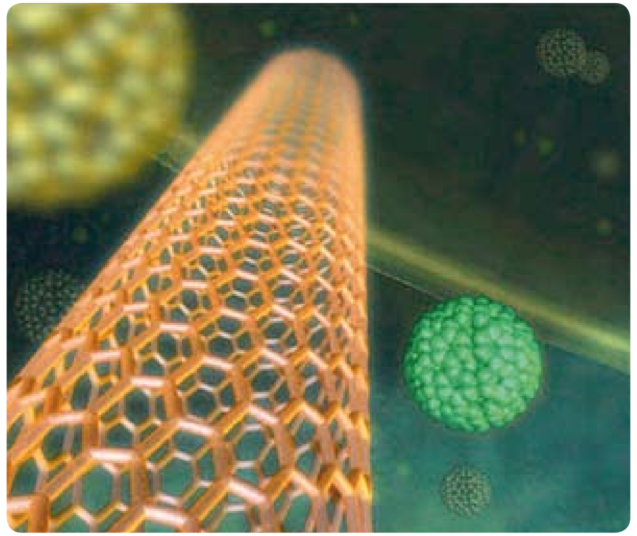
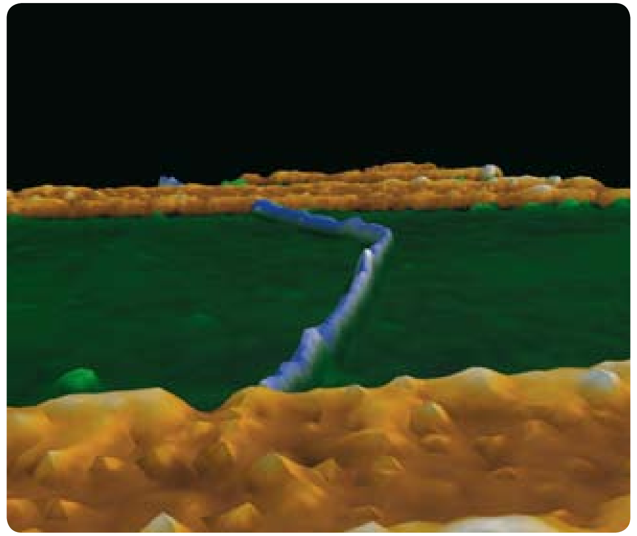
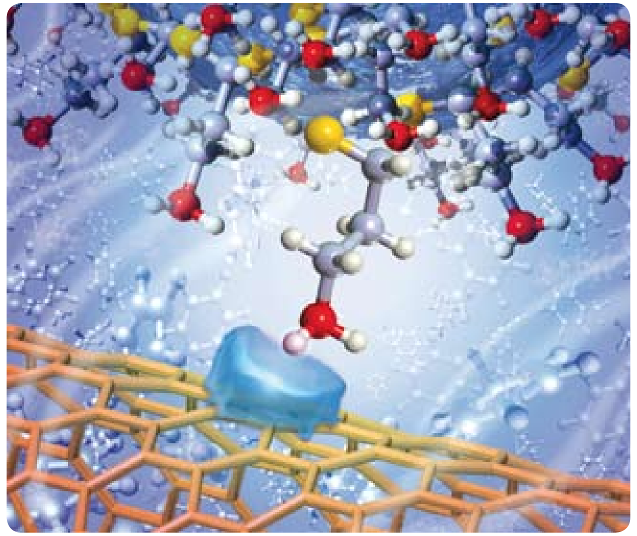
Nanotechnology

innovation opportunities for tomorrow's defence


artist impression future warfare


fullerene family


kinked nanotube on electrodes (Cees Dekker/Kavli)


molecular sensing with a nanotube

Hope and hype of nanotechnology

"Nanotechnology is an area which has highly promising prospects for turning fundamental research into successful innovations. Not only to boost the competitiveness of our industry but also to create new products that will make positive changes in the lives of our citizens, be it in medicine, environment, electronics or any other field. Nanosciences and nanotechnologies open up new avenues of research and lead to new, useful, and sometimes unexpected applications. Novel materials and new-engineered surfaces allow making products that perform better. New medical treatments are emerging for fatal diseases, such as brain tumours and Alzheimer's disease. Computers are built with nanoscale components and improving their performance depends upon shrinking these dimensions yet further".

This quote from the EC's "Nanosciences and Nanotechnologies: an action plan for Europe 2005-2009" clearly indicates the hope and hype of nanotechnology, expecting to bring many innovations and new business in many areas. Nanotechnology has the potential to have impact on virtually all technological sectors as an "enabling" or "key" technology including medicine, health, information technology, energy, materials, food, water and the environment, instruments and security. This has lead to a rapid growth of interest and spending in nanotechnology R&D, growing with 20-40% annually over the last 6 years up to roughly 10 billion Euro (public and private) in 2008.

Impact of nanotechnology on defence

With the highly promising expectations of nanotechnology for new innovative products, materials and power sources it is evident that nanotechnology can bring many innovations into the defence world. In order to assess how these nanotechnology developments can or will have impact on future military operations, the NL Defence R&D Organisation has requested to compile a nanotechnology roadmap for military applications, including:

- survey of current nano- and microsystem technology developments in both the civil and defence markets.
- clarification of the impact on future military operations and organisation, 10-15 years from now.
- guidance on how to translate and adapt such nano- and microsystem technologies into a military context.

This book

This nanotechnology book provides an overview of current developments, expectations for time-to-market and several future concepts for military applications. The structure is as follows:

- Introduction to nanotechnology
  - what is nanotechnology, global R&D landscape, key technologies, overall prospects for defence (technology radars)
  - expected impact on future defence platforms
- Possible impact on future defence
  Sceneries with future concepts, outlook on possible future defence platforms and product concepts, enabled by nanotechnology, for:
  - land
  - water
  - air
  - urban
- Conclusions and strategy
  - civil versus defence driven developments
  - opportunities for soldier system

We hope this book will serve as a basis for further discussion and decision making on the direction of future nanotechnology developments.

May 2009, Steven Schilthuizen & Frank Simonis

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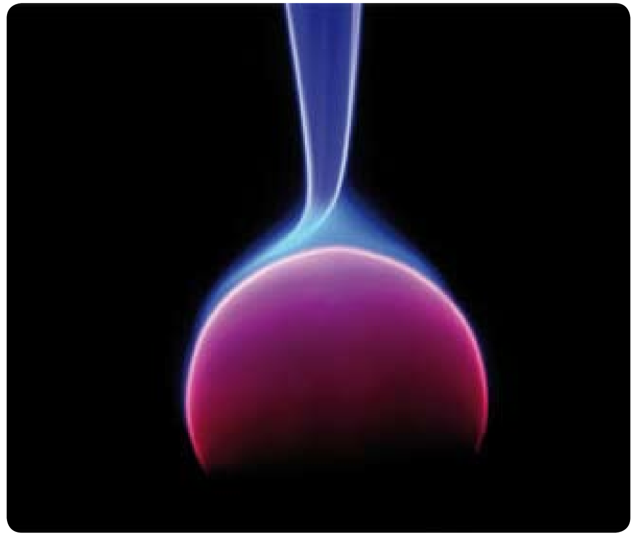
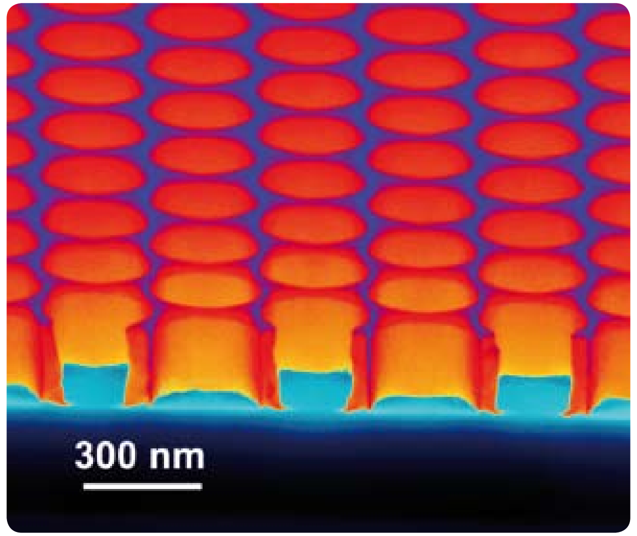
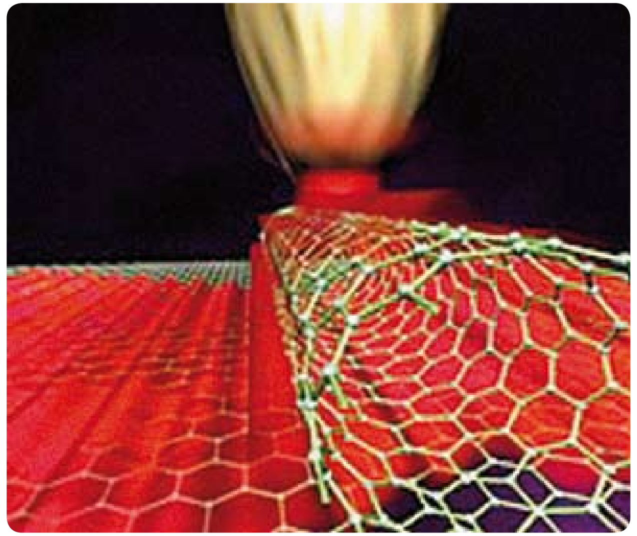


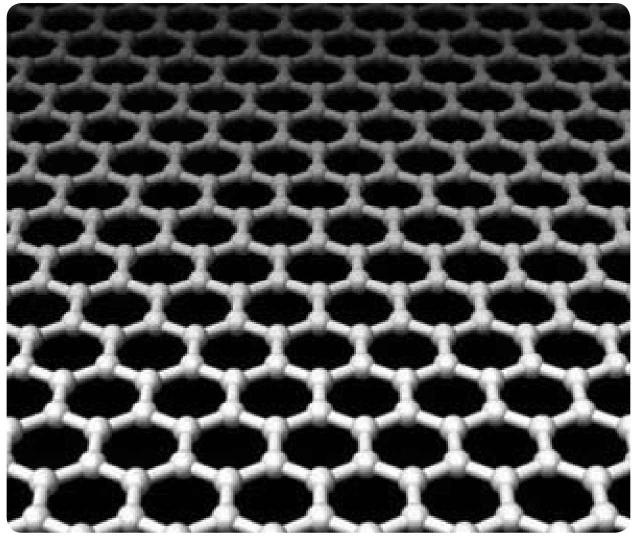
nanoenergetic particle



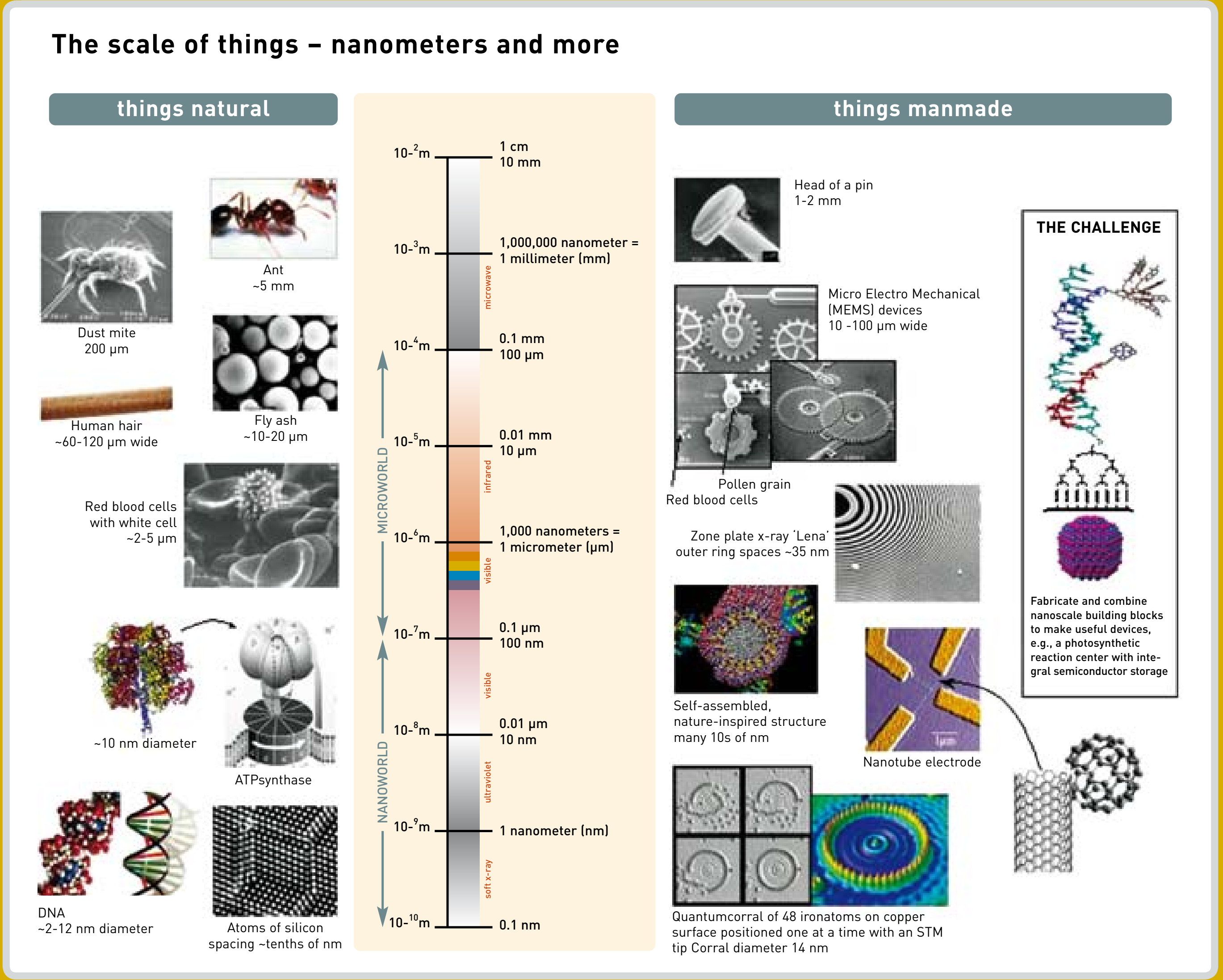
photonic crystal



AFM-tip sensing a nanotube



graphene structure



Technology at nanometer scale

Nanotechnology is the understanding, control and manufacturing of matter at dimensions of roughly 1-100 nm, where unique phenomena enable novel applications. A nanometer is one billionth (10^{-9}) of a meter; a sheet of paper is about 100,000 nm thick. Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale. At this level, the physical, chemical and biological properties of materials differ in fundamental and valuable ways from both the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices and systems that exploit these new properties. (source USA National Nanotechnology Initiative – Strategic Plan 2004)

The unique properties of nanotechnology originate from:

- small dimensions, enabling high speed and high functional density (nanoelectronics, lab-on-chip), small and lightweight devices and sensors (smart dust), high sensitivity (sensors, nanowires) and special surface effects (such as lotus effect)
- very large surface area, providing reinforcement and catalytic effects
- quantum effects, such as highly efficient optical fluorescent quantum dots
- new molecular structures, with new material properties: high strength nanotubes, nanofibers and nanocomposites

Top-down

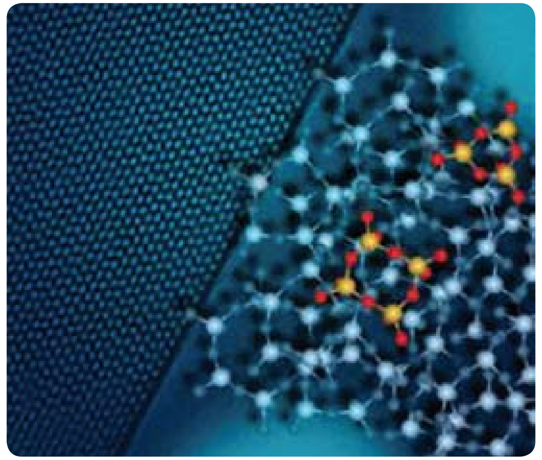
Nanostructures can be made by two complementary approaches. With top-down technology nanostructures and devices are made through scaling and miniaturization. It requires precision engineering down to the nano-scale, usually by lithographic patterning, embossing or imprint techniques with subsequent etching and coating steps. Examples are:

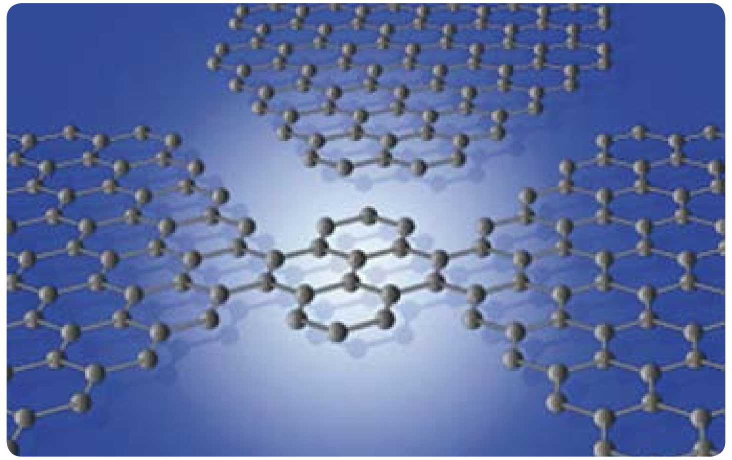
- micro- and nanoelectronics, next generation computer processors, spintronics for electronic memory
- micro electro mechanical systems (MEMS): nanoscaled chemical, mechanical and magnetic sensors
- quantum wells for photonics and light sensing
- nanostructures such as lotus coatings, catalytic surfaces and nano-porous membranes
- nanostructured coatings in displays, solar cells, flat batteries
- nanofibers by electrospinning
- nanoclay platelets and tubes by exfoliation

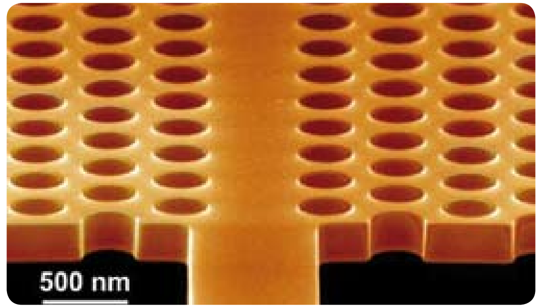
Bottom-up

The other complementary route is bottom-up, constructing nano-structures through atom-by-atom or molecule-by-molecule enginee-ring. It usually requires wet-chemical or vapour-phase processing routes such as atomic layer deposition. In some cases atomic or molecular manipulation is applied via optical, electrical or mechanical nanoprobes. Typical examples are:

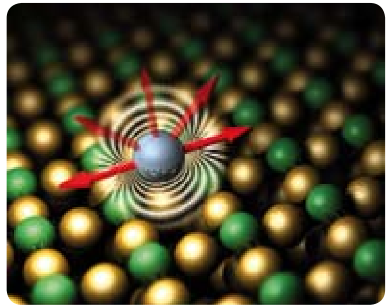
- nano carbon fullerene family: carbon nanotubes (CNT's), bucky balls and (flat) graphene by gas phase deposition. The C-C bond is typically 0.142 nm.
- other nanoparticles (metals, oxides, compounds) by gas phase deposition or fluidic precipitation
- nanowires made from metal, metal oxide, ceramic or even polymer type by gas phase deposition
- quantum dots
- self assembling, molecular and biostructures
- nanomedicine, encapsulation and molecular labellings of drugs with nanoparticles


self assembling molecular structure

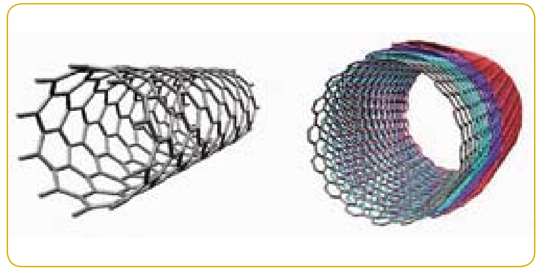

graphene transistor structure

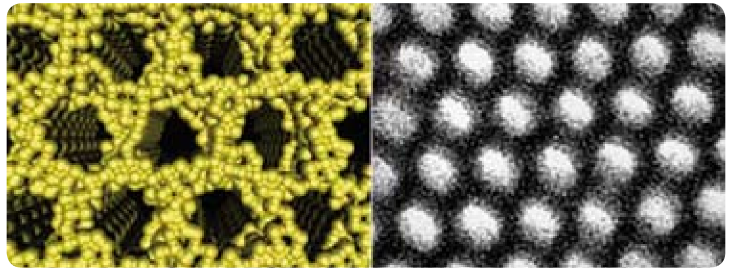


photonic crystals


atomic spin high density memory


memory resistor structure at nanoscale


single and multiwall carbon nanotube


self assembled 2 nm Pt particle structure for catalysis

Why nanotechnology

Miniaturisation down to micro & nano level not only leads to smaller products suited for mass production and lower costs, it also enables completely new functionalities that cannot be obtained at the macro level. The new functionalities are gained by physical and chemical effects of the small dimensions, the ability to produce new atomic structures, handling of very small volumes and ratio effects on the natural environment.

