such as gallium arsenic on silicon. The ability to realize vertical nanowires composed of metals, semiconductors, and insulators on silicon and other substrates will enable new types of high performance, heterogeneous micro- and nanosystems. And they can be formed without the usual considerations of lattice strain matching that occurs in microscale dimensions. Consider, for instance, nanowire transistors that are composed of the best materials transport properties of III-V and silicon semiconductors. Imagine high-speed, electrical isolation, and complementary metal oxide semiconductor (CMOS) compatibility all in a vertical nanometer scale post. Entirely new nano-optoelectronic structures such as nano-lasers, nano-field emitters, and nano-solar cells are also a possibility using this same vertical nanowire structure and materials and processing methods we know. Imagine replacing all the electrical interconnections on a complex chip with a reconfigurable optical router based on nanowire LEDs and lasers.

Exposure Screening. Now imagine nanoparticle optical reporter beacons that can be delivered into various regions of the cell to understand basic cellular transport mechanisms that are activated, for example, when a Soldier is under stress, has been exposed to a chemical pathogen, or is not responding in the intended manner to a medication. Now let's think about what might be achieved by bringing biology and nanowires together. For instance, the multi-material nanostructure is actually a nanobarcode formed by alternating layers of gold and silver. It's just like the barcode on the side of a can of cola but 100,000 times smaller. The nanoparticles encode specific information such as the identity of a type of biomolecule that might be attached to its surface. And, best of all, the structure is made using very simple MEMS processing methods. Consider what we might be able to do with a library of over ten thousand distinct nanobarcodes, each of which has each a unique biomolecule on its surface important to understanding an individual's current health condition. We would have a powerful system enabling a multi-analyte bioanalysis capability that can identify predisposition and early exposure to a variety of diseases. But such a multiplexed bioanalysis system might also tell you how a medication is addressing your own individual symptoms, a concept called precision medicine. Let's take this technology one step further onto the battlefield, where it could provide a means for rapidly screening Soldiers to detect early exposure to biological agents through the best sensor possible – the response of the human body.

Environmental Pathogen Detection. NEMS will also enable other important new opportunities in the emerging field of nanobiotechnology. For example, consider nanoresonators fabricated on a silicon substrate. On the surface of the nanoresonator is a small organic molecule that provides a generic attachment to a variety of other biomolecules. In this case the biomolecules are captured antibodies sensitive to Botulism Toxoid A. When just one botulism toxoid biomolecule is exposed to the surface of this device, complementary lock-and-key biomolecular binding takes place and the mass loading of the nanoresonator surface is electronically detected as a shift to a new lower resonant frequency. This ultrasensitive detection method could replace complicated optical fluorophore tags and optical readout methods routinely used by molecular biologists with a simple electrically measured parameter – frequency. A biocantilever diving board fabricated by Professor Michael Roukes at CalTech has shown the ability to detect small mass changes as low as 7 zeptograms, which is roughly the mass of a single protein molecule! We look forward to using such nanobioresonators for multiplexed detection of environmental pathogens.

Nanoanalytics to detect chemical and biological agents. Chemical and biological agent detection at safe, stand-off distances remains an important technical challenge. Conventional detection approaches usually require sample collection in the field and subsequent analysis back at a well-equipped laboratory using large instruments. In some cases, difficult optical analysis at large standoff distances, given stressing signal-to-noise considerations and false-positives, make these methods particularly problematic or virtually impossible. But what if we could bring the analysis instrumentation directly into the region to be monitored? What if the instrumentation required for rapid and accurate analysis could be made so small that it could be conveniently and covertly deployed directly in the area to be monitored? One could immediately gather critical information about potential threats. Nanoanalytics therefore represents an exciting new frontier that will enable entirely new and sophisticated instruments such as ultra-small Raman spectrometers on a chip, IR microspectrometers, nanopolychromators, and label-free nanobiological analyzers. And all of these technologies operate where the laws of physics, biology, and chemistry are scaled to their ultimate sub-micrometer limits.

Nanoassembly for building systems and components in situ. At this point you might be wondering whether the tools and capabilities required to make NEMS a reality can in fact be developed. I firmly believe that they can. And that's where, perhaps, the most important area of NEMS opportunity arises – programmable self-assembly for heterogeneous nanointegration. Let's simply call this nanoassembly – a new manufacturing paradigm that allows for the directed self-assembly of components into precise locations on a substrate. Nanoassembly might also be used to build systems on non-planar or 3D surfaces where traditional monolithic integration has failed. In other words, we let nature, not lithography, do the work of assembly, integration, and packaging of nanocomponents.