The unique properties of nanotechnogy originate from:

Small dimensions: mm > μm > nm

Going to small dimensions offers a large number of advantages for electronic and sensor devices:

- high speed and high functional density (nanoelectronics, high density memory, lab on chip)
- function integration: sensing, dsp, radio, memory and power can be integrated
- efficient and fast electronic, optical, thermal and material transport
- small and lightweight devices and sensors, portable, anywhere, everywhere (smart dust)
- enabling mass production, featuring low costs, lightweight, disposable
- high sensitivity (sensors, nanowires and cantilevers)
- special surface effects (such as lotus effect)

Small volume: μL > nL > pL

A small volume is especially advantageous for fluidic devices such as measurement devices and chemical processors because of:

- fast response
- high throughput
- multi parallel analysis, matrix array
- less chemical waste

Scaling sensor devices down to the nano level brings the sensing element in the same dimensional range as the elements to be detected. This results in:

- high sensitivity, towards single cell/molecule detection
- high signal to noise ratios

Large surface area, providing

- high capacity adsorption, (gas) storage and filtering
- reinforcement, diffusion barier
- catalytic effects

New material structures with new properties

- improved mechanical and electrical properties: control at the nanoscale enables perfect, defect free structures, featuring exceptional properties for mechanical strength and electrical conductivity such as high strength carbon nanotubes and spun nanotube fibers
- large interface area: nanostructures and particles create a very large surface area, featuring unique surface activity for sensing, catalysis, absorption and ability to modify the molecular structure of the matrix in composites such as in high strength and durable nanocomposites
- molecular interaction: the molecular dimensions of nanoparticles allows molecular interaction with other molecules, for use in molecular labelling, encapsulation, usage as molecular sorbent, carrier and chemical template
- new materials: completely new particles, unknown in nature, can be produced with new properties, such as carbon nanotubes, conductive nanofibers

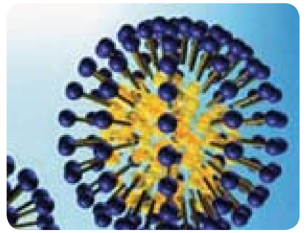
Quantum effects

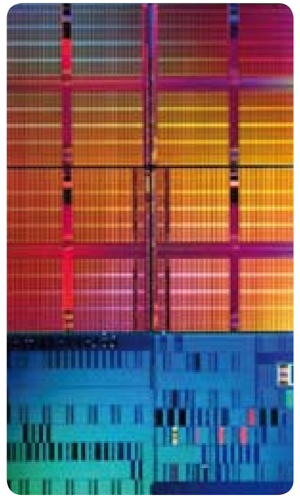
In confined spaces at the nanoscale quantum effects occur that can be used to obtain new opto- and optomechanical effects:

- quantum wells/dots for efficient single photon emission/adsorption/sensing
- high density magnetic memory
- (super) conductivity


water repellant textile

gas barrier coating in tennis balls

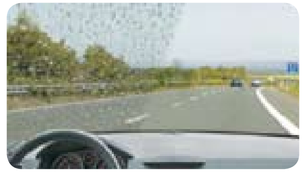

nano encapsulated medicin


45 nm processor chip

anti microbial nanosilver in wound treatment

suncreams with nano ZnO


preservation of wood


waterrepellent glass coating


anti-odor socks

lightweight tennis racket

Nano in consumer products

Anno 2009, over 600 consumer nanotech products have been registered and this number is rapidly increasing (www.nanotechproject.org).

Nanomaterials and nanostructures are being applied in consumer products mainly because of the following nanotechnology effects:

chemical reactivity

- self cleaning surfaces via photocatalytic TiO_2 nanoparticles
- water filtration with nanoporous aerogels (carbon, silica)
- UV absorption via ZnO and TiO_2 nanoparticles
- antimicrobial additives based on nano silver particles
- anti-oxidant bucky balls, radical scavenging
- hydrogen storage in aerogels and metal-organic-frameworks

mechanical strength

- high mechanical strength: nanotube fibers, nanocrystalline metals, nanocomposites
- wear and tear resistance: nanofiber and nanoclay reinforced composites and coatings
- scratch resistant coatings with SiO_2 and ZrO_2 nanoparticles

electrical properties

- transparant conductive plastics with nanotubes or graphene
- flexible electronics and displays, wearable electronics
- efficient batteries via conductive nanowire electrodes
- electrical storage in nanoporous capacitors (carbon aerogel)
- high temperature super conductive nanoparticles

durability

- gas tight packaging via nanoclay diffusion barrier composites
- anti-fouling, water repellant, non-stick lotus coatings
- UV-stability of plastics via nanoclay additives
- temperature and flame resistance via nanoclay composites

smart packaging

- nano encapsulation for tageted drug release (nanomedicine)
- nano encapsulation for smart release of nutricients (nanofood)

quantum effects

- high efficient lighting with LEDs based on quantum dots
- single photon camera systems via quantum well structures
- encryptography of optical data transfer via photonic crystals
- high density memory via quantum tunneling magnetics
- Nanotechnology products can be found in various sectors.

Health and fitness

Targeted drug delivery, skinceutical delivery (cosmetics), water repellant and self cleaning coatings, antimicrobial textile and wound dressing , UV-blockers in sunscreens, high strength/lightweight sporting equipment, air tight tennis balls, nanowax for skiing.

Food and beverage

Antimicrobial tableware, coatings and packaging, non-stick coatings, targeted delivery of food ingredients and supplements (minerals, vitamins), self signaling, long shelf life packaging materials.

Automotive

Lightweight nanocomposites, scratch resistant coatings, self repair lacquers, anti-fog coatings, nanowax and polish, UV resistant polymers, air purifiers, antimicrobial filters, catalytic exhaust converter, anti-static plastics, engine oil lubricant additives, nano silica additives for tire improvement.

Infrastructure, home, appliances

Self-cleaning glass, hydrophobic and UV-stable facade paint, thermal insulation (aerogel), antimicrobial surfaces, flame retardant coatings, Li-Fe-nanophosphate battery, fuel cells, more efficient solar cells.

Electronics

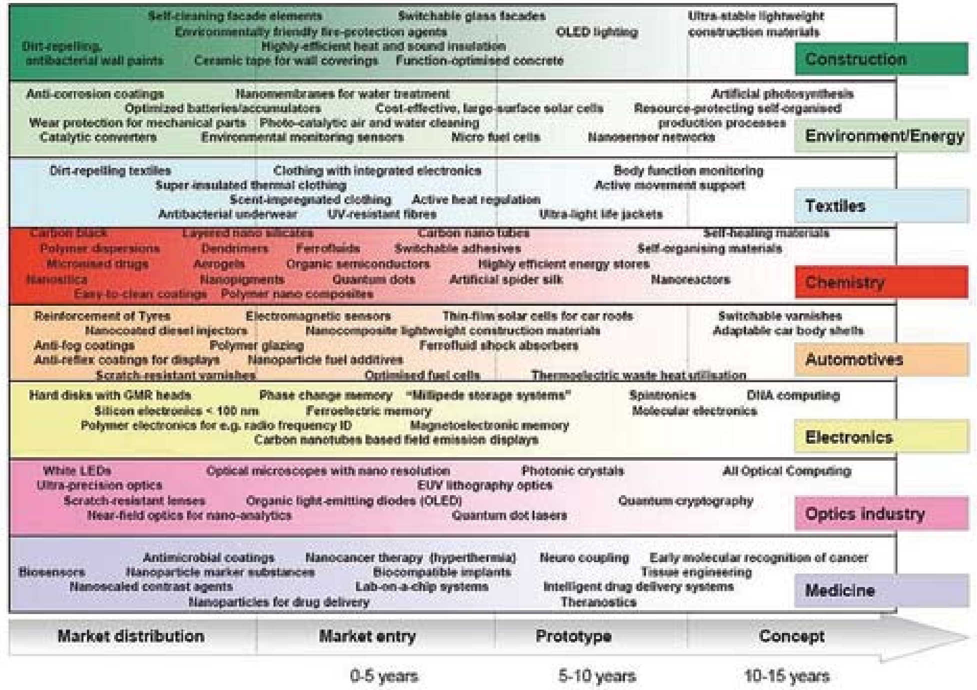
Computer processor (<50 nm transistors), high density solid state memory (optical, magnetic, electronic), transparent conductive coatings for rollable displays, flexible organic LED displays, image and camera sensor systems (quantum well based).

Energy

High strength/low weight construction materials and transport means, reduced maintenance via corrosion protection, fuel cells, thermoelectric energy scavenging, improved photovoltaics, energy storage systems (e.g. hydrogen) low weight batteries enabling electric cars.

Impact on the environment

The increasing spread of nanomaterials in consumer products has lead to significant concern about the long term effects of nanoparticles in the environment. A striking example is the indication that anti-microbial silver nanoparticles stay effective after waste disposable and may attack the natural microbial habitat. Awaiting further research, some countries have banned such products and some manufacturers have withdrawn freely their products from the market.



nanotechnology roadmap of the German VDI

The evolution of nanotechnology

Michael Rocco from the NNI and NSF (USA) expects that the development of nanotechnology will emerge and move from passive nanomaterials en nanostructures (1st phase) towards active nanostructures (2nd phase), followed by the development of nanosystems (3rd phase) and eventually molecular nanosystems (4th phase).

Passive Nanostructures (2000-2005)

As we have seen in the first period, products take advantage of the passive properties of nanomaterials. Examples are TiO2 and ZnO nanoparticles in sunscreens, carbon nanotubes to deliver greater stiffness in composites without additional weight, self cleaning and water repellent coatings on various products like glass, metal, wood and textiles. Each of these products takes advantage of the unique property of a material when it is manufactured at a nanoscale. However, in each case the nanomaterial itself remains static once it has been encapsulated into the product.

Active Nanostructures (2005-2010)

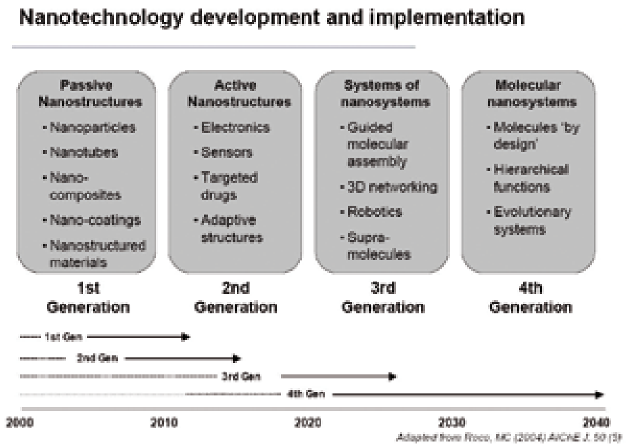
Active nanostructures change their state during use, responding in predicable ways to the environment around them. Nanoparticles might seek out cancer cells and then release an attached drug. A nanoelectromechancial device embedded into construction material could sense when the material is under strain and release an epoxy that repairs any rupture. Or a layer of nanomaterial might respond to the presence of sunlight by emitting an electrical charge to power an appliance. Products in this phase require a greater understanding of how the structure of a nanomaterial determines its properties and a corresponding ability to design unique materials.

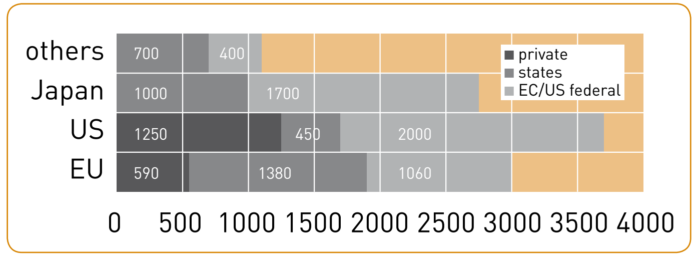
Systems of Nanosystems (2010-2015)

In this stage assemblies of nanotools work together to achieve a final goal. Proteins or viruses might assemble small batteries. Nanostructures could self-assemble into a lattice on which bone or other tissues could grow. Smart dust strewn over an area could sense the presence of human beings and communicate their location. Small nanoelectromechancial devices could search out cancer cells and turn off their reproductive capacity. At this stage significant advancements in robotics, biotechnology, and new generation information technology will begin to appear in products.

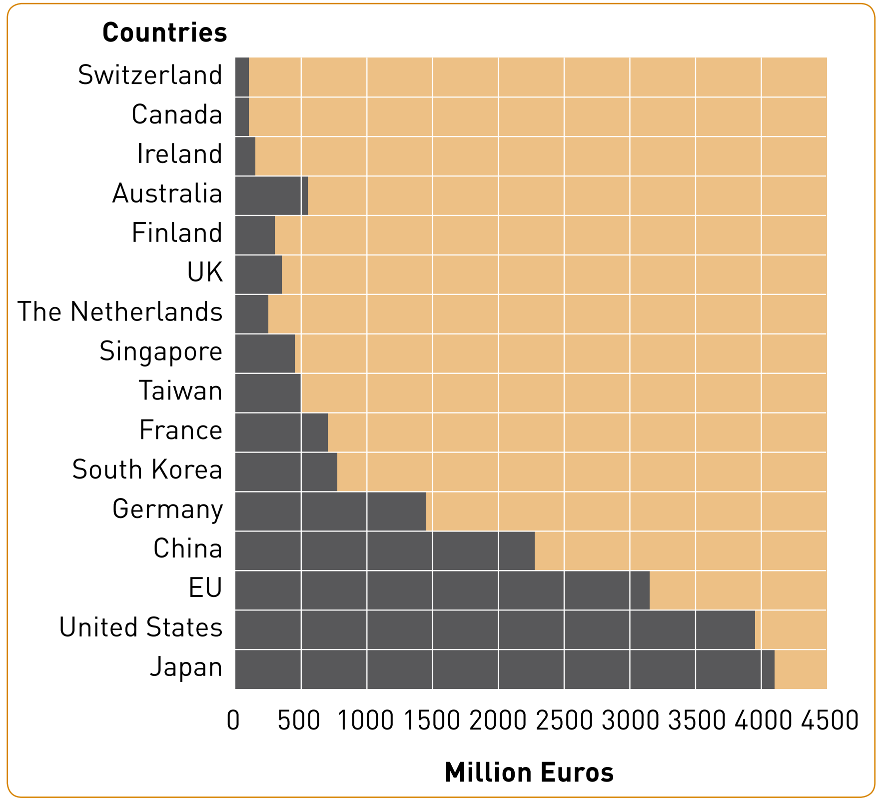
Molecular Nanosystems (2015-2020)

This stage involves the intelligent design of molecular and atomic devices, leading to "unprecedented understanding and control over the basic building blocks of all natural and man-made things." Among the examples that Dr. Roco foresees are "multifunctional molecules, catalysts for synthesis and controlling of engineered nanostructures, subcellular interventions, and biomimetics for complex system dynamics and control." At this stage a single product will integrate a wide variety of capacities including independent power generation, information processing and communication, and mechanical operation. Nanoproducts regularly applied to a field might search out and transform hazardous materials and mix a specified amount of oxygen into the soil. Nanodevices could roam the body, fixing the DNA of damaged cells, monitoring vital conditions and displaying data in a readable form on skin cells in a form similar to a tattoo. Computers might operate by reading the brain waves of the operator.





public R&D funds nanotechnology worldwide in 2005 (in M$)



public R&D funds Nanotechnology 2006-2010 (in MEuro)

No. Nanotech companies 2008

USA	946
Europe	531
Asia	206
Germany	194
UK	108
Canada	78
Japan	55
China	43
Autralia	40
Switserland	37
S-Korea	28
France	27
Finland	22
Spain	19
Danmark	16
Netherlands	15
Sweden	13
Taiwan	12
India	11
Russia	10

number of nanotech companies worldwide in 2008

Nanotechnology developments worldwide

The worldwide run on nanotechnology.

Nanotechnology is recognized as a very strong driver for innovation and is therefore seen as a strategic technology for the world's future economy. This perception is globally present and many countries invest heavily in nanotechnology through national or transnational nanotechnology programs with high technological and economical expectations.

Market for nanotech products will grow exponentially

Analysts estimate that the market for products based on nanotechnology could rise to several hundreds of billions by 2010 and could exceed one trillion after that. Nanotechnology is expected to have impact on virtually all technological sectors as an "enabling" or "key" technology, especially on:

- medicine and health
- information technology
- energy production and storage
- transportation, vehicles and infrastructure
- materials science
- food, water and the environment
- instruments
- security

Next to the ongoing progress in nanoelectronics, expectations are especially high for:

- nano-bio applications
- nano based sensors
- and nanomaterials in the longer term (10 years)

Public investments show 20% growth annually

Global public investments in R&D have grown by 20% annually over the last years and have reached a level of 5500 million USD in 2005. The top 7 investors (rated to their public investment) with indication of their focus areas, are:

- Europe: nanoelectronics, optoelectronics, medicine, materials ~ 2000 M$
- USA: all aspects of nanotechnology ~ 1700 M$
- Japan: nanoelectronics, nanomaterials, nanotubes ~ 1000 M$
- S-Korea: high density memory, displays ~ 200 M$
- China: mass production nanomaterials ~ 400 M$
- Taiwan: display, optoelectronics ~100 M$
- Australia: nanomaterials ~ 150 M$

The public funds of Europe, USA and Asia are about equal and close to 2000 M$ annually.

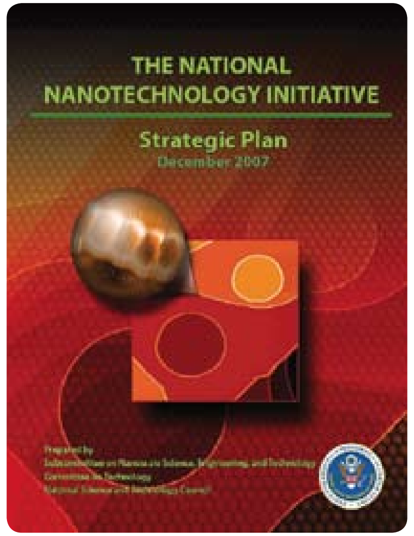
R&D investments doubled by private expenditures

The worldwide private expenditures are at the same level as the public investments now. Leaders in the field are the USA and Japan (with 2000 and 1700 M$ private investments in 2005, 20% increase annually) followed by Europe (1000 M$ in 2005) and rest of Asia (400 M$ private).

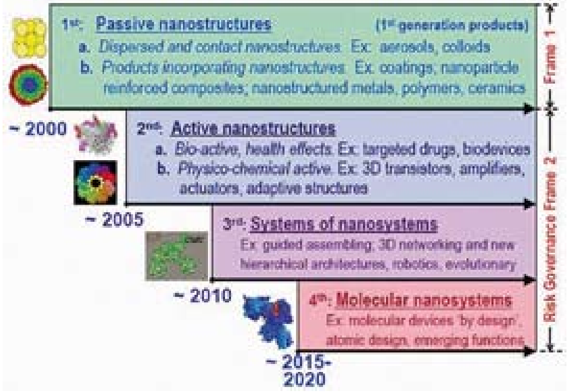
Nothing small about Nanotech's market potential

Estimates for the market potential of nanotechnology according to Cientifica ltd.

Year	Market excl semicon	Market incl semicon
2007	83 billion $	135 billion $
2012	263 billion $	693 billion $
2015	1500 billion $	2950 billion $



NNI 2007-2010 USA



USA roadmap for nanotechnology

NNI Budget 2007 - 2009 (in M$)

	2007 Actual	2008 Estimate	2009 Proposed
DOD	450	487	431
NSF	389	389	397
DOE	236	251	311
DHHS (NIH)	215	226	226
DOC (NIST)	88	89	110
NASA	20	18	19
EPA	8	10	15
DHHS (NIOSH)	7	6	6
USDA (FS)	3	5	5
USDA (CSREES)	4	6	3
DOJ	2	2	2
DHS	2	1	1
DOT (FHWA)	1	1	1
TOTAL	**1,425**	**1,491**	**1,527**

NNI budget from thirteen federal agencies

Nanotechnology in the USA

USA: 6000 MEuro (public) in 2006-2010

The National Nanotechnology Initiative (NNI) originates from 2000 and is now jointly driven by thirteen federal agencies: CREES, DOD, DOE, DHS, DOJ, DOT, EPA, FS, NASA, NIOSH, NIST, NIH, NSF and twelve other agencies. The NNI strategic plan was launched in 2004 and has recently been updated by the end of 2007. Since 2000, 30 nanotech research centers have been formed. In 2007 the federal NNI funding has reached an annual level of 1400 M$, with additionally 500 M$ estimated funding from the individual states.

Impact on economy and security

Nanotechnology is seen as a technology of national importance to the economy and security of the US, with a similar impact as semicon in the past. There is a strong belief that nanotechnology will bring many innovations to industry in many sectors and will create strong economic power. High impact is expected in the following sectors:

- aerospace: high strength, low weight, multifunctional materials; small and compact planes; fully automated, self-guided, unmanned air vehicles for reconnaissance and surveillance
- agriculture and food: secure production, processing and shipment; improved agricultural efficiency; reduced waste and waste conversion into valuable products
- national defence and homeland security: high speed and capacity systems for command, control, communication and surveillance; automation and robotics; innovative sensors; advanced war fighter and battle systems capability; electrochemical power (batteries, fuel cells)
- energy: high performance batteries, fuel cells, solar cells, thermo-electric converters; catalysts for efficient conversion
- environmental applications: improved monitoring; reduced pollution by new, green technologies; remediation and removal of contaminants
- information technologies: improved computer speed; further scaling of nanoelectronics; reduced power consumption; expansion mass storage; flexible, flat displays; molecular electronics
- medicine and health: novel sensor arrays for rapid diagnostics; composite structures for tissue replacement; targeted, highly effective medicine
- transportation and civil infrastructure: new material composite structure; efficient vehicles; improved safety

Illustrative examples in the new program

- let nature do the work: biological process for producing nano-products
- safe and affordable water: sorption and filtering with nano-membranes
- computers: faster, smaller, low power: graphene based semicon
- nanotoxicology: predicting toxicity of nanomaterials before manufacturing
- energy-efficient materials: lightweight, magnetic and structural nanomaterials
- reference standards and procedures for nanomaterial measurements
- durable energy solutions in particular solar, wind, fuel cell, batteries and ultra capacitors

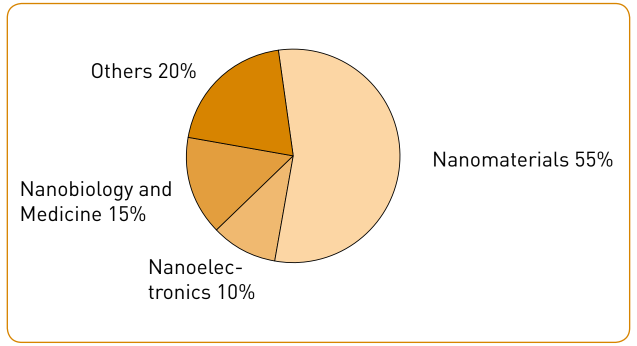
DOD participation

DOD strongly participates in all program component areas. Examples of DOD related achievements (stage 2007) are:

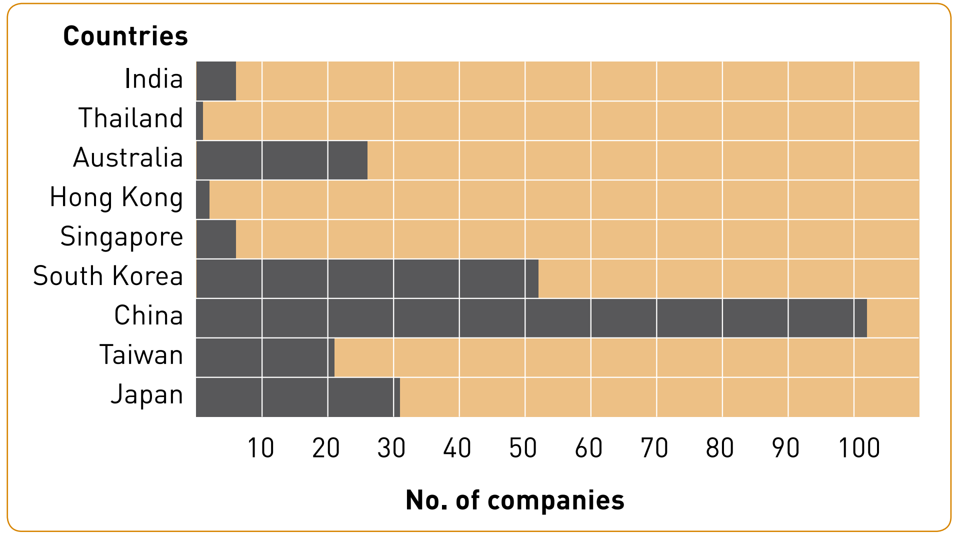
- sensitive spectrum analyzer 3Hz – 50 GHz
- quantum dots for nanoelectronics and sensors (e.g. infrared)
- highest Q mechanical resonator (cantilever, nanowire) for chemical sensing
- nanomagnetic materials for DNA detection
- nanoscale aluminum particles for energetics
- smallest individual oLED device
- long shelf life packaging for food (nanoclay PE composite)
- high strength fiber from twisted nanotube yarns
- maskless lithographic process for semicon

Major companies involved in nanotechnology

- BASF: functional surfaces, nanocubes for hydrogen storage
- Dow: nanostructured particles, drug delivery
- General Electric: nanotubes, nanowires, nanocomposites
- General Motors: nanocomposites, hydrocarbon fuel cells
- Hewlett-Packard: molecular electronics, nanowires
- Intel: advanced semiconductor components
- IBM: microscopy, cantilever sensors, nanoelectronics



nanotechnology areas in China



Sumio Iijima (Japan/NEC) discoverer of carbon nanotube

Nanotechnology in Asia

With Japan in the lead and with China as upcoming nation, Asia is spending 8000 MEuro public funds during 2006-2010

Japan: 4200 MEuro (public) in 2006-2010

In 2006 Japan launched its 3rd Science and Technology Basic Plan 2006-2010, promoting nanotechnology and nanomaterials as one of the four priority areas (next to life sciences, IT and environment) with a nanotechnology public fund allocation of 4200 MEuro. The program involves participation from METI (Ministry of Economy, Trade and Industries), MEXT (Education, Culture, Sports, Science and Technology), MHLW (Ministry of Health, Labor and Welfare), MAFF (Agriculture, Forestry and Fishing) and MOE (Environment). The fund is being managed by the NTPT: Nanotechnology & Materials Project Team under supervision of the Council for Science and Technology Policy. Also the Japanese private sector invests heavily in nanotechnology with a R&D budget of around 1500 MEuro annually.
Key players are the two major trading houses, Mitsui & Co and the Mitsubishi Corporation and a range of major Japanese companies, such as NEC, Hitachi, Sharp, Fujitsu, NTT, Toshiba, Sony, Sumitomo Electric, Fuji Xerox and Toray. The priority areas in the nanotechnology program are:

- Nano-electronics
  - next generation silicon semiconductors, faster processors, low power, high packing density
  - photo-electronics, coupling to broad band communication
  - nano-scaled processing (equipment) of nano-electronic devices
- Nanomaterials
  - clean energy conversion such as photovoltaics, fuel cells and storage
  - high strength/light weight materials for transportation and secure constructions
  - substitution of rare and deficit materials
- Nano-biotechnology and -biomaterials
  - molecular imaging and manipulation of internal molecules (non invasive treatment)
  - early detection (ultra tracers) and diagnosis
  - in situ initiating of regeneration of tissue
  - patient friendly bio-devices
  - nano-biomaterials for food
- R&D fundamentals
  - advanced nano-measurement systems and nano-processing technology
  - quantum computational technology for design and better understanding
  - responsible R&D of nanotechnology

There are five major nanotech research centers: AIST (national institute of advanced industrial science and technology), Riken (institute of physical and chemical research), NIMS (national institute of materials science), CRL (communications research lab) and JRCAT (joint research center for atom technology) next to seven universities with recogized nanotech research activities (Tokyo institute of technology, universities in Tokyo, Osaka, Tohoku, Waseda, Ritsumeikan, Kyoto).

China: 2200 MEuro (public) in 2006-2010

In 2005, the spending on nanotehnology in China amounted to USD 250 million. This has been increased drastically in the period 2006-2010 upto a level of 2200 Meuros. The nanotech arena in China is spread over about 50 universities, 20 CAS (Chinese Academy of Science) Institutes, 300 industry enterprises and 3,000 researchers from different institutes, universities, enterprises (stage 2007). There are two national nanotech platforms: NCNST, the National Center for Nanoscience and Technology (Beijing) and SNERC, the Shanghai National Engineering Research Centers for nanotechnology (Shanghai). Main working areas are:

- nano-materials and nano-structures
- nano-medicine and nano-biotechnology
- nano-processing and nano-devices
- nano-structure characterization and testing

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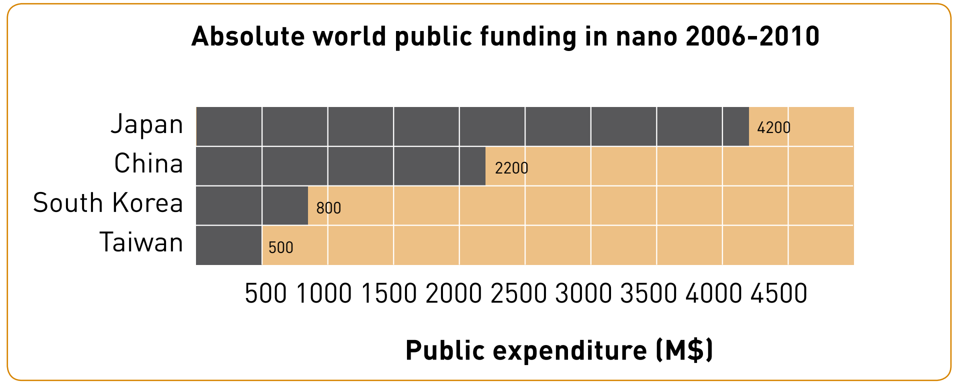
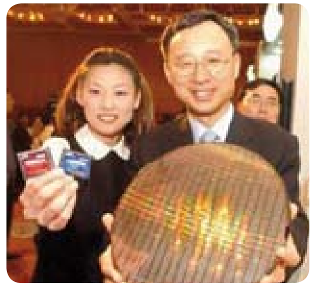
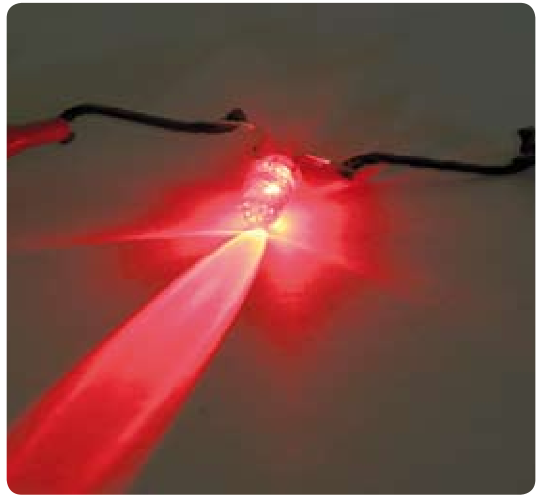
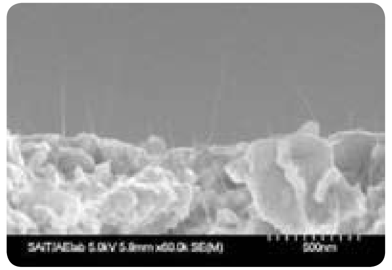
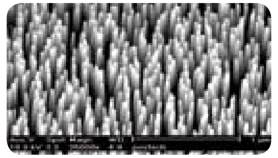



nano data storage chips on wafer

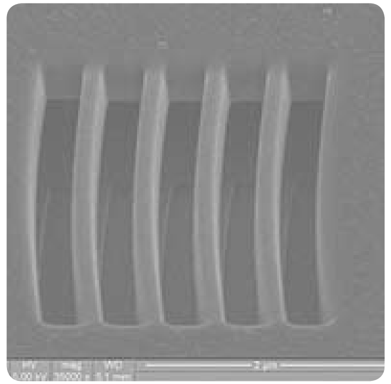

CNT coated smart yarn powering LED


CNT emitter for FED (Samsung)

rollable display ITRI


ZnO nanorods for display application


flexible oLED sony


diamond grating

Fujitsu health phone

Nanotechnology Industrialization Base of China (NIBC) and the China National Academy of Nanotechnology & Engineering (CNANE) focus on the following applications:

- materials: lighter, stronger; e.g. bullet proof vest, self-cleaning surfaces
- medicine and health: rapid and efficient genetic sequencing, diagnosis, and treatment technology;
- new drug delivery system: magnetic nanoparticles can be coated with anti-cancer drugs or antibiotics
- space craft and aviation: super-light aircraft made of polymers
- environment and energy: clean energy, nanoporous material to clean water and air
- energy: Tianjin Alliance Technology: CNT-based super capacitor; provides uniform high-voltage power supply in the face of power fluctuations (pilot project)

Strengths of China Nanoscience

- carbon nanotubes; CNT yarns with great tensile strength (Fan Shushan, Tsinghua University)
- nanoporous materials: catalysts, environmental filtration (Zhao Dongyuan, Fudan University)
- commercialization of basic nanomaterial applications, such as coatings and composites
- 30+ product lines employ nanomaterials, including textiles, plastics, porcelains, lubricants and rubbers

S-Korea: 800 MEuro (public) in 2006-2010

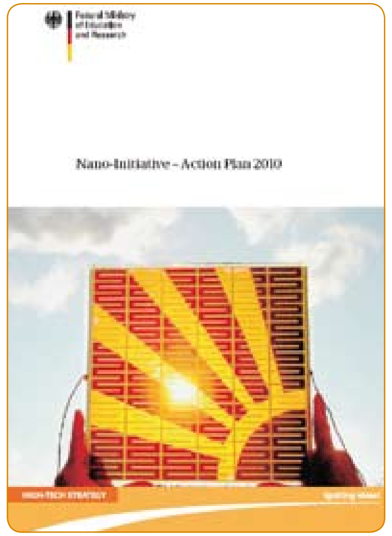
In 2001 a 10-year nanotechnology program has started. Two Korean advanced nanofabrication (nanofab) centers have been created, one silicon based and one non-silicon based, as well as three nanotechnology integrated centers for industry: National Centre for Nanofabrication (Korea Electronics Technology Institute); National Centre for Development of Nanomaterials (Technology Institute of Science and Technology) and the National Centre for Development of Nano Electronic devices Technology (Pohang University of Science and Technology). The strategy is defined via Frontier Research Programs on the following areas:

- tera-level nanodevices:
  - tera-bit memory (magnetoelectronics)
  - tera-Hertz processors, ultra fast, optical broad band communication
  - tera level logic
- nanostructured materials
  - high strength materials (bulk, composites and coatings)
  - environmental (catalysts) and energy storage materials (active materials for batteries)
- nanomechatronics and manufacturing
- nanocor: carbon nanotube research (20 universities)
- nanobasic: fusion on nano-bio-IT (4 programs)
- nanofundamental: quantum functional semiconductor research

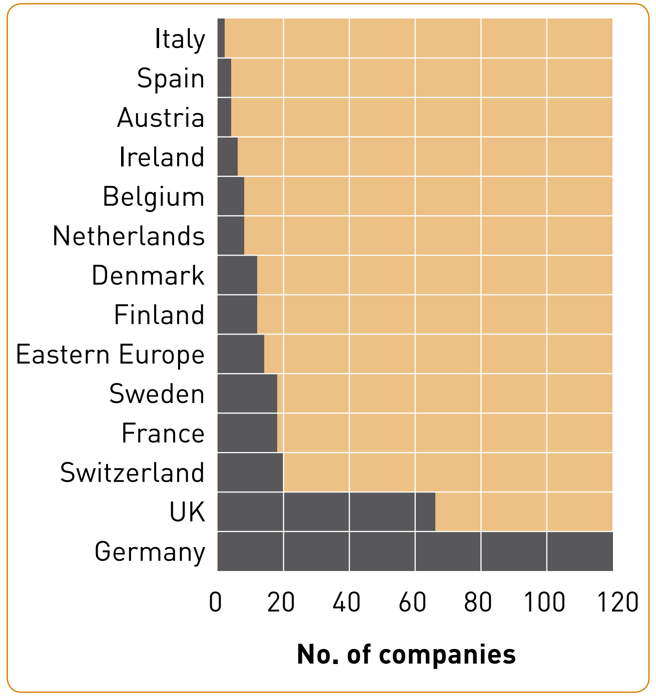
Taiwan: 500 MEuro (public) in 2006-2010

There are two centers for nanotechnology in Taiwan: ITRI for development, transfer and industrialization of nanotechnology and Academia Sinica for the academic/fundamental research. Priority areas are:

- nanomaterials
- optoelectronics, nonvolatile memory



German Nano Initiative-Action Plan 2010



nanotechnology action plan European Commission 2005-2009

Nanotechnology in Europe

Europe: 9000 MEuro (public) in 2006-2010

Most of the European countries have national nanotechnology programs. In 2005 the individual countries invested in total 900 MEuro. In addition to that, the central EC spent an additional 500 MEuro. With the expected increase in budget, the total public investment in nanotechnology over the period 2006-2010 is therefore estimated at 9000 MEuro. The EC published in 2005 their action plan: "Nanoscience and nanotechnologies: an action plan for Europe 2005-2009". This has resulted in a nano materials program (NMP) within the seventh framework program (FP7, 2007-2013, budget 3475 MEuro) with the following topics:

- Nanoscience
  - nano-scale mechanisms of bio/non-bio interactions
  - self-assembling and self-organisation
- Nanotechnology
  - production technology for nanomaterials and nano/micro-devices
  - nanobiomaterials
  - Impact assessment and societal issues
  - portable devices for measurement and analysis of nano risks
  - toxicological issues and risk assessment of nanomaterials
- Nanomaterials
  - nanostructured polymer-matrix composites, coatings, magnetics and catalysts
  - organic materials for electronics and photonics
  - nanomaterials for energy conversion, fuel cells and hydrogen storage
  - aerostructures
- Nanoelectronics
  - next generation nanoelelectronics, nanoscale ICT components
- Nanomedicine
  - in-vivo diagnosis and therapy, point-of-care diagnosis
  - targeted drug delivery
  - nanoporous active scaffolds and tissue engineering

Germany: 1750 MEuro (public) in 2006-2010

Germany is the leading investor in nanotechnology in Europe. The new German Nano Initiative Action Plan 2010 was launched in 2007. It puts it's focus on the following lead innovations:

- Electronics: next generation production procedures in nanoelectronics (nanofab)
- Automotive engineering: ultra-light nanomaterials, nanosensors, scratch resistance lacquers for improved driver safety and energy consumption (nanomobile)
- Chemistry: microprocess technology, nanocoatings, safe materials (nanomikrochem)
- Medicine: early diagnosis and cancer treatment, aging disease (nanoforlife)
- Light engineering: energy efficient LEDs (nanolux) for automotive and domestic, organic LED technology (oled) for flexible and large area lighting.
- Energy: fuel cell technology

Next to this special attention/funds on "nanotechnology enters into production":

- optical industry (volume optics): optical components for medicine, automotive and multimedia
- textile industry (nanotex): self-cleaning, insulation, smart electronic textile
- building industry (nanotecture): nanocoated glazing, insulation, fire resistance, new concrete
- medicine/health (nano for life): molecular imaging (biophotonics), early detection/diagnosis, targeted medicine, improved implants, biomicrosystems (bio integrated nano/microdevices)
- measurement and sensor technologie
- plant engineering and construction: lightweight materials and wear/corrosion resistant coatings
- environment: filter system for water, replacement of toxic materials
- energy: batteries, H2 storage, solar, fuel cells, thermo-electric scavenging

Nine nanotechnology competence centers have been founded: Nanomaterials (Karlsruhe), Ultraprecision surface engineering (Braunschweig) and nano coatings (Dresden), Nanooptics (Berlin), Nanobiotechnology (Munich and Kaiserslautern), Nanochemistry (Saarbrucken), Hanse Nanotec (Hamburg); CeNtech (Münster)

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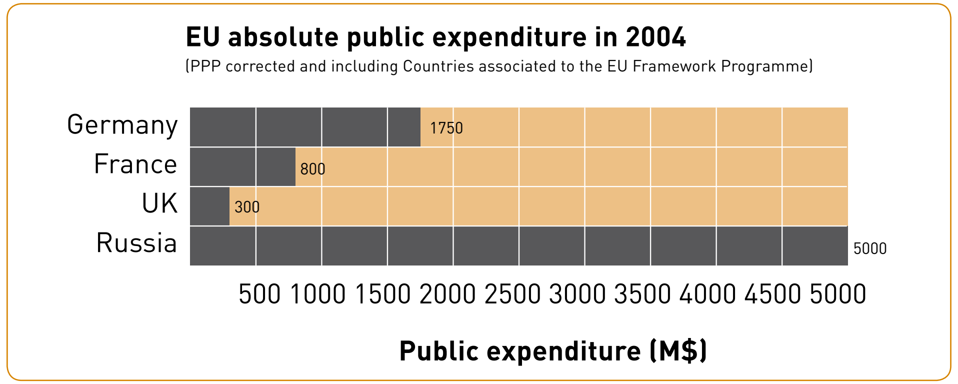
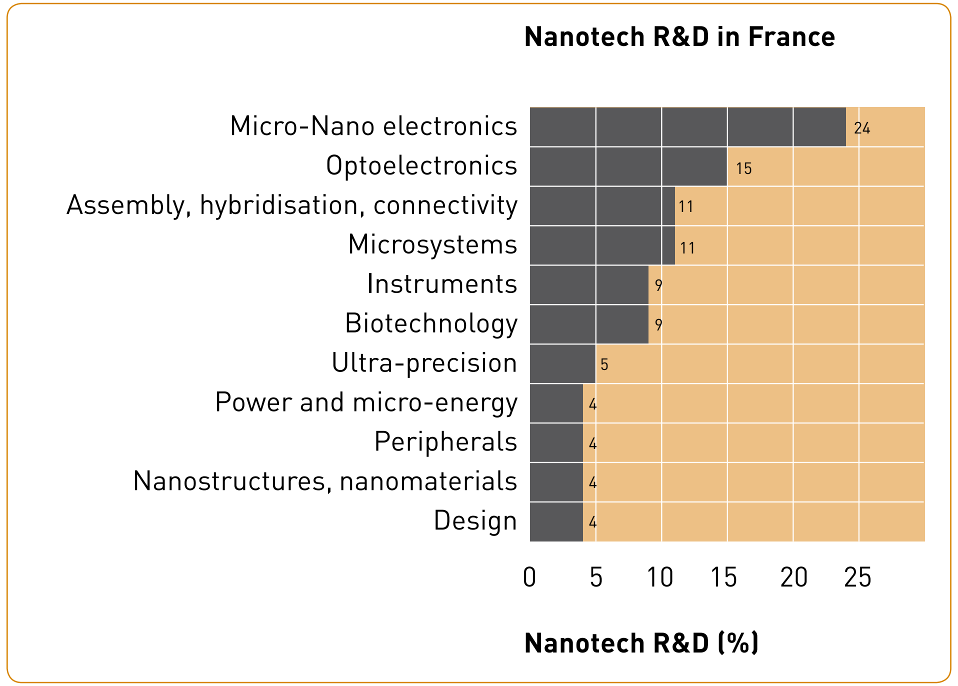




France: 800 MEuro (public) in 2006-2010

The French research structure for nanotechnology is based around a group of five centers of excellence. This network covers the facilities at CEA-Leti in Grenoble (centered in Minatec, which brings together the CEA, the CNRS, the Institut National Polytechnique and the Université Joseph Fourier); the Laboratoire d'Analyses et d'Architectures des Systemes (LAAS) in Toulouse; the Laboratoire de Photonique et de Nanostructures (LPN) in Marcoussis; the Institut d'Electronique Fondamentale in Orsay (IEF) (centered on Minerve) and the Institut d'Electronique, de Microelectronique et de Nanotechnologies (IEMN) in Lille. Priorities are:

- micro & nanoelectronics
- opto-electronics
- microsystems and assembly
- biotechnology and instrumentation

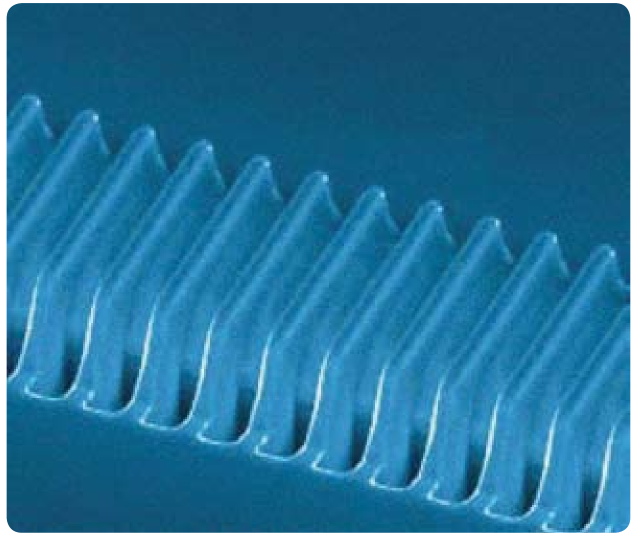
UK: 300 MEuro (public) in 2006-2010

After the National Initiative on Nanotechnology (NION) and LINK nanotechnology program (LNP) both ended in 2002, the UK launched in 2003 the Micro and Nanotechnology Initiative (MNT) to create a network of micro and nanotechnology facilities. At present the UK has 1500 nanotechnology workers. Well recognized nanotechnology centers are at the universities of Oxford, Cambridge, Newcastle, Durham and Glasgow. A special nanomaterials production facility is present at Farnborough, run by Qinetiq. Inex, innovation in nanotechnology exploitation, offers a one-stop-shop facility for micro- and nanosystems including production facilities.

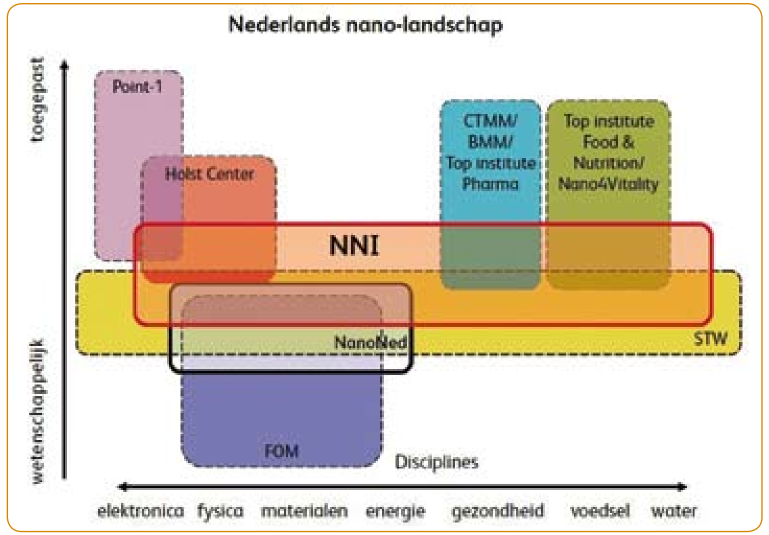
Russia: 5000 MEuro (public, announced) in 2008-2015

In 2007 the Russian Corporation of Nanotechnology (RCNT) has been established to address the growing challenge that arises with the rapid development of new technologies in the nanoscale. There is not yet an integral nanotechnology action plan at the moment. Looking at the economic potential in the near future, Russia has announced to invest 5000 MEuro in the upcoming eight years.
It has been reported that the Kurchatov (nuclear) institute will play a leading role and that 90% will be civilian and 10% will be military oriented. So far, the following areas have been mentioned:

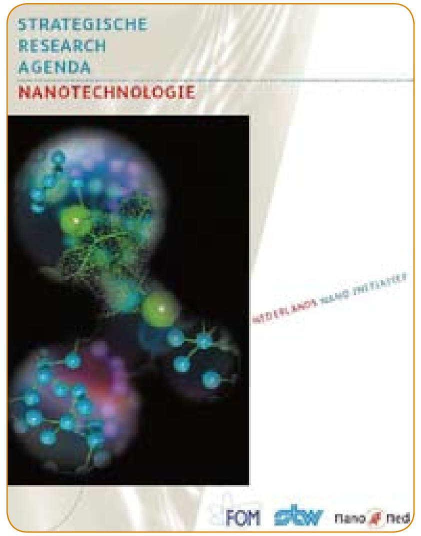
- nanomaterials, high strength and hard nanocrystalline metals and coatings
- nano-enabled photovoltaics and nuclear power
- nano-medicine and bionics
- space and aerospace/aircraft applications



diffraction grating



nanotechnology in the core of Dutch R&D



Nanotechnology in the Netherlands

Netherlands: 1000 MEuro (public) in 2010-2020

Nanotechnology is considered as crucial for the high tech industry in the Netherlands, not only for the multinationals such as Philips, ASML, ASMI, DSM, AKZO-Nobel but also for a large number of small and medium sized companies. The first national nanotechnology initiative started with NanoImpuls in 2003 followed by Nanoned in 2005. In 2008 a strategic research agenda (SRA) of the new Netherlands Nanotechnology Initiative (NNI) has been launched.

Strategic research agenda Netherlands Nanotechnology Initiative (SRA NNI)

The SRA NNI will allocate 100 MEuro public funds per annum on the following 10 areas:

- Risk analysis
  - human health risks, environmental risks
- Energy
  - sustainable energy, secondary conversion of energy and separation
- Nanomedicine and integrated microsystems:
  - biomolecular interactions, lab-on-a-chip, molecular imaging, drug delivery, microsystems for biosensing
- Clean water
  - nanotechnology in water applications
- Food
  - process monitoring and quality assessment, molecular structure, products and processes, microdevices for structuring and isolation
- Beyond Moore
  - nanoelectronic devices, functional and active nanophotonics, nano-bio devices
- Nanomaterials
  - supramolecular and bio-inspired materials, multilayered and artificial materials
- Bio-nano
  - nanomolecular machines in cellular force-transduction, bio-sensing
- Nanofabrication
  - Nano inspection, characterization and patterning
- Sensors and Actuators
  - systems and packaging, micro nozzles, microdevices for chemical processing

Running Programs

The new NNI will be complementary to other running innovative technology programs in the NL. These programs also have a strong involvement with nanotechnology. A short list of these programs (with public funds over a timeframe of 5 years):

Holst Centre (MEuro 112)

The Holst Centre has been founded in 2005 by IMEC (B) and TNO (NL) in order to valorize nano- and microsystems technology into innovative products. It has two technology programs:

- system in a package: wireless, autonomous sensors
- system in a foil: flexible electronics in a foil for lighting, sensors, tags and energy

It is an open innovation center and industrial partners can sign in and participate in the technology programs.

Point-One (MEuro 343)

Point-One is a national strategic innovation program on nano-electronics and 'embedded systems' with participation of Philips, NXP Semiconductors, ASML, many small SME's and knowledge centers. This consortium strives to build an international 'hotspot' for nano-elektronics and embedded systems.

Center Translational Molecular Medicine CTMM (MEuro 150-200)

CTMM, with companies as Philips, Schering-Plough, DSM, Numico, FEI, TNO, many SME's and with all university medical centers and many universities is a public-private cooperation in the field of molecular medicine. It has its focus on oncology, cardiovascular, neurodegenerative disorders and infectuous diseases. .

BioMedical Materials Program, BMM (MEuro 45)

BMM is a consortium of Dutch industries (DSM, Philips, Schering-Plough) and knowledge centers (TNO, universities) aiming at the development of innovative biomedical materials and applications. It has 5 research lines: cardiovascular, musculoskeletal, nephrology, coatings and drug delivery.

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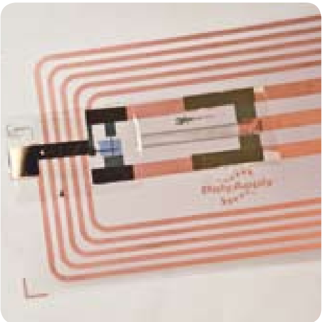
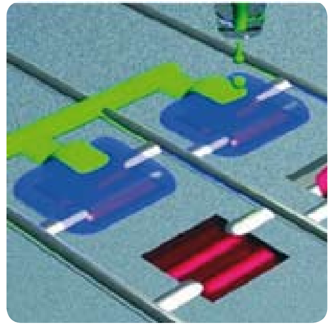
cleanroom lab for conductive polymers



polymer 13.56 MHz RFID-tag



printing of polymers

wireless ECG-patch

smart bandage with leds and diodes

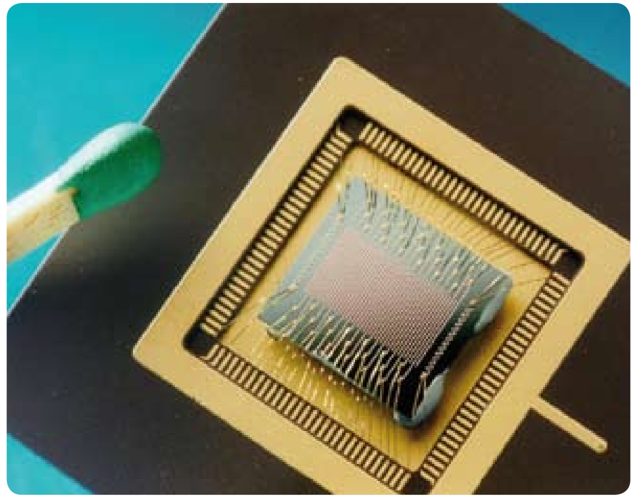
Topinstitute Pharma, TI Pharma (MEuro 130)
TI Pharma is a consortium of 12 academic centers and 22 (bio)pharmaceutical companies developing nano medications and delivery systems for 5 disease areas: cardiovascular, auto-immune deseases, oncology, infectuous deseases and neural-disorders.

Topinstituut Food & Nutrition (MEuro 63,5)
TI Food &Nutrition is focussing on "nutrigenomics" in order to detect early indicators of food related disorders. Based on this, new healthy food can be developed. It also involves the development of high-throughput micro-detection systems and the development of new generation food structures.

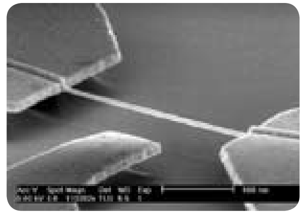
Nano4Vitality (MEuro 11)
Nano4Vitality runs a programma aiming at more rapid implementation of nanotechnology in food and health. It has 4 specific themes: sensors and analysis, smart active packaging, processing, encapsulation and delivery.

Overview of expertise research institutes in NL:

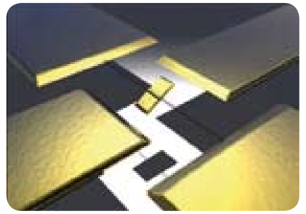
- Kavli Institute for Nanoscience & DelftChemTech (TUDelft): quantum computing, superconductivity, graphene, photonic crystals, advanced nanoprobing, nanoparticles for hydrogen storage, fuel cells, drug delivery and diagnostics, membranes
- MESA+ Institute for nanotechnology (UT): photonics, spintronics, plastic electronics, superconductors, supra-molecular chemistry, soft- and imprint lithography, self assembling materials layers, advanced nanoprobing, hydrogen storage, fuel cells, solar cells, membranes
- TU/Eindhoven: catalysis, nanophotonics, photo-voltaic quantum dots, self-assembling nanostructures, magnetic nanoparticles for biosensing, organic led, electricity storage, solar cells, spintronics, supra-molecular chemistry (Centre for Nanomaterials & COBRA)
- Debye Instituut (UUtrecht): quantum dots
- Institute for Molecules and Materials (RUN): spintronics, graphene, quantum-effects
- Zernike Instituut and Biomade (RuG): organic materials, supra-molecular chemistry, nano-spectroscopy, solar cells
- Van der Waals and Van 't Hoff Institute for Molecular Sciences (UvA) : quantum-effects, catalysis nano-objects, mechanics biological nanoparticles, interacting living cells
- Leiden University: superconductivity, spintronics, nanostructures, quantum effects, graphene, photosynthesis
- FOM-institute AMOLF: nanophotonics, photonic crystals, biological nanoparticles, interaction living cells
- Philips Research: nano-photonic materials and devices, system-in-package, sensors, nanoparticles and -surfaces for imaging, diagnostics and sensing, inorganic and organic leds, energy scavenging, batteries
- Holst Centre: plastic electronics, sensors and actuators, energy scavenging
- NXP: RFID-tags & smart cards, magnetic biosensors, electronic components for automotive and health & wellness
- Utrecht University: supramolecular chemistry, photonics, catalysis, energy storage, quantum effects
- Wageningen University: colloïds and supramolecular chemistry
- Nijmegen University: magnetic data storage, advanced nanoprobing, self-assembly, bio-inspired materials, UV solar cells, organic solar cells
- TNO: nanoparticles for delivery and sensor systems, nanostructured surfaces, toxicology, environmental impact
- ECN: solar energy, wind, membranes
- Shell Research Rijswijk: sensors for oil exploration
- Hogeschool Zuyd: side effects of nanoparticles
- IVAM/UvA: health- and environmental impact of nanotechnology
- RIKIL: food safety
- RIVM: health riscs
- Rathenau Institute: social-ethical implications
- TILT (University of Tilburg): law & nanotechnology
- NMI: measurement standards



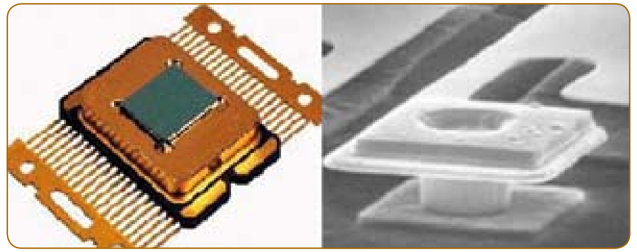
gas sensor array on chip (electronic nose)



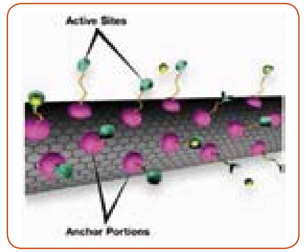
CNT pianowire sensor



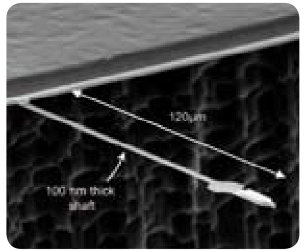
nanowire molecular sensor



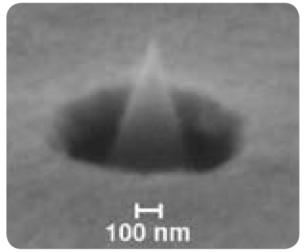
2D nanosized bolometer array for THz imaging (CEA-Leti)



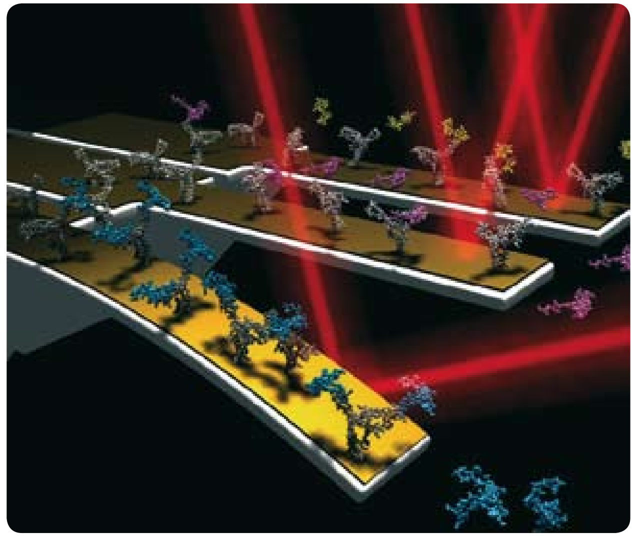
nanotube sensor



100 nm cantilever sensor



electron emitter tip for a miniature X-ray device



mechanical cantilever e-nose, readout via laser

Ultrasensitive sensors at nano dimensions

Nanotechnology is very enabling for the development of a new range of sensors. Thanks to miniaturization down to micron & nano level the following features can be realized:

- function integration: sensing, data processing and storage, wireless communication all integrated in one chip
- multi parallel analysis for high throughput analysis
- matrix arrays for better sensitivity and directional information
- high sensitivity at single cell/molecule level (10^{-21} gram)
- efficient thermal and material transport, low power consumption
- energy scavenging (solar, heat, mechanical)
- portable, wearable, self operating at remote point of analysis
- enabling mass production, low cost, disposable

Mechanical sensors

Mechanical nanosensors are based on the displacement of a tiny cantilever, beam or nanowire under the influence of an inertial force, vibration or pressure difference. The displacement is being measured via a change in the system capacitance or electronically (field effect transistor), optically (laser deflection) or via a piezo surface charge effect (ZnO). Thanks to the nanometer dimensions, very small forces can be detected down to a range of 10^{-18} N. Current world record even a sensitivity of 10^{-19} gram, or 100 zepto (10^{-21}) grams. Examples are 3D-acceleration sensors, pressure sensors and vibration sensors.