In summary, the MEMS revolution that began at DARPA in the early 1990s will continue to bring new and more powerful microsystems to the commercial world and defense community. I have no doubt that the Age of NEMS will produce exciting new capabilities we are only now beginning to imagine. And by continuing to support a wide range of high-payoff research and development efforts, DARPA intends to help turn those nanoscale imaginations into reality. n

Dr. Dennis Polla, Program Manager, Microsystems Technology Office, DARPA

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Optical MEMS	March 25	Munich	DE
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Military Nanotechnology

– New Issues for Ethical Assessment?

IN THIS ARTICLE, JÜRGEN ALTMANN DISCUSSES THE POTENTIAL MILITARY APPLICATIONS OF NANOTECHNOLOGY, AND LOOKS AT ETHICAL CONCERNS. HE DESCRIBES A FRAMEWORK FOR AN ETHICAL ASSESSMENT, AND FOLLOWS THIS WITH A DISCUSSION OF THE CURRENT SYSTEM OF PREVENTIVE ARMS CONTROL. HE ASKS WHETHER NANOTECHNOLOGY WILL LEAD TO A REVOLUTIONARY CHANGE IN THIS INTERNATIONAL SYSTEM.

Experts, as well as governments, hold that nanotechnology will bring revolutionary changes throughout society. If these changes will be as pervasive as they say, it is unsurprising that nanotechnology will be widely used in the military too – in fact, in some areas, military applications are driving research directions. Because technological superiority can be a decisive factor in war, the most-industrialised countries traditionally spend high sums on research and development of new technologies of warfare, and nanotechnology has opened up many new fields to them.

Descriptions of potential military applications of nanotechnology produce long lists of ways in which the armed forces can profit from their use in various areas. Sometimes such texts contain small hints at ethical problems, however these are rarely specified, or discussed in any detail. Even the research into the ethical, legal and societal aspects of nanotechnology leaves a big gap concerning military uses.

Military Research and Development of Nanotechnology

Following its general goal to use science and technology for "military superiority to defeat any adversary on any battlefield", the USA is investing the most heavily in military nanotechnology. Since the beginning of the National Nanotechnology Initiative (NNI) in 2001, one quarter to one third of its funding has gone to the Department of Defense. In 2008 this sum was $460 million out of a $1,554 million budget. Most of the money is for basic research and technology development as the development of deployable systems is not yet relevant. (There are exceptions where nanotechnology is already used, such as sub-100-nanometre semiconductor chips and in some nanoparticle preparations.)

The USA is alone in spending such a large share of government nanotechnology support on military application. Many other countries have started military nanotechnology programmes, too, but at markedly lower expenditure. Budget figures are only available for some (Great Britain, Netherlands, Sweden), but it is reasonable to assume that countries such as France, Israel, India, Russia, China and Iran spend not hundreds of millions of dollars per year, but rather millions, only very few transcending ten million. This means that the US funding represents 80-90% of the world total, clearly more than the 66% US share in overall military research and development. Should other countries follow the US precedent and increase their military-nanotechnology efforts, perhaps when the first new weapons systems have been fielded, the ratio of the US spending in the world total will decrease, maybe to the (not so) "normal" overall value. Certainly China and Russia are very potent actors in nanotechnology; they would be able to follow a US lead in nano-enabled weaponry with only a few years delay.

Potential Military Applications of Nanotechnology

For military uses, nanotechnology will provide many fundamental capabilities. Most relevant are the following areas:

- Materials: Nanoparticles can make composites more flame resistant and electrically conductive. Composites with carbon nanotubes promise much higher strength with markedly lower weight. With integrated sensors and actuators, smart materials can monitor their condition and modify their properties accordingly.

- Information and communication: Electronics in processors, memory etc. will continue to shrink in size, leading to further big increases in computing power in ever smaller components. This opens the possibility for more intelligence onboard uninhabited vehicles and in munitions. Nanostructures can be used for flexible displays, for antennae conforming to airframes and wings, for optical processing and ad-hoc wireless networks.

- Energy conversion and storage: Fuel cells and batteries will gain in efficiency from electrode nanostructures, as will solar cells with quantum dots; organic solar cells will be cheaper than silicon-based ones. In small amounts, energy can be harvested from movement or body fluids. Nanoporous material could be used for hydrogen storage.

- Engines will profit from nano-coatings allowing higher temperature and thus increased efficiency.

- Sensors and actuators: Nano-sized components will enable very small sensors for temperature, pressure, light measurements etc. Functionalised quantum dots or cantilevers can detect explosive vapours, chemical or biological agents with high sensitivity and specificity. Actuation can use piezoelectric material or electroactive polymers.

- Biological principles/systems, medicine: Nanotechnology will help in the understanding and mimicking of biological systems and will provide new means for their manipulation. Important areas are nanoparticles (for easier entry into the body, for selective targeting of organs and release of agents) and implants for contacting nerves or the brain.

In many of these areas, components and systems can become very small. These fundamental capabilities can be used in specific military systems and applications, for operations on land, at sea, in the air and in outer space. Among them are:

- guidance systems, even for small munitions;

- energetic materials (explosives, propellants) of higher energy density and efficiency;

- variable camouflage – displays, or modifiable nanostructures for optical interference, on the surface of vehicles or battle suits;
- land and sea vehicles of lower size and weight, many of them without crew on board;
- uninhabited aircraft with lower weight and higher agility;
- small satellites with capabilities for docking and manipulation or for impact;
- mini and micro-robots in all media, for reconnaissance, communication or weapons, sometimes acting as swarms;
- small arms and munitions without any metal;
- microwave and laser weapons using solid-state components;
- logistics systems with radiofrequency identification tags, monitoring of storage and transport conditions, under adaptive, autonomous control;
- new, selective chemical and biological warfare agents using principles from individualised, targeted pharmacology and therapy;
- scatterable microsensors forming a distributed network;
- soldier systems: multifunctional combat suits with processing and communication, body monitoring, brain-machine interface (at first with electro-encephalogram, later possibly invasive with electrodes in the brain), protection against chemical/biological agents and bullets, thermal regulation;
- body manipulation: modification of the biochemistry, tissue engineering, "smart implants" – for healing/repair or enhancement.

For most of these applications, it will take ten years to reach a stage where they can be deployed, some may take twenty or more. Not all such ideas need become successes – for example, power for small systems may remain a hurdle.

A Framework for Ethical Assessment

What kind of ethical problems could arise with military uses of nanotechnology? Obviously, the military are about intentional killing and destruction, so the normal framework of risk assessment and regulation - to avoid or at least minimise damage and death - as used for new technologies in the civilian realm, cannot be applied.

It is self-evident that an approach that essentially assumes "what is good for our armed forces is good for the world" is deficient.

Often, the ethical assessment of military issues uses the criteria of 'a just war'. They ask when it is morally justifiable to start a war (*jus ad bellum* – these criteria are soft and open to interpretation) and how a war is to be waged (*jus in bello* – these criteria are similar to the international law of warfare which holds strictly for all warring parties, independent of whether the war is just or not).

The criteria for starting a war demand:

- there must be a just cause (for example, defending against aggression);
- the war must be the last resort;
- the decision has to be made by a proper authority with a public declaration;
- the state must have the right intention;
- there must be a reasonable probability of success;
- the means must be proportional to the end.

These criteria have not yet been operationalised in a judicial sense (e.g. what constitutes aggression justifying armed defence?) and can be interpreted politically in widely different ways.

The criteria for behaviour in war centre around two requirements:

- Armed forces have to discriminate: only combatants and military installations are legitimate targets of attack. Civilian persons and installations are to be protected (even though some collateral damage is acceptable).
- The amount of force used must be proportional to the military goal.

These requirements are legally firm, and regulated in impressive detail in international humanitarian law.

According to the theory, all criteria have to be fulfilled in order to call a war 'just'.

Because the just-war theory asks when a war is justified, it does not give much thought to war prevention. In particular, systemic issues on the international level are not taken into view. An ethical judgement on war and peace thus has to be broadened.

A systematic framework for assessing new military technologies has been developed within the concept of preventive arms control. A technology is to be evaluated against three groups of criteria:

I. **Does it endanger arms-control and disarmament treaties? Does it bring problems for the international law of warfare? Can it be used for weapons of mass destruction?**

II. **Will it destabilise the military situation between potential adversaries? Will it lead to a technological arms race? Is it prone to proliferation?**

III. **In peacetime, does it bring dangers to humans, the environment or society?**

Whenever the evaluation is negative in one or more of these criteria, then considerations about preventive limitation should be made. At which stage should a prohibition hold (development, test, acquisition, use)? How should civilian uses be treated? What verification methods can be used?

Preventive arms control works by international treaties. Prominent precedents are the Nuclear Nonproliferation Treaty, preventing access to nuclear weapons for the states that do not have them; the Test-Ban Treaties, prohibiting tests of nuclear weapons; the Chemical and the Biological Weapons Conventions, which ban not only the acquisition and use, but also the development of these weapons.

Preventive Arms Control for Nanotechnology

Concerning nanotechnology, one can argue that more precise weapons with smaller payloads and destruction areas improve the discrimination capabilities of forces and decrease collateral damage, fitting to the jus in bello. However, if seen in a wider, systemic view, including thoughts about the propensity toward war, quantities of weapons, stability in crises etc., the judgement becomes more ambiguous. Similarly, better protection of one's soldiers – at first sight purely

defensive – can be part of a more offensive posture.