Radiation sensors

EM radiation can be sensed using a nano-sized dipole antenna with optical dimensions (50 nm – 100 μm length) connected to a micro bolometer matrix array. More accurate is the use of a quantum well structure: here electrons tunnel through a barrier under the activation of external radiation. This enfavours a high signal to noise ratio and a large number of quantum wells on a chip yields a large signal output. Main applications f are infrared and THz radiation.

Chemical sensors

Nanotechnology techniques are usually applied in combination with a lab-on-chip microsystem for the fluidic processing, filtering, and pretreatment. The fluidic sensors are based on binding with a:

- fluorescent quantum dot with optical readout ($10^{-12/13}$ mol/liter) magnetic particle and GMR readout ($10^{-13/14}$ mol/liter) nano-structured surface with surface plasmon resonance readout ($10^{-8/9}$ mol/liter)
- planar waveguide with fluorescence readout (10^{-13} mol/liter)
- eletrochemically reactive metal oxide nanostructure (10^{-9} mol/liter) optionally with enzymatic activity ($10^{-15/16}$ mol/liter)

In gaseous form the sensing occurs via:

- electron transfer with a nanostructure, nanotubes or wires (10^{-9}, ppb)
- specific binding of airborn particles to a nanostructured surface, read-out by surface enhanced raman spectroscopy (10^{-12}, ppt)
- mechanical: binding to a resonating cantilever (10^{-12}) or nanowire (10^{-15})

Magnetic sensors

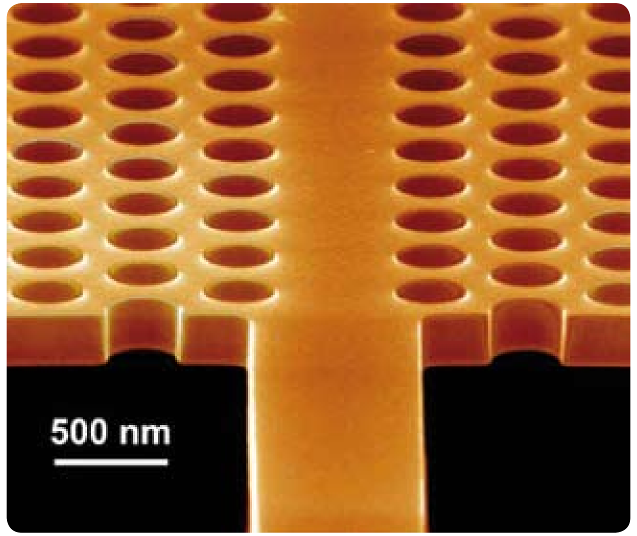
GMR and TMR, giant and tunneling magnetic resistance, are magnetic sensor techniques using the quantum effects of electrons (spintronics) flowing in a confined space of a nanolayer under the influence of magnetic field. A sensitivity of 10^{-9} Tesla can be achieved. Recently IBM has developed of a magnetic resonance force microscope (MRFM), a magnetic tip on an ultrasensitive cantilever able to detect and analyse the spin of electrons in a sample.

Miniature X-ray sensors

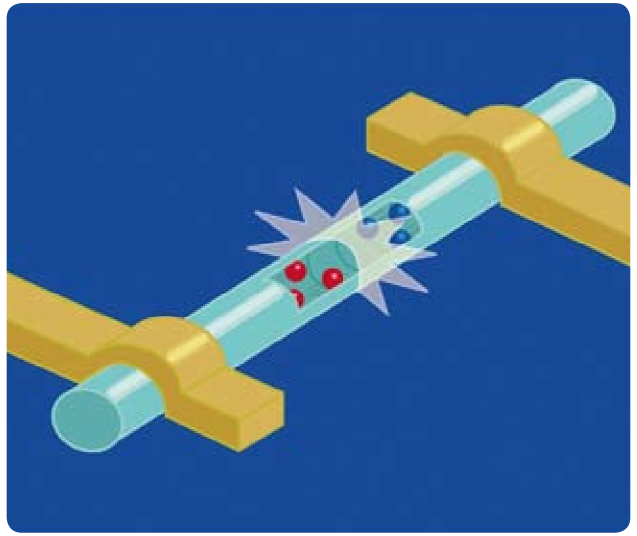
Carbon nanotubes are very effective electron emitters and can be applied as a miniature electron source to generate X-rays. X-ray sources down to millimter scale are now in development, to be used in handheld X-ray detection devices.

Surface enhanced raman spectroscopy

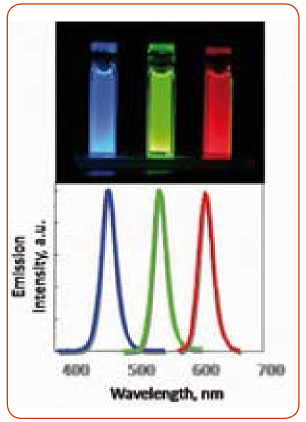
SERS can provide ultra low trace level chemical detection of airborne explosives and contraband molecules with a sensitivity in the parts-per-trillion range. It allows the remote detection of these materials at room temperature. Examples of detection at ppt level are: TNT, DNT, RDX, TATP, PETN, DMDNB and traces of cocaine.



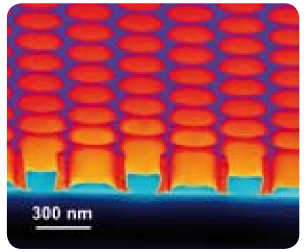
photonic crystal structures


electrically driven light emitting molecules confined in a nanotube

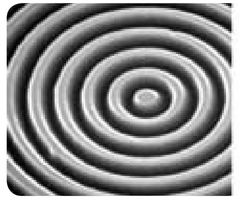

very efficient light emittent quantum dots

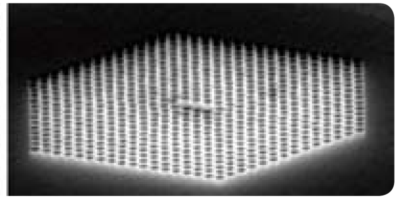


quantum dots wavelengths



photonic crystal





Quantum dots and single photon devices

Quantum dots are nanometer-sized, inorganic crystals that create light when stimulated with photons or electrons. Quantum dots have extraordinary electronic properties, like the ability to bottle-up normally slippery and speedy electrons. This allows controlled interactions among electrons to be put to use to do computations.

Often referred to as artificial atoms, quantum dots have previously been ranged in size from 2-10 nanometers in diameter. While typically composed of several thousand atoms, all the atoms pool their electrons to “sing with one voice”, that is, the electrons are shared and coordinated as if there is only one atomic nucleus at the centre. That property enables numerous revolutionary schemes for electronic, photonic and sensoric devices.

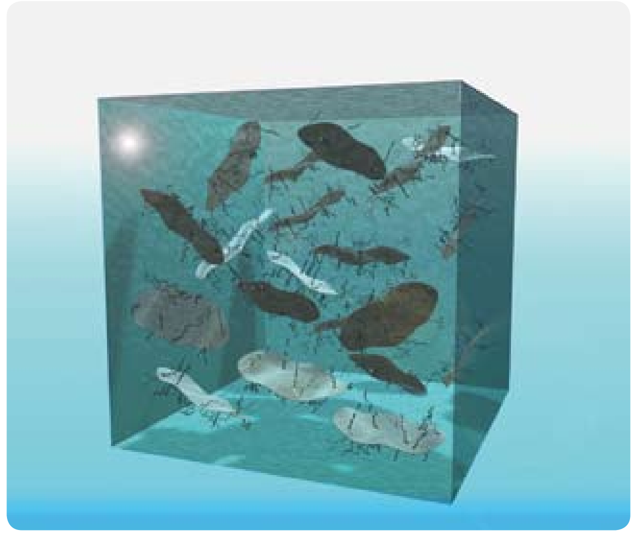
The single atom quantum dots have also demonstrated another advantage – significant control over individual electrons by using very little energy. Some researchers see this low energy control as the key to quantum dot application in entirely new forms of silicon-based electronic devices, such as ultra low power computers. The capacity to compose these quantum dots on silicon, the most established electronic material, and to achieve control over electron placement among dots at room temperature puts new kinds of extremely low energy computation devices within reach.

Single photon devices

A light-emitting diode (LED) based on single nanowires is an example of an electrically driven single photon source. The active region for electron-hole recombination is formed by a quantum dot. Because all the injected current will flow through the active region, a very efficient conversion of electron-hole pairs into photons is being obtained. The quantum dot nanowire LED can ideally be used both as a single photon emitter as well as a photodetector (“a single electron source”). Furthermore, a coherent conversion of electrons into photons would define the photon polarization with the injected electron’s spin orientation. Photoexcitation with a given polarization would generate a spin-polarized current. In this way, the devices eventually will enable optical readout and programming of an electron spin based quantum bit important for quantum cryptography.

Applications

- light emitting devices
- optical dyes for sensing
- single photon capture:
  - efficient solar cells
  - single photon detection
- quantum computing



nanoclay platelets dispersed in polymer

flame retardancy with nanoclay

UV-stable nanopigments

transparant conductive coating

high strength nanocomposite polymers

lightweight nanoX-cell for jetski

improved gas barrier properties with nanoclays

Nanocomposites: materials with superior properties

The new SHO and HO jetskis of Yamaha use a new material NanoXcel for the hull and the hood to make it lightweight, stiff, strong and durable. NanoXcel is a nanocomposite based on a polyurethane matrix with a dispersion of exfoliated nanoclay. It has received the best innovation award at the JEC 2008.

Nanocomposites are polymers (epoxy, PE, PP, ABS, PET etc) that have been blended with nanoparticles in order to enhance mechanical, electrical or chemical properties. The nanoparticles create an enormous large surface area inside the matrix material, herewith affecting the polymer structure and overall properties. Good dispersion, interfacial bonding to the matrix, orientation and alignment are the major technological challenges in order to achieve the desired material improvements. Various types of nanoparticles are on the market, ranging from spherical, platelets, tubes to fibers.Their shapes vary and include:

- needle-like structures such as one-dimensional particles, for example, sepiolites, attapulgites and carbon nanotubes
- two-dimensional platelet structures, for example, layered double hydroxides and smectites, graphene or nano-graphite platelets
- sphere-like three-dimensional structures, for example, silica, zinc oxide and bariumtitanate.

Intercalated nanocomposites. Here, the polymer chains alternate with the inorganic layers in a fixed compositional ratio and have a well-defined number of polymer layers in the intralamellar space. These nanocomposites are more compound-like than the exfoliated versions because of the fixed polymer to layer ratio; it is their electronic and current carrying properties that make them interesting.

Exfoliated nanocomposites. Here, the number of polymer chains between the layers is almost continuously variable and the layers are > 10 nm apart. These nanocomposites are interesting because of their superior mechanical properties:

- improved tensile and impact strength
- improved fatigue behaviour
- reduced oxygen- and water-vapour permeability
- improved flame retardancy
- reduced linear thermal expansion
- improved temperature stability
- enhanced thermal stability of additives
- improved crystallinity
- improved resistance to organic solvents
- improved surface finish
- new nanopigment basis (planocolors)
- enhanced UV-light stability.

Nanotubes: carbon nanotubes, single wall, double and multi wall nanotubes (SWNT, DWNT, MWNT). With carbon nanotubes (diameter 1-2 nm, aspect ratio 10^3,10^4, typically 100$/kg) the following ultimate material properties are foreseen:

- mechanical: elastic modulus up to 1-5 MPa, ultimate tensile strength: 30-180 GPa
- electrical conductivity: 6000 S/cm, thermal conductivity: 2000 W/mK
- ultrahigh surface area: 1500 m^2/gram

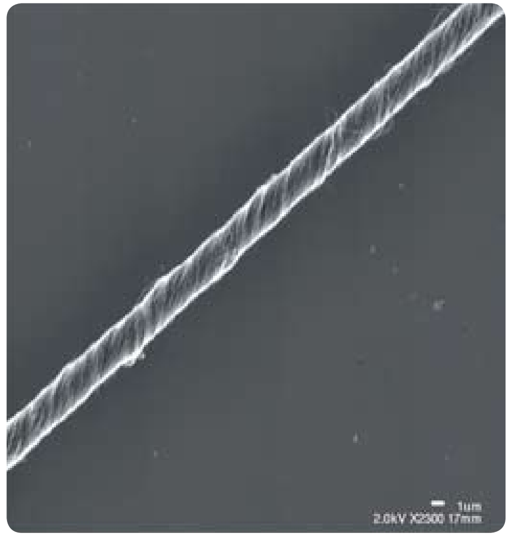
Exceptional tensile strength properties have only been realized on macroscopic scale by the company Superthread (see chapter “high strength materials”).

Nanoplatelets: graphite/graphene, exfoliated nanoclay platelets. Nanoplatelets (thickness 1-2 nm, aspect ratio 10^2, 10^3) are relatively low cost nanoadditives (5-10 $/kg) and are being applied in order to:

- increase chemical, UV and thermal stability (usually 50 to 100 K up)
- increase fracture toughness: typically a factor 1000
- increase tensile strength: factor 2
- diffusion barrier: factor 2-10

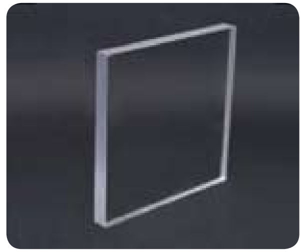
Nanofibers: vapour phase grown graphite (VGNF, pyrograf), electrospun nanofibers or phase separated liquid crystal (LC) fibres. Nanofibers can be electrospun out of any polymer. First application can be found in nano-filtering systems. The mechanical properties are not very well researched so far. With proper orientated nanofibers a high mechanical strength is to be expected.

space elevator made from nanotube fibers

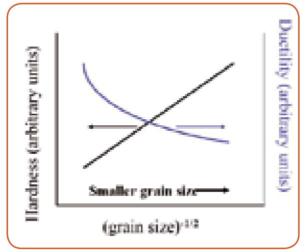


CNT fiber 60x stronger than steel, 5x stronger than Dyneema

high strength buckypaper



transparant steel made from nanoclays



effect of (nano)grainsize on hardness

Nanomaterials for super high strength

With the introduction of nanoparticles in material engineering, a couple of new features arise:

- the nanoparticles itself can offer outstanding mechanical properties thanks to a perfect material structure; this is especially true for the carbon nanotubes with giant intrinsic strength properties In both cases substantial improvement of the mechanical strength can be achieved
- nanoparticles (and nanopores) create an enormous and dense network of interfaces in the material leading to a high threshold for crack growth and leading to material with a structure that is governed by interfacial interaction. In both cases substantial improvement of the mechanical strength can be achieved

It means that nanotechnology can bring stronger materials and hereby a substantial reduction in weight. As the need for lightweight materials is high in aerospace, for land vehicles and not at least for the soldier, the interest and investments in nanotechnology to obtain lightweight materials is correspondingly. Impressive technical results have been obtained already. An overall weight reduction of a factor 2-3 is technically feasible. However it will need more time (estimated to 5 years) and further investments before these technical solutions can produced in an economically attractive way and before it will be introduced on the market on large scale.

Carbon nanotube super strength fiber

Theoretically carbon nanotubes can have tensile strengths beyond 120 GPa, in practice the highest tensile strength ever observed in a single-walled tube is 52 GPa and in multi-walled nanotubes (MWNT) 62 GPa. The difficulty has been maintaining this strength up to macrolength fibers/ropes and sheets. The best result reported so far is by Superthread (CNT technologies) with a CNT fiber strength of around 20 GPa. The corresponding specific strength (strength/weight) denoted in breaking length amounts to 1700 km. This is 5-6 times better than current available high strength fibers (carbon, aramide, HDPE) and a factor 60 better than steel. A future weight reduction of factor 2-3 seems realistic for construction parts and e.g. body armour and helmets.

Nano super hard steel

Super hard steel alloys feature a refined amorphous or nanoscale microstructure that provides improved wear and corrosion performance characteristics superior to conventional steels. SHS alloys for thermal spraying feature a nano sized (10 - 100 nm) microstructure and SHS alloys for weld overlay applications feature a near-nano sized, micron to submicron (≤ 400 nm) microstructure. The refined microstructures of SHS alloys improve toughness, abrasion resistance and corrosion resistance to allow for extreme damage tolerance in a wide variety of industrial applications.

Nanocrystalline metals and ceramics

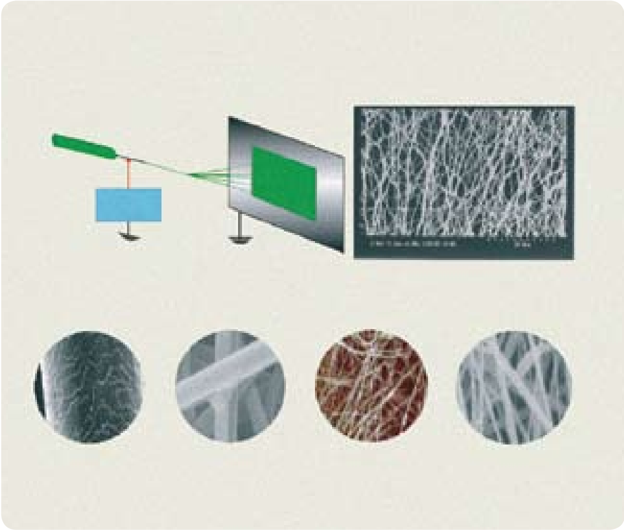
Ceramics and metals usually have a microcrystalline structure. If this microstructure is transferred into a nanocrystalline structure < 100nm, e.g. by forging the material under high pressure loads, the internal grain boundary surface area per unit volume increases drastically. As a result the hardness and strength may increase by typically a factor 2-3. This has e.g. been observed in aluminum and titanium.