When one assesses only the direct effects of potential military applications of nanotechnology, there are only two categories that get mainly positive marks: sensors for improving treaty verification and systems for warning, protection and mitigation of terrorist attacks. Most areas receive neutral or mixed evaluations, in particular the generic ones. A few applications turn out highly problematic. New chemical/biological agents would violate the existing conventions. Armed uninhabited air and space vehicles can endanger stability in a crisis. Small missiles, aircraft and land robots can present potent tools for terrorists. Body manipulation for soldiers pre-empts a broad societal debate whether such operations should be allowed at all.

It is for these latter applications that preventive arms control is recommended. To avoid difficult definition issues and too intrusive verification, prohibitions should not be linked to nanotechnology as such, but to military systems characterised by externally observable properties.

In some areas, existing regulation just needs to be adapted or strengthened: In the Treaty on Conventional Armed Forces in Europe, the definition of a main battle tank can be modified to comprise vehicles below 16.5 tons; smaller land vehicles and light-weight aircraft can be introduced as new categories (and similar treaties should be concluded for other regions of the world). The global Biological Weapons Convention needs augmentation by a Compliance and Verification Protocol even without nanotechnology.

In other fields, new regulation is needed: Small-satellite weapons are best outlawed in the framework of a general ban on space weapons which the international community has demanded for decades. Bans on armed uninhabited (land, air, sea) vehicles and on very small vehicles need specific, new agreements, as does a moratorium on non-medical body manipulation.

Nanotechnology: Making a Revolutionary Change in the International System of Arms Control

Given sufficient political will, preventive limitations along these lines can work for the next one or two decades, with verification mainly relying on traditional forms of on-site inspections. However, as nanotechnology and the other converging technologies advance, the problems of limitation, and in particular verification, will become increasingly difficult. Technologies and systems will become cheaper and more wide-spread, objects will become drastically smaller, civilian products can be more easily converted for hostile uses. Production of dangerous things could take place in small buildings and potential actors could be counted in millions. Verification of compliance with prohibitions would need extremely intrusive inspections, virtually anytime, anywhere, using any possible tool.

Would this be compatible with military secrecy, as needed for successful combat? If not, then international regulation becomes impossible, and the world will have to face unprecedented threats from armed forces or terrorists. For example, military systems could be infiltrated covertly by micro-robots for later paralysis. Mosquitoes could carry spy equipment or inject lethal poisons. "Molecular hackers" could synthesise unknown infectious agents. Politicians could be assassinated by 10-cm, target-seeking missiles.

Alternatively, the international community could take this perspective as sufficient reason to begin a fundamental change in the international system. For their security, countries would no longer rely on their own armed forces, instead creating a democratically controlled overarching authority with a monopoly of legitimate violence, similar to the way in which the security of citizens and provinces is ensured within countries today. This authority would have similar rights of inspection and action worldwide, as national authorities now command inside their borders. In the long term, an ethical approach to potential hostile/military uses of nanotechnology may demand far-reaching political changes to a global security system, in which the abolition of nuclear weapons will also become possible.

At present, ethical considerations should lead to preventive prohibition of the foreseeable, most dangerous military uses of nanotechnology. Simultaneously, all steps toward strengthening civil-society elements in the international systems should be supported.