Nanocomposites

Nanocomposites are polymers that have been blended with nanoplatelets or nanotubes. Thanks to the alignment of the nanoparticles the impact and tensile strength increases, typically by a factor 2 for nanoclays to a factor 3 for nanotubes with a load 3-5 wt%. A remarkable development is the making of “transparent steel” out of nanoclay platelets that are being glued with a polymer binder layer by layer to form a ductile, transparent plate with steel like properties.

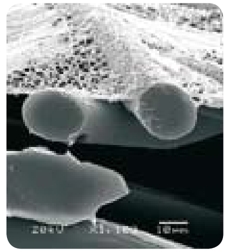
Specific strength	Breaking length[1)] (km)
Steel	26
Glass fiber (S)	133
LCP/Vectran	211
Carbon fiber	250
Aramide/Kevlar	256
HMPE/Dyneema	369
PBO	378
CNT Superthread	1727 [2)]
CNT single nanotube	4716 [3)]

[1)] Length at which fiber breaks under its own weight
[2)] CNT fiber from spun nanotubes, in development
[3)] single nanotube, length about 1 mm



high throughput electrospinning of nanofibers (Tandec, USA)

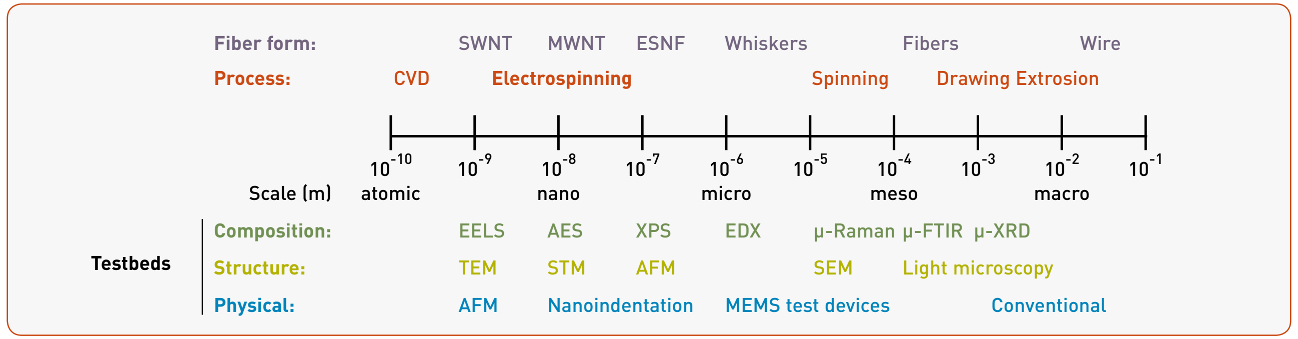
non woven nanofiber filter



nanofiber mat on fabric

electrospinning installation

eSpin airfilter tube



Nanofibers by electrospinning

Electrospinning is a cheap and relatively simple technique to produce nanofibers. The technique is very old but has regained interest since it enables the production of cheap nanostructures. The process simply consists of:

- blowing a polymer solution through a small nozzle
- applying a high voltage (25 - 50 kV) over nozzle and substrate to reduce the fiber diameter electrostatically down nanoscale
- recollect the nonwoven nanofiber mat from the substrate

Other characteristics are:

- typical fiber diameters are in the range of 50 – 200 nm
- long fibers: typically cm range
- also suited to produce ceramic, metaloxide and carbon nanofibers
- high throughput

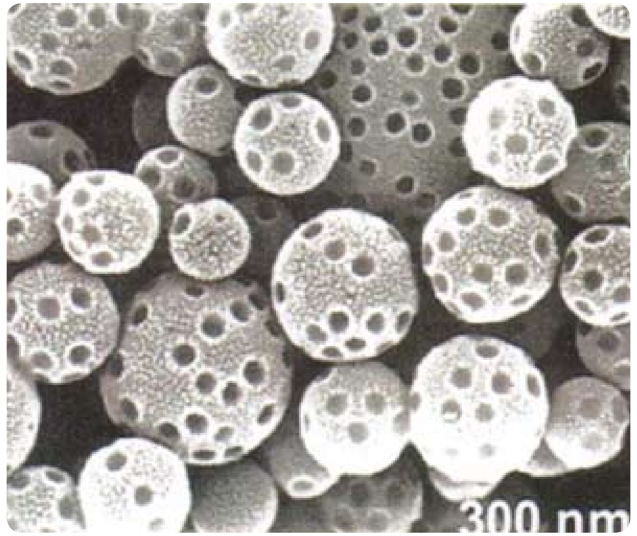
Nanofibers can be used in nonwoven mats but can also be spun into yarn. The following applications are in development:

- nanofiltration and absorption (see eSpin, Amsoil etc, USA)
- catalytic breakdown (catalytic active nanofiber, or nanofibers with a catalytic coating, BC breakdown)
- sensors, thanks to the large surface area sensitive to absorption and subsequent change in e.g. electrical resistance (polymer conductive nanofiber)
- to be investigated:
  - structural applications, reinforcement fiber, e.g. for antiballistics
  - insulation
  - selective gas permeation (breathing, BC protective fabric)
  - carbon nanotube polymer composite fiber (high strength)

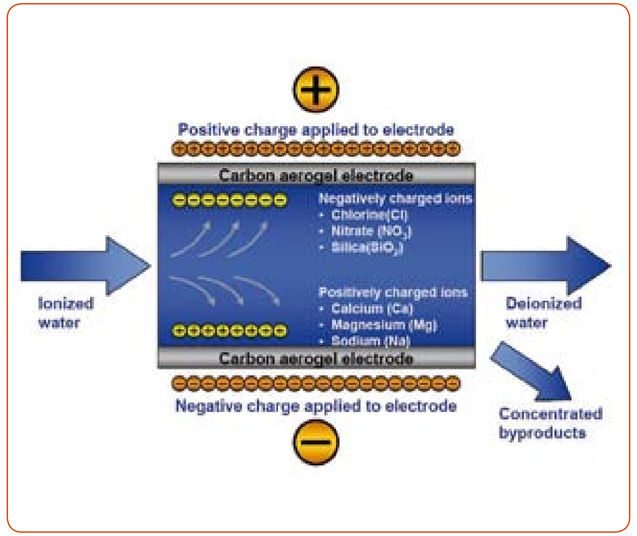
Tensile strength

The tensile strength of nanofibers has not been researched much. First experiments with nonwoven mats indicate that the tensile strength increases significantly with reduction of the fiber diameter: e.g. going from a 6 micrometer fiber to a 60 nm fiber resulted in a 10 fold tensile strength. The increase is expected to originate from:

- increase in number fiber-to-fiber bonds
- orientation of the polymeric molecules in the fiber length direction

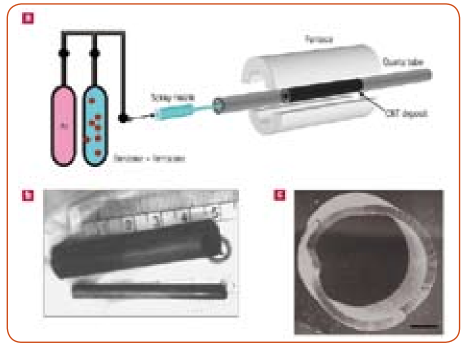


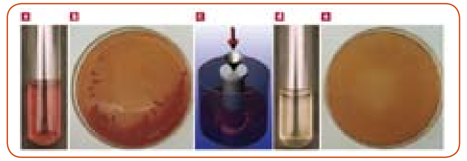
nanoporous nanoparticles (iron) as efficient, selective adsorbents



electrodeionisation with carbon aerogel


lifesaver bottle


radially aligned nanotubes creating hollow cylindrical filter


filtration of e-coli polluted water with CNT-filter

Nanotechnology for purification: nanowater

Water-treatment plants have been using nanofiltration and ultrafiltration membranes to separate good water from polluted for many years now, but the technology and the use of nanomaterials is still increasing.

Nanotechnology water treatment devices

Given the importance of clean water to people in developed and developing countries, numerous organizations are considering the potential application of nanoscience to solve technical challenges associated with the removal of water contaminants. Technology developers and others claim that these technologies offer more effective, efficient, durable, and affordable approaches to removing specific types of pollutants from water. A range of water treatment devices that incorporate nanotechnology are already on the market and others are in advanced stages of development. These nanotechnology applications include:

- Nanofiltration membranes, including desalination technologies
- Attapulgite clay, zeolite, active carbon and polymer filters
- Nanocatalysts (e.g. TiO_2 particles under UV-light)
- Magnetic nanoparticles; and
- Nanosensors for the detection of contaminants.

Lifesaver bottle

The lifesaver bottle (UK) contains a membrane system with 15 nm pores preventing bacteria and viruses to pass. In combination with a standard dirt filter, active carbon and a hand-operated pump it can be used to transform any (sweet) water into drinking water.

Nanofiltration and desalination

Nanofiltration membrane technology is already widely applied for removal of dissolved salts from salty water, removal of micro pollutants, water softening, and wastewater treatment. Nanofiltration membranes selectively reject substances, which enables the removal of harmful pollutants and retention of nutrients present in water that are required for the normal functioning of the body. It is expected that nanotechnology will contribute to improvements in membrane technology that will drive down the costs of desalination, which is currently a significant impediment to wider adoption of desalination technology.

Source materials for nanofilters include naturally occurring zeolites and attapulgite clays, which can now be manipulated on the nanoscale to allow for greater control over pore size of filter membranes. Researchers are also developing new classes of nanoporous polymeric materials that are more effective than conventional polymer filters.

Nanocatalysts and magnetic manoparticles

Researchers expect that nanocatalysts and magnetic nanoparticles will enable the use of heavily polluted water for drinking, sanitation, and irrigation. Using catalytic particles could chemically degrade pollutants instead of simply moving them somewhere else, including pollutants for which existing technologies are inefficient or cost prohibitive. Magnetic nanoparticles, when coated with different compounds that have a selective affinity for diverse contaminating substances, could be used to remove pollutants, including arsenic, from water. Companies are commercializing these technologies and researchers are frequently publishing new discoveries in this area.

Nanotube filters

An exciting development is the membrane filter made from 100% CNT's (carbon nanotubes): here the carbon nanotube itself is used to filter the water. Because of the small internal diameter, only water is transported through the tube and other components such as bacteria, viruses, heavy metals, human acids, endotoxins and middle and large sized molecules are excluded. Surprisingly, the pressure drop is very little and the water flux very high. The advantages are:

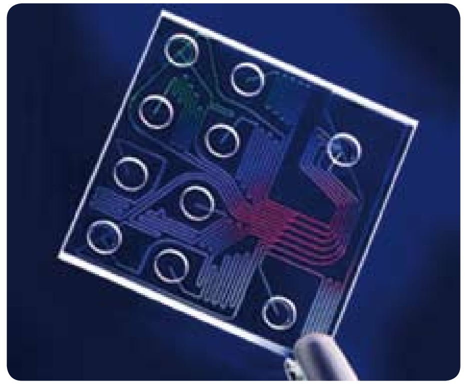
- highly efficient
- low pressure loss
- additional adsorption is possible via functionalisation

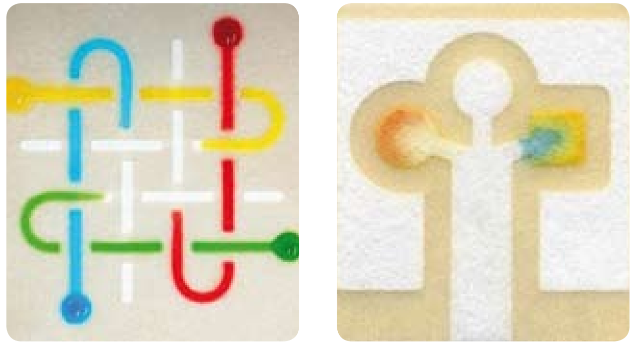
Capacitive deionisation with carbon aerogels

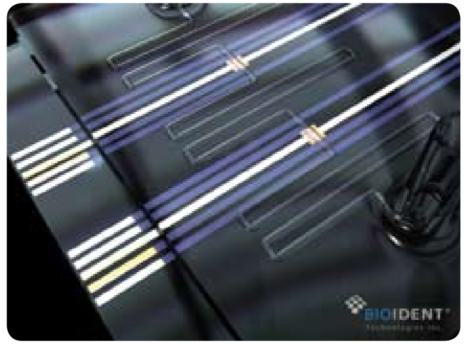
Carbon aerogel is an unique material with a very high specific surface area, up to 4000 m2/gram, that lend itself to some extremely useful applications for capacitors (see nano battery) but also for water purification. For instance, when a voltage is applied across two adjacent sheets of carbon aerogel submerged in water:

- Between 1 to 3 volts, the carbon aerogel can remove contaminants from the water in a process known as capacitive deionization.
- Above 3 volts, the carbon aerogel breaks the water down into hydrogen and oxygen in a process known as electrolysis.

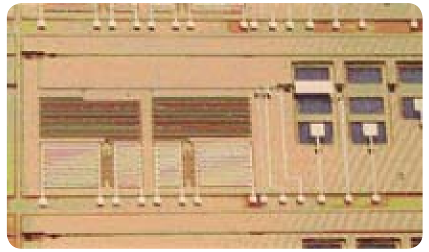
disease diagnosis with a phone

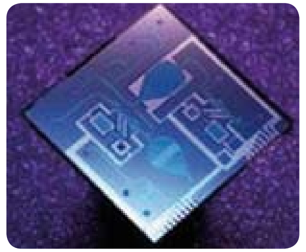

polymer lab on chip with microfuidics (Agilent)

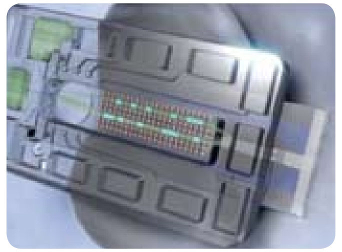

lab-in-paper



printed photonics on lab-on-chip


detail of a lab on chip with nanofluidics and sensors


lab on silicon chip


integrated readout

Lab-on-chip at point of use

A lab-on-a-chip (LOC) is a device that integrates one or several laboratory functions on a single chip of only millimeters to a few square centimeters in size. LOC's deal with the handling and multi-parameter analysis of extremely small (micro) fluid volumes down to less than pico liters. Existing microfluidic lab-on-chips are generally made from comparatively expensive materials like silicon, glass, or plastic with tiny pumps and valves in combination with sophisticated readout equipment such as lasers and advanced CCD-camera ssytems. This has restricted their use to laboratory environments ("chip in lab"). Eliminating expensive cameras and other optical components will reduce the size and cost of these biosensor systems making a handheld sensor possible. This next generation should provide a real portable diagnostic systems that can be used at the point of need.

Printable lab-on-chip

A new technology from Bioident integrates highly sensitive printed photodetectors and electronics with various existing lab-on-a-chip (LOC) technologies including lateral flow, microfluidics and microarrays This so-called photonic lab technology eliminates the need for large, expensive external readout systems and opens up new opportunities for applications in medical in-vitro diagnostics, chemical and biological threat detection and environmental water testing. The printing of electronic sensors will reduce their cost and enable faster manufacturing times and the ability to cheaply do small batches of different sensors.

Lab-in-paper

By taking advantage of the natural movement of liquid through paper, microfluidics technology can b e made much cheaper (Whiteside, Harvard Univ.) The result is a disposable diagnostic tests simple and cheap enough for abundant use. The minilab is made up of layers of patterned paper, between which are waterproof double-sided tape. Each square of paper -which naturally soaks up liquid in its fibers- has been treated with photoresist, hydrophobic material, to create channels that funnel liquid to tiny wells coated with proteins or antibodies and nanodyed reagents. The fluid interacts with that area of the paper and turns the well a certain color, changing hues, for example, with varying concentrations of glucose or proteins. A pinprick of blood or drop of urine soaked up at the edge of the device moves naturally through the paper into the different test zones. White to brown shows the presence of glucose, while yellow to blue indicates protein. The system is being commercialized by the start-up company Diagnostic for All, especially for use in developing countries.

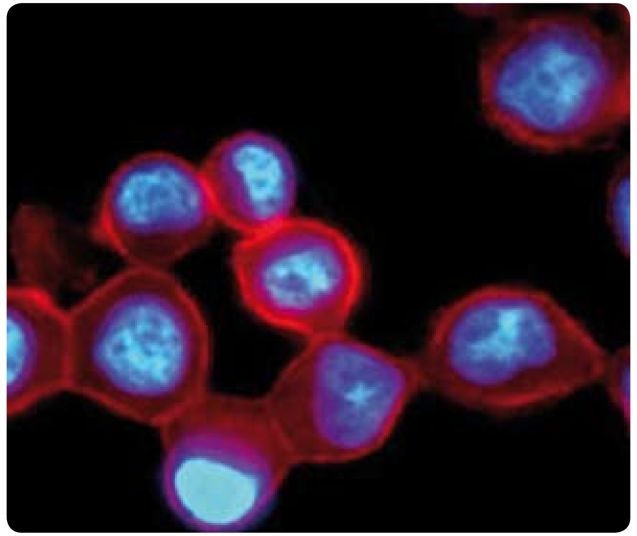
Lab-on-phone

A standard cellphone can be converted into a portable blood diagnosis machine (UCLA). The phone modification is able to detect HIV, malaria and various other illnesses. The device works by analyzing blood cells that are placed on the integrated camera sensor and lit up with a tiny filtered light source. The light source exposes unique qualities in cells and from their the camera runs special software which interprets the data and determines the state of the cell structures.

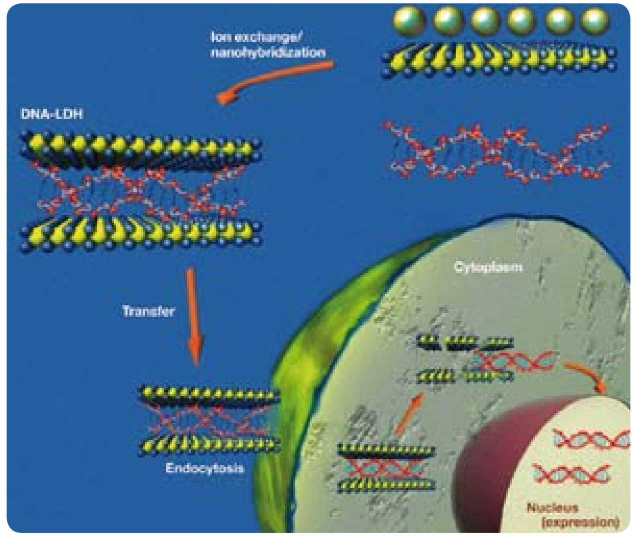
Lab-on-chip for DNA profiling

When a fluid containing thousands of electrically-charged microscopic silica beads is in contact with the surface of a DNA microarray, the Brownian motion of the spheres provides measurements of the electrical charges of the DNA molecules (Berkeley). This can be used to interrogate millions of DNA sequences at a time and what's more with a simple hand-held imaging device even a cell phone camera will do. The electrostatic interactions on the microarray surface result in charge-density contrasts that are readily observed. Surface areas containing DNA segments take on a frosted or translucent appearance, and can be correlated to specific hybridizations that reveal the presence of genes, mutations and pathogens. It is shown that changes in surface charge density as a result of specific DNA hybridization can be detected and quantified with 50-picomolar sensitivity, single base-pair mismatch selectivity, and in the presence of complex backgrounds. The electrostatic detection technique could render DNA and RNA microarrays sufficiently cost effective for broad world-health applications.