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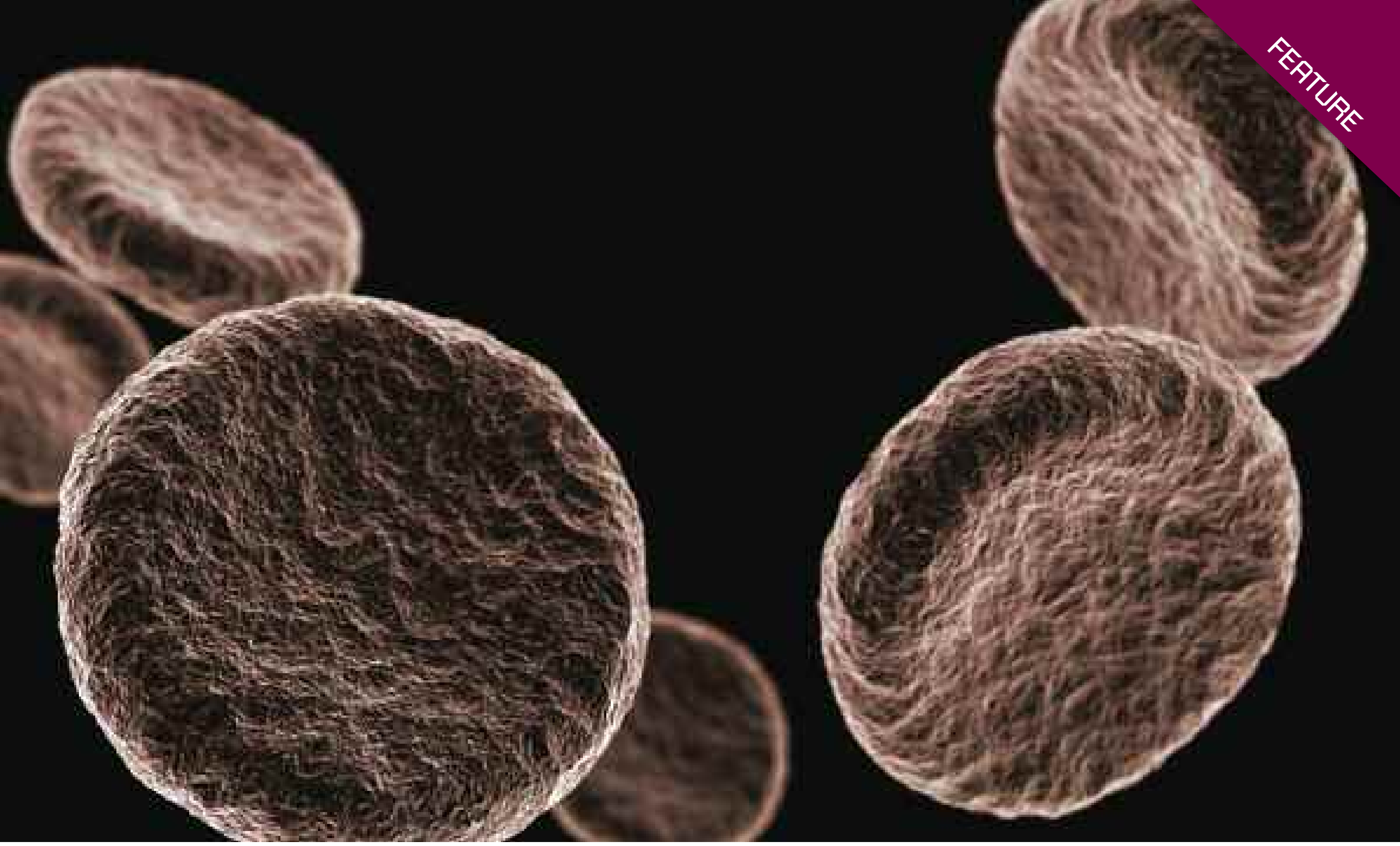


'Star Trek' Magnetic Nanoparticles

THE IMPORTANCE OF EARLY DIAGNOSIS OF DISEASE AND CANCERS TO EFFECTIVE TREATMENT IS CLEAR. HERE, CATHERINE BERRY LOOKS AT THE POTENTIAL OF MAGNETIC NANOPARTICLES TO ACT AS HIGHLY SELECTIVE TREATMENTS FOR DISEASE COMBINING BOTH THERAPY AND DIAGNOSIS.

Nanotechnology plays an increasingly important role in molecular diagnostics, in vivo imaging and improved treatment of disease. In particular magnetic nanoparticles have become important tools for the imaging of prevalent diseases, such as cancer, atherosclerosis and diabetes. First generation nanoparticles were generally nonspecific, however more recent multi-functional particles are hailed as being the future of both therapy and diagnostics, as novel 'theranostic' delivery platforms.

The problem with most frontline disease treatments today is that they are not selective enough for the diseased tissue or cells. Furthermore, the possibility to perform an early diagnosis is among the most important goals in medicine, particularly cancer. For example, most current cancer diagnoses rely on the detection of tumoral markers in the bloodstream; or on investigation technologies (TAC, PET, MRI) based on relatively toxic contrast agents, having low resolution, and offering diagnosis often only when the disease is at an advanced stage. Thus, the availability of a methodology to specifically detect diseased cells, monitor their distribution and deliver accurate therapy in situ would represent an invaluable tool.

The design of a multifunctional theranostic nanoparticle which can target a disease site within the body and allow for that site to simultaneously be imaged and deliver therapy, is a large challenge, but it is evident that such multifunctional particles can be created successfully. For example, viral particles have these very characteristics. One of the main forerunners in this area is magnetic nanoparticles (mNPs). The usefulness of mNPs is mainly derived from their small size that allows ubiquitous tissue accessibility, their large surface area for functionalising with various ligands, and their unique nanoscale magnetic phenomena which enables them to be remotely directed via a magnetic field.