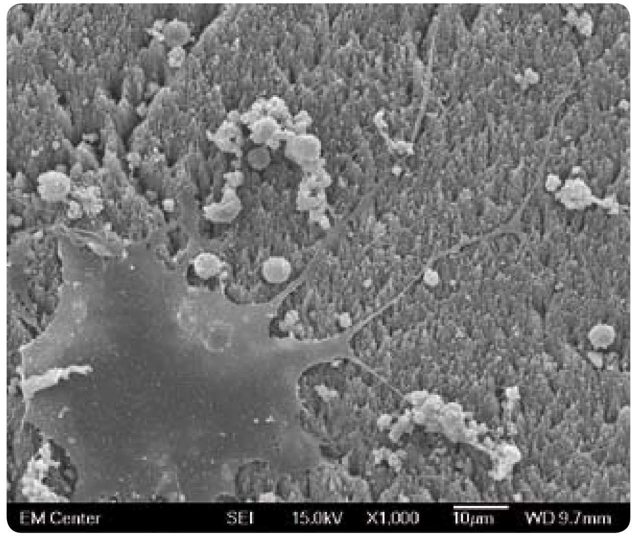
targeted drug delivery



quantum dot labelled (imaged) breast cancer cells



LDH nanoparticles as drug delivery carrier into cells



stemcells on polycaprolacton (PLC) nanowire scaffold

Nanomedicine

The ageing population, the expectations for better quality of life and changing lifestyle of the society lead to the need for improved, more efficient, and affordable healthcare. Nanomedicine is defined as the application of nanotechnology in medicine and is expected to lead us to new diagnostic tools, advanced drug delivery systems, and new ways to treat disease or repair damaged tissues and cells.

Diagnostics for early identification and diagnosis

This area ranges from biosensors to contrast agents and therapeutic molecules:

- high sensitive nano-bio sensor devices for detection of (early) biomarkers in blood, urine, saliva or breath, preferentially via single molecule detection
- quantum dots as efficient optical marker for protein reactions
- target specific nanostructures as reporter platforms and contrast enhancing agents for in-vivo imaging techniques such as MRI, CT, PET and ultrasound imaging, especially for cancer
- high resolution theranostics: combination of diagnostic (targetted contrast agents) with therapeutic molecules (e.g. radio isotopes)

Drug delivery and controlled release

Lipid or polymer-based nanoparticles are taken up by cells due to their small size, rather than being cleared from the body. These nanoparticles can be used to shuttle drugs into cells which may not have accepted the drug on its own. Main developments in this field:

- nanoparticles that can release on demand pharmaceuticals, triggered by bioreaction or by external forces (ultrasound, heat, radiation, inflammation, magnetic triggering).
- biodegradable fine dispersed microspheres of polylactide (PLA) and its copolymers with glycolide (PLGA) for local drug delivery (Nanomi)
- dendrimer (1nm diameter) nanoparticles loaded with DNA that can be transfected into cells to repair malfunctioning of cells; dendrimers do not trigger immune respons
- drug delivery microchip technology, implantable (e.g. automated glucose delivery)

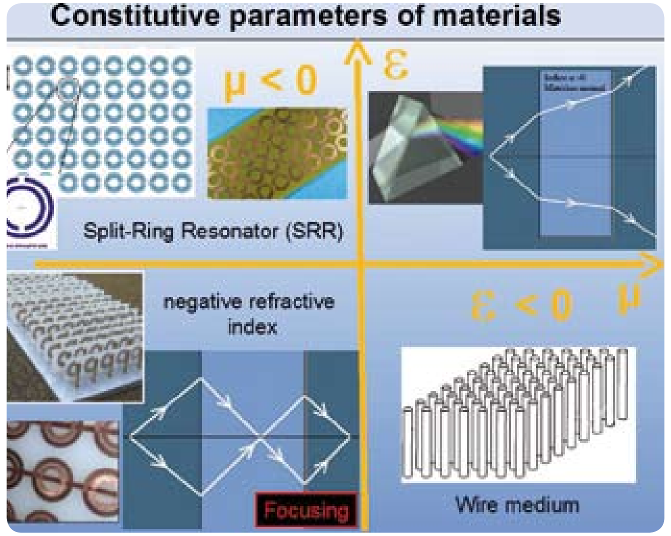
In-situ tissue repair

In regenerative medicine, nanotechnology is applied in order to stimulate the body to generate in-situ new cells via:

- bioactive (dna carrying) particles that induce specific cell growth
- biomimic nanostructures in scaffolds for optimal uptake and growth of new cells
- molecular nano motors to synthesize drugs, repair damaged DNA, and releasing drugs in a cell. A first example is an ATPase bonded to a nanoscale nickel pedestal.

Artificial organs

Nanomaterials can be used for selective filtering and purification of the blood e.g. for chronic diseased renal patients, liver disease and for patients suffering from septic shock and acute poisoning. A nice example of such a development is the wearable, extracorporeal artificial kidney of Nanodialysis. In combination with a micropump and nano/microsensors, a wearable device is created for the purification of blood.

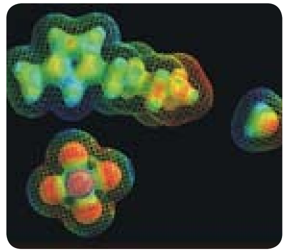


bending of light with resonating metamaterials (Judith Spiegel)

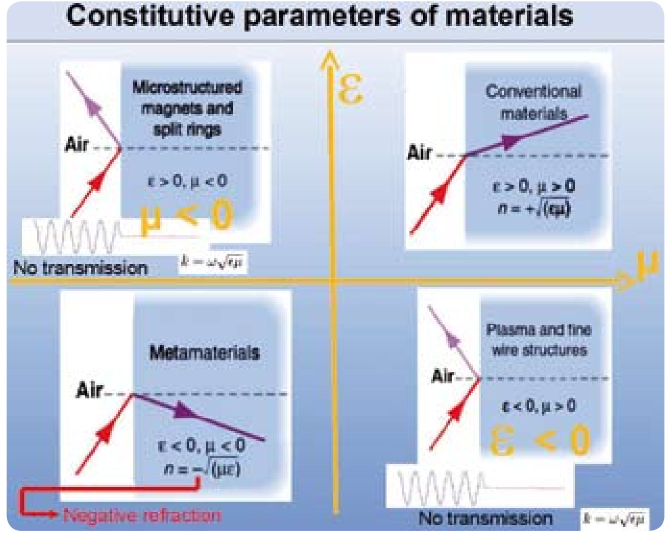
B2 plane, stealth by design

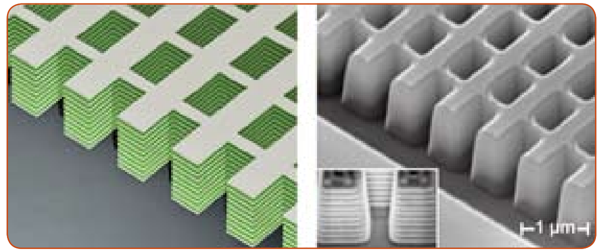
stealth ships Helsingborg and Visby

lightweight carbon foam



ionic liquid molecule





microwave resonator structures

invisible tank

Invisibility with left-handed metamaterials showing a negative refactive index.

The next generation of stealth ships, vehicles or planes could be virtually invisible to the human eye, roaming radars, and heat-seeking missiles, as well as disguising their sound vibrations and their impact on the Earth's magnetic field. If optical and radar metamaterials could be developed, they might provide a way to make a ship or a vehicle invisible to both human observers and radar systems, although the challenges of building a cloak big enough to hide an entire ship are huge.

Left-handed metamaterials

So-called metamaterials consist of stacked micro- or nanostructures with resonator capabilities for electromagnetic radiation such as radar, infrared en visible light radiation. At the resonator frequency these structures can show a negative refractive index. This occurs when both the permittivity ε and the permeability μ have negative values. Normal materials have positive values for both the permittivity and permeability and are called right-handed materials. Materials with negative ε and μ are called left-handed materials. The "EM-radiation resonator" metamaterials show negative values at the resonator frequencies.

Negative refractive index: radiation bends around objects

With a negative refractive index, incoming radiation is not being reflected or absorbed by the material, but it will be guided and transported along its surface just like in waveguides. The radiation is bended around the object. It means that you can not see through the object but your are able to see around the object. to see what is behind the object, without seeing the object itself. Several research groups such as Duke University, Purdue, Ames, UC Berkeley (USA), Louvain La Neuve (B), Imperial College (UK) and the Karlsruhe and Stuttgart University (Germany) have proven the concept and have built prototype materials. At first at microwave (radar) wavelengths, but since 2007 also for visible light: a refractive index of -0,6 was reported at a wavelength of 780 nm (joint effort Ames and Karlsruhe).

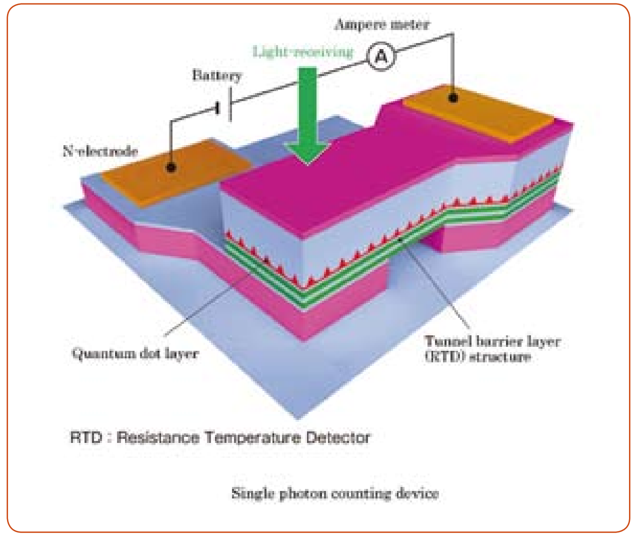
The application of an "invisible cloak" based on metamaterials can be foreseen in the area of radar stealth since it concerns a system that should work at a distinct radar (micro)wavelength. For visible and infrared it should work for a broad wavelength spectrum, which will need considerable future development and time.

Alternative 1: radar absorption with carbon nanotubes

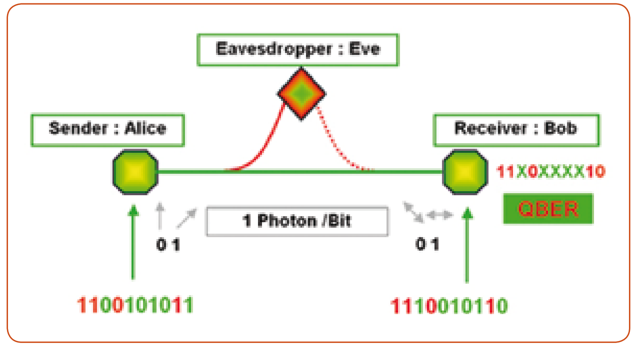
One of the most commonly known types of radar absorbing material (RAM) is iron ball paint. It contains tiny spheres coated with carbonyl iron or ferrite. Radar waves (100 MHz - 100 GHz, typically 8-12 GHz in military) induce molecular oscillations from the alternating magnetic field in this paint, which leads to conversion of the radar energy into heat. The heat is then transferred to the aircraft and dissipated. A related type of RAM consists of neoprene polymer sheets with ferrite grains, carbon black or carbon nanotube particles (30% load) embedded in the polymer matrix. Thin absorbing layers are capable of producing good absorption (≥25 dB) with restricted bandwidths by a combination of attenuation within the material and destructive interference at the interface. The electromagnetic properties and the thickness of the layer are such that the initial reflected wave and the sum of the emergent rays resulting from the multiple reflections within the material are equal in magnitude and opposite in phase. The thickness of the layer is close to a quarter-wavelength at the frequency of operation, giving a 180° phase difference between the interface reflection and the emergent waves.

Alternative 2: radar absorption with ionic liquids

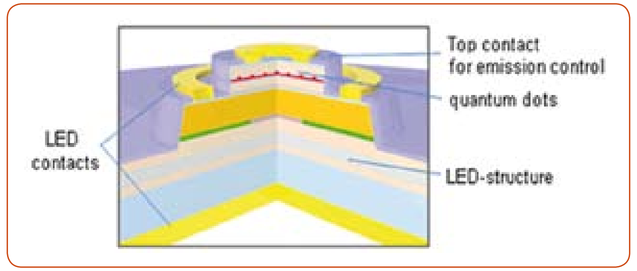
This alternative method of microwave absorption involves the use of poly(ionic liquid)s, which contain separated cations and anions, having very strong microwave absorption properties. Researchers have shown an ability to synthesize ionic liquid polymers by polymerizing monomers containing ionic liquid moieties using free radical polymerization or atom transfer radical polymerization, or other polymerization techniques. These polymers are extremely stable. These poly(ionic liquid)s or their copolymers have high microwave absorption properties due to the presence of high concentration of anions and cations. They can be fabricated into various shapes such as films, formulated into coating, painting or other applications. They have many potential applications, especially in military (University of Wyoming).



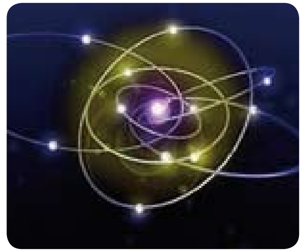
single photon counting device

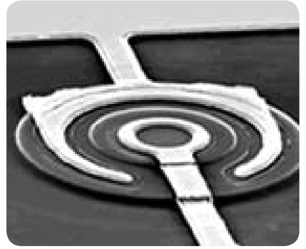


quantum cryptography principle



construction single photon source with quantum dots




single photon source with quantum dots

Quantum cryptography

Cryptography is about scrambling information so that it is unintelligible to anyone but those who know how to decode it using a secret key. Up until today, existing cryptosystems use software solutions based on mathematics to distribute keys. Mathematics are penetrable - an intruder can copy a classical key, decode it and expose data leaving no evidence of his snooping.

Quantum Cryptography is a new approach to the key distribution problem and is the absolute security technology to protect voice, data or video communications. Instead of transmitting keys, this technology generates them dynamically using quantum physical phenomena which makes unbreakable security possible for the first time.

The difference with Quantum Cryptography is the sender simply transmits a string of bits to the receiver whose values are carried by single photons. If an intruder tries to intercept them, their state will irreparably changed. The sender and receiver will detect eavesdropping and the transmitted string of information is discarded. These suspect bits will not be used to establish the key. Only undamaged photons provide risk-less information to forge a step-by-step secret key.

In digital cryptography, an intruder's attack can be undetectable. The intruder is able to make identical copies of transmitted messages and then perform extensive computer analysis off-line. This is unnoticeable espionage and with today's traditional cryptosystems, there is no defence against this type of interception.

In contrast, Quantum Cryptography will always detect intruders and eradicate eavesdropping. If an intruder attempts to clone the information carried by the photons riding on the optical link between legitimate users, quantum mechanics guarantees that this attack will lead to disturbance. Both users postpone sending any valuable information until the security of the optical link is assured.

For the very first time in the history of cryptography, unbreakable communications via optical links are made possible by using the laws of quantum physics.

Advantages of Quantum Cryptography

Quantum Cryptography fulfils some of the digital cryptography security functions. It therefore provides a brick of additional security to existing digital cryptography systems.

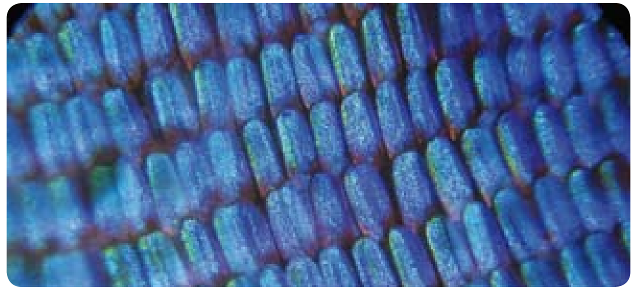
- It gives the ability to provide absolutely secured keys
- It gives the ability to detect intruders and eradicates espionage on optical networks
- It allows high-speed key updating
- It simplifies the key management and suppresses the risk due to key saving
- It provides timeless security based on the universal laws of quantum physics
- Finally, it removes the human risk within the security chain

Single-Photon devices for quantum cryptography communications

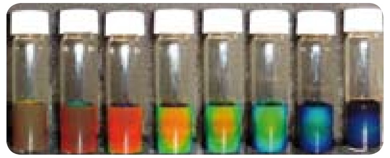
The ultimate in cryptography communications, is the development of single-photon detection devices that make possible low-noise, high-speed operation and single-photon generation devices with a low incidence of simultaneous generation of multiple photons. State of the art is a high-speed detection device with a dark count probability of 10^{-9} per ns or less and operating frequency of 3 Mhz or higher (Toshiba). It contains a single-photon generation device: within a resonator structure, self-organized InAs quantum dots have been selectively grown on gallium arsenic and confirmed the generation of single photons in the optical communications waveband by electrical drive.

adaptive camouflage with tunable dyes in textiles

octopus vulgaris changes its reflectivity by muscle contraction



tunable diffraction colours (wing of a butterfly)



tunable (by magnetic field) iron oxide quantum dots

Adaptive camouflage

Adaptive camouflage that changes rapidly in response to the environment is in the works. E.g. TNO is using thin, textile-like plastic sheets embedded with light-emitting diodes (LEDs). A small camera scans the environment, and the colours and patterns displayed on the sheet are changed accordingly. Such "chameleon" sheeting is regarded to be an urgent requirement. At first for vehicles and tanks that can be draped with the sheeting and parked in front of a grassy slope displays an image of grass on its exposed side, for example. Once in a flexible and lightweight form it could also used for the soldiers suit.

Several nanotechnology enabled techniques are in development that can be applied for adaptive camouflage, both for suits for the soldiers as well as for vehicles.

- active lighting techniques, mainly based on LED-technologies (micronized solid state LEDs as well as flexible polymeric LED systems) and future quantum well light sources
- passive systems such as tunable photonic crystals

Numerous LEDs integrated into structures or fabric

In reaching a square millimeter or less in size, LEDs can now actually be integrated into fabric. Lumalive has the look and feel of a flexible, lightweight fabric panel. It can be worn or attached under the surface of a garment and turned on to create a moving panel of glowing shapes and colours on shirts, jackets, backpacks, upholstery or curtains. The niftiest part of all is that the technology is completely programmable. The electronics and battery component can be connected to a PC to download images and applications, creating unique materials that carry dynamic messages, graphics, full-colour animation or even text messages. Drapes, cushions, sofa coverings, jackets or shirts can be programmed to "come alive" to showcase a product, to deliver corporate messaging or simply to say hello.

Integrated glass fibers + LED source

The company Luminex is creating a type of luminescent fiber by weaving fiber-optics into fabric. This fabric can be used and treated like any other type of fabric. The fibers are attached to super bright LEDs that are controlled via a microchip with a battery power source. The fibers are colorless by default, but they emit whatever color the microchip instructs them to emit. For example by adding a optical sensor, the clothes glow by constantly changing the colors to match the surroundings. Walk from room to room in a dark club and you'll change colors like a chameleon. Or imagine using audio sensors to make the colors pulsate with the surrounding music.