Metal oxides, in particular iron oxide, have been used since the early 1960's for magnetic separations. Around 1978 mNPs were used for magnetic resonance imaging (MRI). Over the course of the following three decades, numerous preparations of mNPs

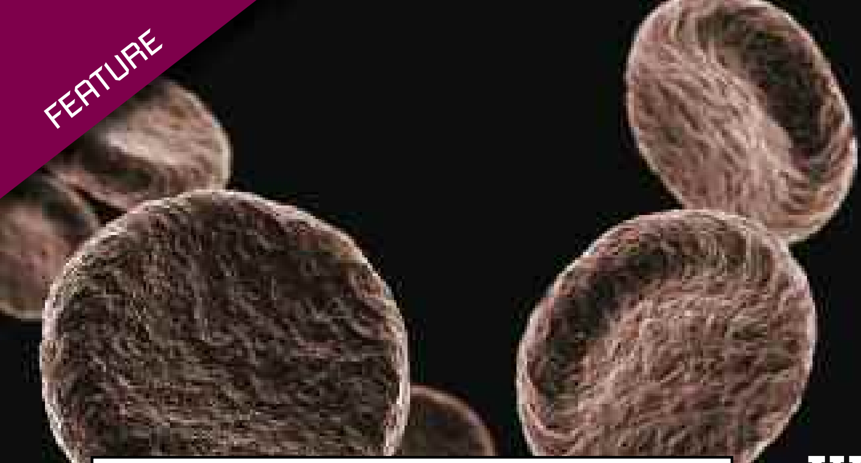
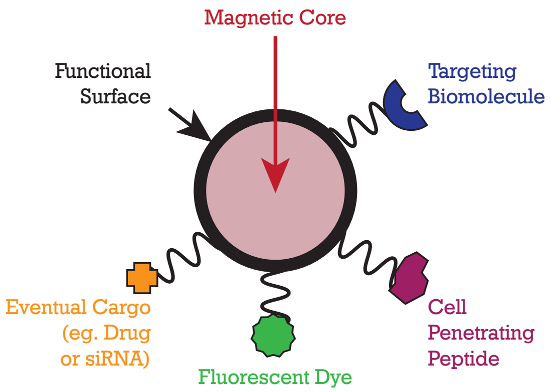


Figure 1. Schematic of the proposed multifunctional magnetic nanoparticle depicting the magnetic core and functional surface whereby the specific groups will be attached to the particle, and each functional addition.



What is Theranostics?

Theranostics is a relatively new term. It refers to research in medicine to combine the dual benefits of "therapy" and "diagnostics" in the one system to the advantage of patients. It refers particularly to imaging techniques for diagnosis to aid in the targeted delivery of drugs, the tracking of their distribution and monitoring of their effects on disease and patient. The aim is towards a more personalised way of targeting the needs of individual patients in individual cases. By allowing the study of the effectiveness of treatments on patients it will permit quick response to adverse affects or irresponsiveness to drugs whilst aiding drug development by identifying those likely to benefit from new drugs.

have been reported and used in cellular therapy, tissue repair, drug/gene delivery, hyperthermia, and MRI. When considering their biological use, mNPs must be stable in aqueous solutions and non-toxic, while exhibiting a responsive surface for functionalisation. To achieve this, the particles require sophisticated coatings. While many coatings have been tried, most clinical preparations (eg. Ferridex, Combidex and Resovist) have been based upon dextran or a similar carbohydrate coating. Dextran-coated iron oxide mNPs have become an important part of clinical cancer imaging, able to better delineate primary tumours and detect metastases.

The physical characteristics of mNPs also affect their in vivo performance. Surface morphology, particle size and surface charge are all considered important factors that determine pharmacokinetics, toxicity and biodistribution. The overall particle size must be small enough to evade uptake by the reticuloendothelial system (RES; phagocytic cells residing in tissues forming part of the body's immune system), but large enough to avoid renal clearance. It has been reported that larger-sized nanoparticles are eliminated from the bloodstream faster than smaller sized particles, leaving an ideal-size window of between 5.5 nm and 200 nm. Many such studies have reported greater than 75% uptake of mNPs by the RES, particularly by the liver, where it has been suggested that the Kupffer cells can degrade most of the iron into ferritin. When considering the use of multifunctional mNPs, an ideal size would be between 20 and 150 nm diameter, thus allowing for carrier payloads of several tens of thousands of molecules associated with each particle.

Historically, the impermeable nature of both the plasma and nuclear membranes hinder potential uptake. Researchers combat this by developing techniques to enhance cellular and nuclear uptake. Current ongoing studies in the Centre for Cell Engineering (CCE) are concentrating on two currently popular methods; using external magnetic fields to remotely control particle direction or functionalising the nanoparticles with a cell penetrating peptide (CPP); both of which facilitate cell entry. Magnetic force manipulation is currently used commercially as a means of increasing cellular uptake (magnetofection; Chemicell.com) and in clinical cancer drug trials as a means of remotely controlling site delivery for drug administration. Meanwhile CPPs are a family of proteins defined by the presence of a domain conferring the ability to cross the plasma membrane, termed the 'protein transduction domain'. By using this domain, CPPs are taken into cells via what appears to partly be a receptor-independent pathway. The 1988 discovery that purified HIV found transactivator of transcription (tat) peptide could induce transcription in cell culture, and led to its classification as the first CPP, with many other naturally derived peptides to follow. Work in the CCE has demonstrated the high efficiency of tat peptide functionalised NPs to increase cellular uptake.

Utilising such knowledge, the CCE is now focusing on the concept of theranostics. In this context, the aim of the proposed research area is the development of a variety of multifunctional nanoparticles suitable for disease diagnosis and targeted delivery for disease treatment. A variety of magnetic nanoparticles, functionalised with cell recognition markers (e.g. folate for cancer cells) and CPPs to facilitate rapid cell internalisation, are being synthesised. It is envisaged that MRI will be used to locate these nanoparticles as a diagnosis technique. In terms of treatment, the nanoparticles are also being loaded with siRNA-producing novel nanoparticle vectors, and thus offers a new methodology for gene silencing, which affects every basic and applied biomedical research field where gene knock-out, is the aim. The design of these innovative hybrid nanomaterials will allow their use in disease diagnosis and therapy, converting them into a potent tool for the emerging area of theranostics.

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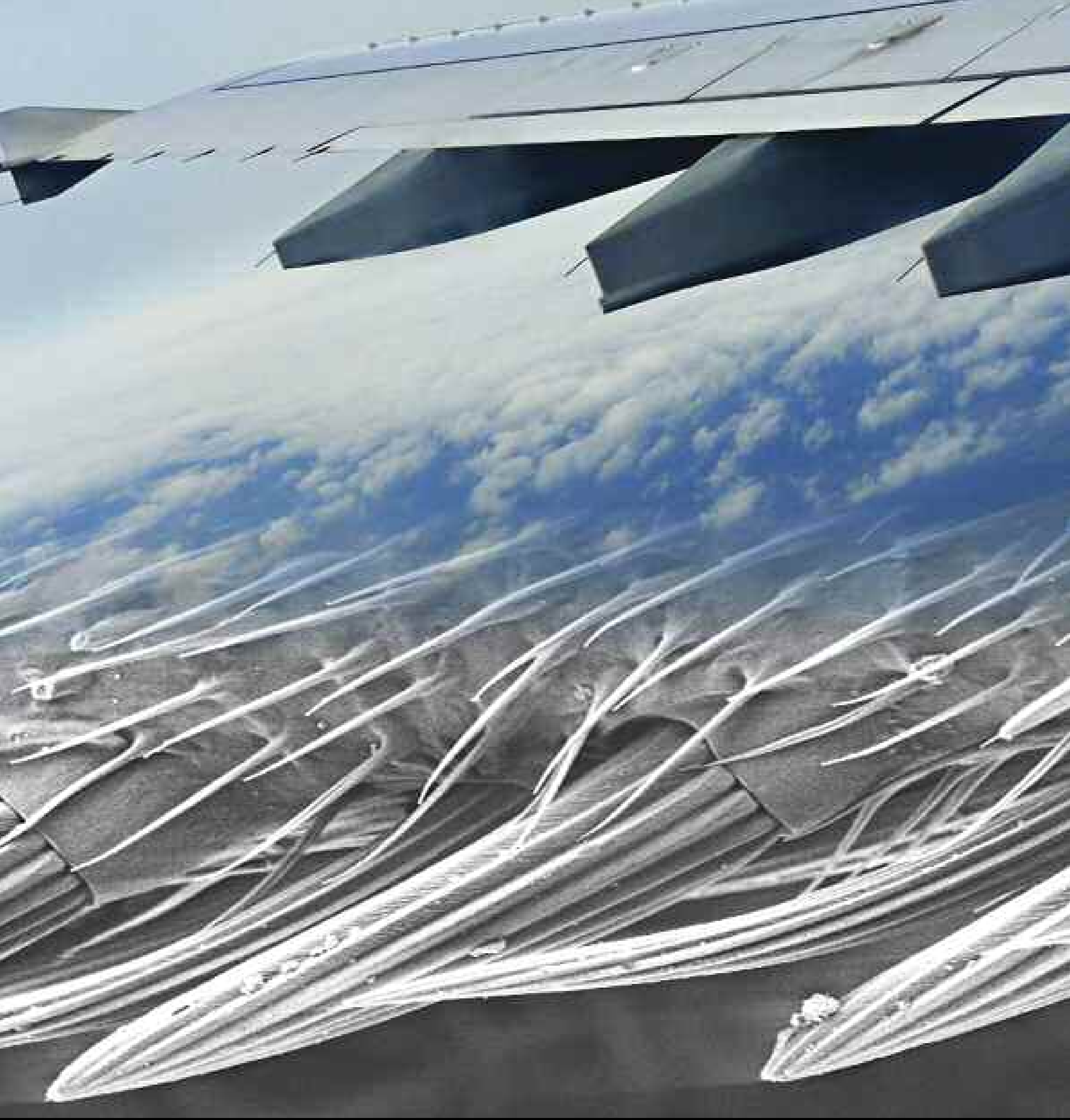
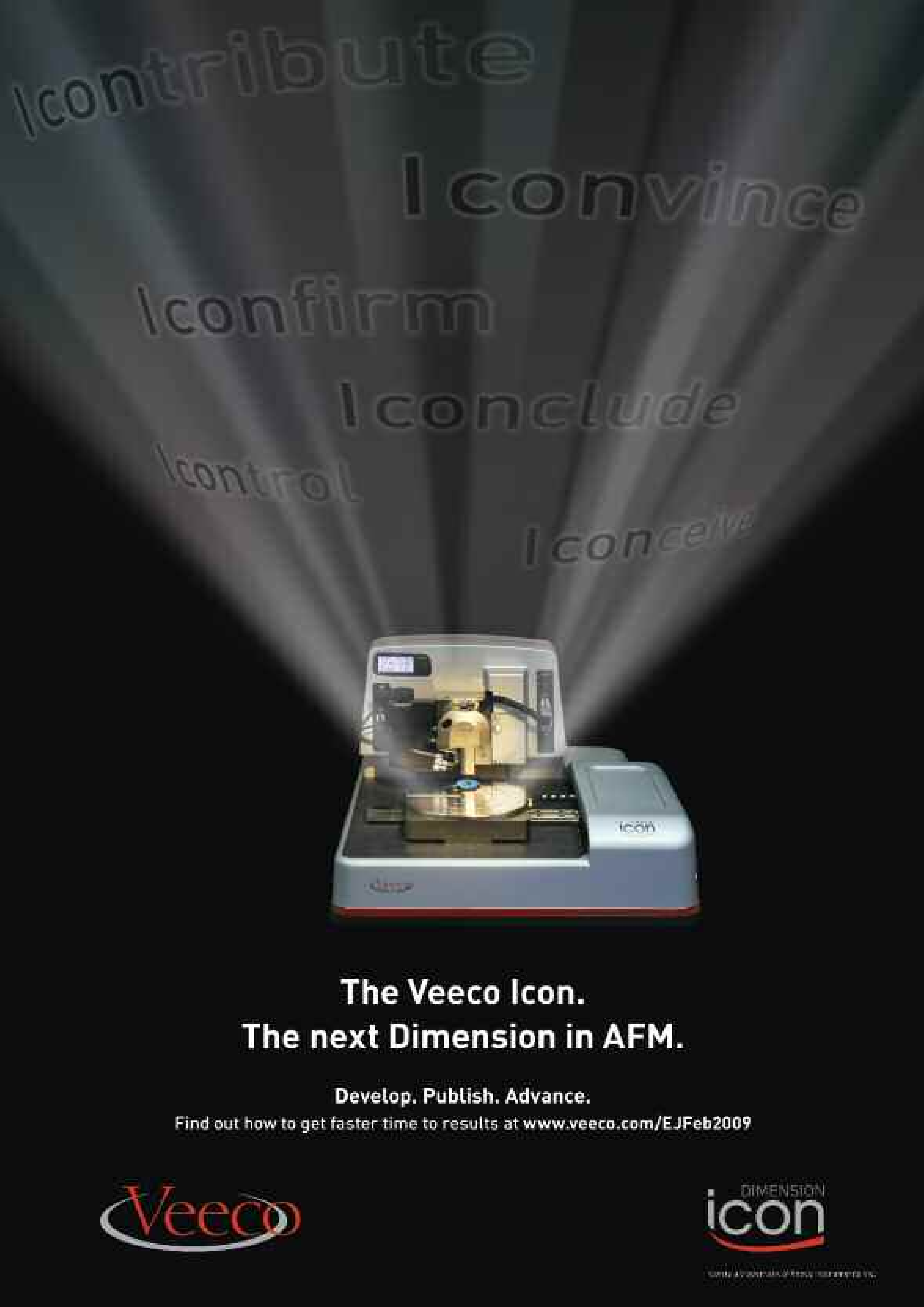


NanoArt

Eva Mutoro is a postdoctoral reseacher at the Institute of Physical Chemistry at the Justus-Liebig-University Giessen. She studied Chemistry in Germany, graduated in Physical Chemistry and received her PhD in the field of Solid State Electrochemistry. Her main research interest is to gain insights into basic electrode phenomena by combining microscopic or spectroscopic techniques with electrochemical characterisation methods in situ.

Besides her research, she is interested in (experimental) digital and analog photography, graphic design, and arts. The presented picture is entitled ‘fly away’. The composition of an aerofoil of a passenger plane (photography) and a magnified wing of a housefly (scanning electron microscopy) visualises the similarity between the macro and nano world.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