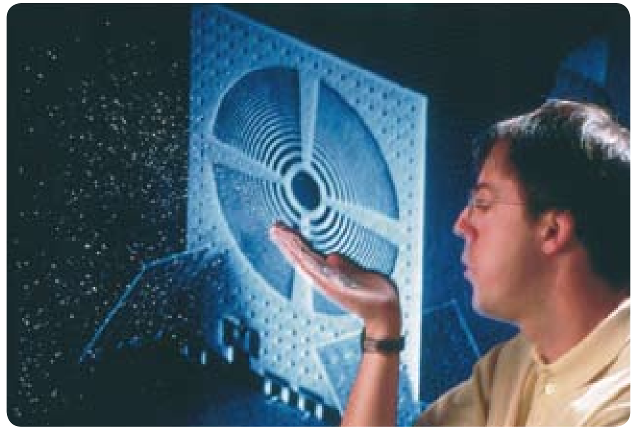
Tunable quantum dots or photonic crystals

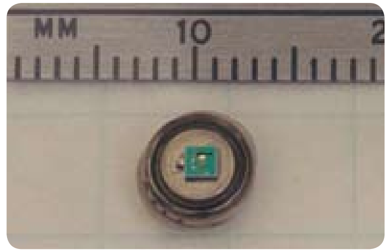
University of California, Riverside nanotechnologists have succeeded in controlling the color of very small, nanosized particles of iron oxide (photonic crystals) simply by applying an external magnetic field to the solution. The discovery has potential to greatly improve the quality and size of electronic display screens and to enable the manufacture of products such as erasable and rewritable electronic paper and ink that can change color electromagnetically. The photonic crystals show brilliant colors, and these iron oxide crystals are the first examples of photonic crystals that is fully tunable in the visible range of the electromagnetic spectrum, from violet light to red light.

Tunable reflectivity biomimicking nature

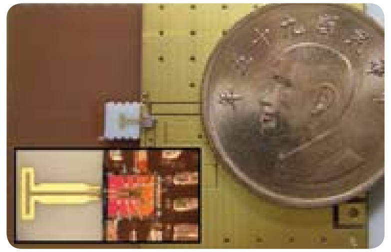
Such a system would e.g. resemble the way the octopus vulgaris changes its colour by changing it's reflectivity via muscle contraction and subsequent stretching and alignment of small platelets in upper part of its skin. Some butterflies have wings with nanosized, transparent, chitin-and-air layered structures that selectively cancel out certain colors through wavelength interference while reflecting others, depending on the exact structure and interspatial distance between diffracting layers. This system of producing and changing colour allows for the dynamic control of light flow and wavelength interaction, which butterflies rely upon for camouflage, thermoregulation, and signaling.

stackable smart dust chip module


nanoelectronic devices as small as dust



smart dust mote (UC Berkeley)


60 GHz WiFi system on a chip

Ubiquitous sensor network

In our world we have become familiar with devices to sense light (photocells), sound (microphones), ground vibrations (seismometers), and force (accelerometers), as well as sensors for magnetic and electric fields, radiation, strain, acidity, and many other phenomena. From the metal detectors we pass through at airports to the smoke detectors that protect our homes, our modern civilization is utterly dependent on sensors.

While the concept of sensors is nothing new, the technology of sensors is undergoing a rapid transformation. The progress in nanotechnology that already have evolutionized the computer, electronics, and biotech industries is converging on the world of sensors from at least three different directions:

- Smaller: rapid advances in fields such as nanotechnology and micro electro-mechanical systems (MEMS) have not only led to ultra-compact versions of traditional sensors, but have inspired the creation of sensors based on entirely new principles. Examples are the electronic nose and the cantilever molecular sensor
- Smarter: the exponentially increasing power of microelectronics has made it possible to create sensors with built-in “intelligence”. In principle, at least, sensors today can store and process data on the spot, selecting only the most relevant and critical items to report
- More Mobile: the rapid proliferation of wireless networking technologies has cut the tether. Today, many sensors send back their data from remote locations, or even while they’re in motion.

Nanotechnology is very enabling for the development of a new range of sensors. Thanks to miniaturization down to micron & nano level the following features can be realized:

- function integration: enabling sensing, data processing, storage and wireless communication in a network, all integrated in one chip
- multi parallel analysis for high throughput
- matrix arrays for better sensitivity and directional information
- high sensitivity towards single cell/molecule detection and zeptogram (10^{-21} gram) sensitivity
- efficient thermal and material transport, less chemical waste, low power consumption
- energy scavenging (solar, temperature, mechanical) for continuous power supply
- portable, wearable, point of analysis and self operating in remote locations
- enabling mass production, low cost, disposable

Ad-hoc networking

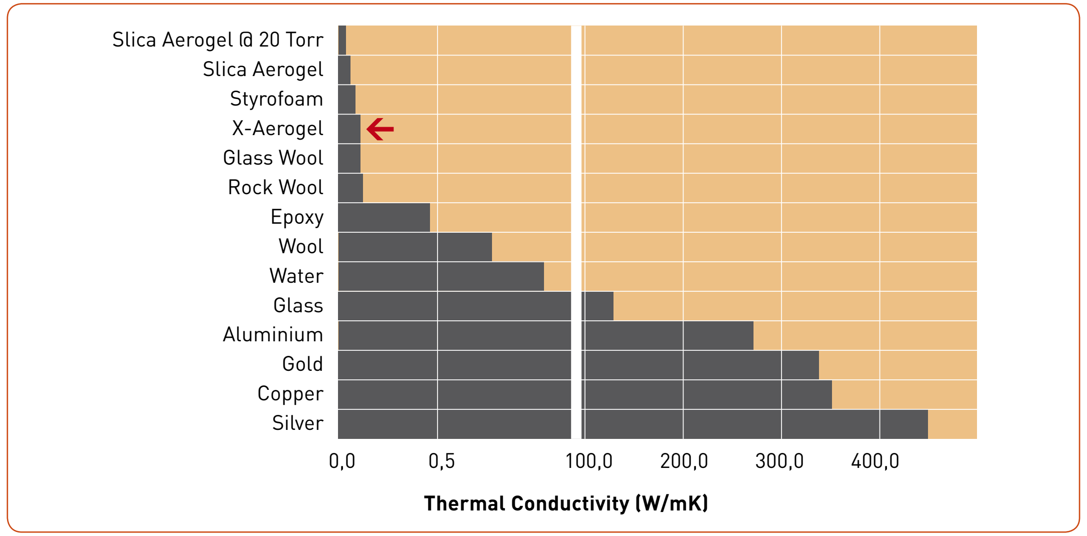
Out in the field, where there is no Internet, sensors have to get their data back to headquarters via wireless networking technology. Each one passes bits on to the next, creating their own network on the fly and ad-hoc network. Once the sensors are in place, they automatically reach out to find their nearest neighbors, and then form the network links that can transmit the data.

Of course, these connections can be pretty chancy. Not only are they generally restricted to very low power, very short distances, and very low data rates, but the sensors themselves are miles from any tech support. They are out there with no protection from being soaked, baked, frozen, buried, stolen, stepped on, or even eaten.

But thanks to the numerous sensors, the ad-hoc network as a whole is far more robust than any one device. If any of the links is blocked or broken, the sensors will automatically reach out and find new links to replace them.

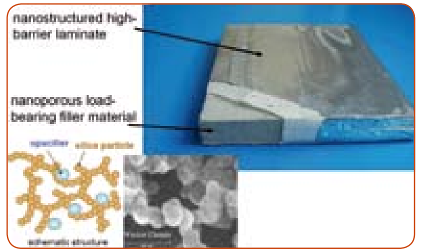
Smart dust

Smart dust refers to tiny, wireless networks of sensors. You also could think of the sensors as tiny chips, or even miniature robots. The smart dust detects data about light, temperatures or vibrations and transmits that data to larger computer systems. Researchers hope to shrink these devices to the size of a speck of dust via nanotechnology -- the science of building molecule-size electronic devices. Some scientists see smart dust as quite possibly a game-changing technology. “Smart dust will be one of the central industries of tomorrow,” futurist Alvin Toffler told Investor’s Business Daily. That’s the future. The reality is that after more than a decade of work, smart dust networks haven’t reached their promise as a technology that will revolutionize medicine, security, space exploration and more. At least not yet.

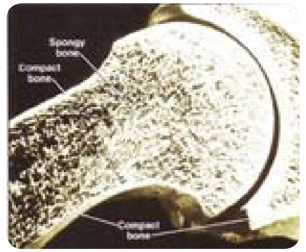



lightweight airship

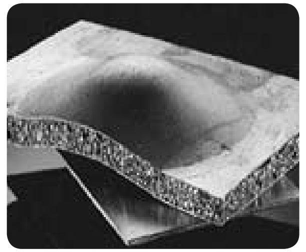

super lightweight insulating aerogel

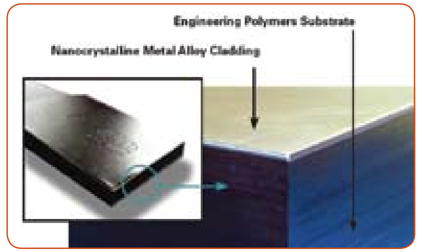


vacuum insulator panel VIP



bone structure with graded porosity


biomimic aluminium porous structure



nanocrystalline metal/polymer hybrid

Nanoporous aerogels

The so-called aerogels are material structures from SiO2 or carbon with a very large nanoporosity. They are usually formed via a sol-gel process to built spatial molecular networks with a high density of nanopores filled with air. The internal surface area is 2000-4000 m^2/gram and the density is typically around 50 mg/cm3. Aerogels use to be mechanically weak, fragile and non-stable against moisture but NASA has developed a versatile polymeric crosslinked SiO2 aerogel compound (X-Aerogel, 0,05 W/mk) that has mechanical flexibility and better resistance against moisture. Next to that, carbon aerogels are in development as a lightweight storage medium for electricity (supercapacitors) and energy (H2).

Biomimic porous structures

Using porous structures in analogue to the structure of natural bone is an effective and by mother nature proven method for weight reduction. It is a well copied concept in the polymeric world, but attempts to obtain such a strong porous structure from metals has failed in the past due to the lack of a suitable process technology. Sintering of metal powders does not give sufficient strength. A relative new process is using nanoparticles as a foaming agent during aluminum production. Herewith a fine microporous structure with closed pores can be created in aluminum (Metcomb, Austria).

Nanocrystalline metal/polymer hybrids

A new nanocrystalline metal/polymer hybrid technology is used to manufacture lightweight components with the strength and stiffness of metal combined with the design flexibility and benefits of high-performance thermoplastics (MetaFuse, a joined Dupont and Integran technology). A significant gain in tensile strength (30%) and a threefold stiffnes and impact strength can be realised e.g. with components made from 25% glass-reinforced PA66 polymer, injection molded into ISO tensile bars and then cladded with 100 microns of nickel/iron nanocrystalline (20-50 nm grainsize) metal alloy encapsulating the bar.

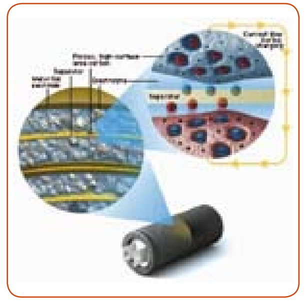
Vacuum insulation panel

Vacuum insulation panels consist of a nano-structured core material, after evacuation tightly sealed in a thin film high barrier envelope, sometimes supplemented with a getter and/or a desiccant. The low gas and water vapour pressure in the pores of this core material is responsible for the high thermal performance of the product. These can be up to ten times more energy efficient for the same thickness than insulation materials currently in use.

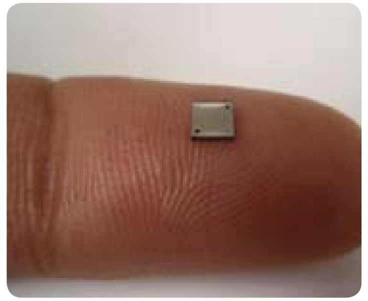
Overview

Technology-materials	Energy density (MJ/liter)
Ultracapacitor	0.05
Lead acid battery	0.15
Flywheel	0.50
Li-ion battery	1.50
Fuel cell	1.60
Li-ion nanowire battery	2.62
Ethanol	24.0
Gasoline	34.6

Property	Supercapacitors	Capacitors	Micro-Fuel Cells	Batteries
Charge/Discarge Time	Milliseconds to Seconds	Picoseconds (10^{-12}) to miliseconds	Typically 10 to 300 hrs. Instant charge (refuel)	1 to 10 hrs
Operating Temperature	-40 tot+85ºC	-20 to +100ºC	+25 to +90ºC	-20 to +65ºC
Operating Voltage	2,3V - 2.75V/cell	6 to 800 V	0.6 V/cell	1.25 to 4.2 V/cell
Capacitance	100mF to> 2F	10 pF to 2.2 mF	N/A	N/A
Life	30,000+ hrs avarage	>100,000 cycles	1500 to 10,000 hrs	150 to 1500 cycles
Weight	1 g to 2 g	1 g to 10 kg	20 g to over 5 kg	1 g to over 10 kg
Power density	10 to 100 kW/kg	0.25 to 10,000 kW/kg	0.001 to 0.1 Kw/kg	0.005 to 0,4 kW/kg
Energy Density	1 to 5 Wh/kg	0.01 to 0.05 Wh/kg	300 to 3000 Wh/kg	8 to 600 Wh/kg
Pulse Load	Up to 100 A	Up to 1000 A	Up to 150 mA/cm2	Up to 5 A


carbon aerogel supercapacitors 20-200 F/gram


sunglasses made from semi-transparant solar cells


very small (3 mm) fuel cell

Nanomaterials for portable power

Energy supply is essential for present and future combat systems. For the wearable garments, head protection and handweapons of the future soldier wearable energy supply is needed for integrated sensors and functions in combat suit and helmet (lifesign and BC sensing, communication, ventilation/heating). Secondly new energy supply systems with low weight will enable the powering of mini and micro UAVs.

Miniature power sources

The future of wireless (nano or micro) sensoric and communication devices will very much depend upon the progress in miniaturization of the power or energy supply. The following small scale energy systems are in development:

- high peak power, short endurance
  - advanced flywheels (not nano)
  - super capacitors
- medium endurance, medium peak power
  - various battery systems, nanotechnology assisted
  - flexible thin film batteries
- long endurance, low peak power
  - fuel cells
  - μ-nuclear battery
- long endurance, medium peak power
  - micro combustion engines

More and more effort goes in to hybrid systems of recharchable batteries and energy harvesting such as:

- solar battery power pack: combined thin film battery with thin film solar cell
- energy scavengers, e.g. electricity from vibrations, radiation, temperature
- remote charging with RF

Portable fuel cells

Fuel cells rely on nanoporous membranes and nano-structured catalysts. Fuel cells are available in various sizes, capacities and fuel types. Two examples:

- 3 L (10x10x30cm), 50 W, 3kWh solid oxide fuel-cell running on 2.5 kg propane (Nanodynamics)
- 0.01 mL (3x3x1mm), 0.35 W, 10Wh, hydrogen fuel cell (Univ. Illinois)

Rechargeable Li-batteries

Rechargeable batteries store electrical energy in a chemical form, with the top end of the market dominated by lithium. Nanocomposites of metal oxide nanoparticles are being developed for the cathode, which offer higher density lithium intercalation, improved diffusion and excellent electrical conductivity. For the anode, carbon-based materials and metal alloys offer the tensile strength to cope with the increase in volume changes during the charging cycle. It has the potential to provide a 3x higher energy electrode material.

Supercapacitors

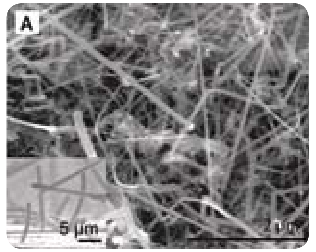
Supercapacitors (or ultracapacitors) differ from rechargeable batteries by storing electrical energy directly as charge on sets of electrodes, which are separated by an insulator and covered with a thin coating of electrolyte. For supercapacitors, the electrode surface area determines the power density. Therefore nanocrystalline materials, carbon nanotubes and aerogels, are all being developed, as they have a large surface to volume ratio. These systems offer a capacitive storage upto 200 F/gram.

Solar Cells

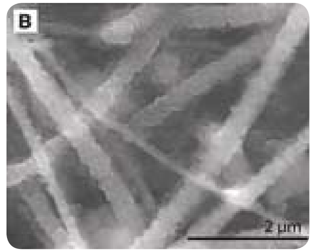
The mainstay is the silicon solar cell which accounts for 90% of the market. However these are costly to manufacture and have limited efficiency (around 14% in most production modules, and up to 25% in the lab). Top efficiencies of 34% are achieved with multi-layer III-V semiconductors (GaAS/InSe/GeTe), however the cost of such solar cells is sufficiently great that they are used primarily in niche applications (space satellite systems). Nanotechnology advances are seen to offer solutions for both costs and efficiency. New nanotechnology based developments are:

- organic dye-sensitised solar cells (or Grätzel cells) using a dye molecule to absorbs a photon and TiO2 nanoparticles to capture the electrons. The costs of such devices are up to 60% lower than silicon based cells, however the efficiency is also low (a maximum of 10% in lab models).
- quantum dots solar cells are predicted to be the highest because the absorption can be tuned to any wavelength of visible light, by altering their size (or composition). As a result three electrons per photon can be generated, compared with one for existing silicon based technologies. An overall efficiency of 86.5% could be achieved.

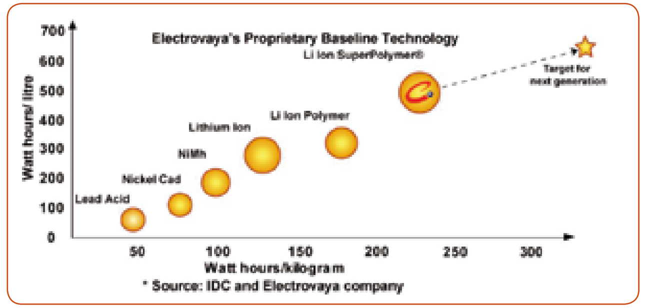
li-ion battery with nano vanadiumoxide



nanowires before absorbing lithium



nanowires after absorbing lithium



Battery technology

With the growing market in wearable electronics, electric vehicles and (future) robotics, the need for lightweight batteries with a high energy density increases rapidly. Over the last decade's impressive progress in Li-ion technology has been made compared to the old lead-acid battery types.

Energy density of Li-ion battery technologies

Lithium-ion batteries are widely known through their use in laptops and consumer electronics. The traditional lithium-ion chemistry involves a lithium iron-phosphate, a cobalt or manganese oxide cathode and a graphite anode. This yields cells with an impressive 160Wh/kg energy density and good power density, and near lossless charge/discharge cycles. The downsides of traditional lithium-ion batteries include short cycle lifes (hundreds to a few thousand charge cycles) and significant degradation with age. New variations on lithium-ion chemistry are aimed to provide extreme power density, fire resistance, environmental friendliness, very rapid charges (as low as a few minutes), and very long lifespans. Both the cathode and anode materials should allow for a high capacity (density) and fast (charging speed) intercallation of Li-ions into their structure: this is greatly enhanced by a nanoporous structure. The currently best available Li-ion batteries have anodes made from nanoparticles (nano lithium vanadium oxide).

Nanostructured anodes

The electrical storage capacity of a Li-ion battery is limited by how much lithium can be held in the battery's anode, which is traditionally made of carbon. Much progress in energy density and also charging speeds is expected from future nanostructured anodes. The recent progress with packed nanoparticles from Li-vanadium-oxide as anode material can be further extended by using an aerogel of Li-vanadium-oxide, with significant gain in capacity and weight. It is anticipated that the energy density can reach values of 1000-2000 Wh/kg, a 10-fold increase.

Stanford researchers have found a way to use silicon nanowires for the anode. Silicon has a much higher capacity than carbon, but also has a drawback that it breaks upon uptake of lithium. The nanowires can be grown on a stainless steel substrate, providing an excellent electrical connection.This new technology could also produce 10 times the amount of electricity of existing lithium-ion, known as Li-ion, batteries. A laptop that now runs on battery for 2 hours could operate for 20 hours.

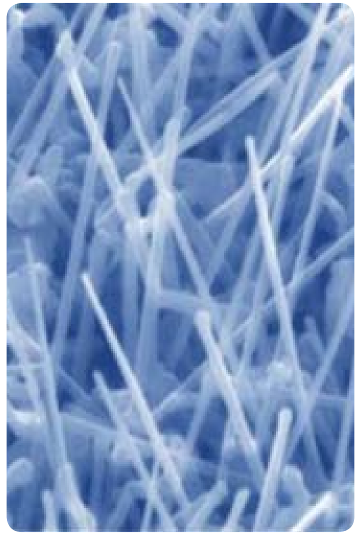
The greatly expanded storage capacity could make Li-ion batteries attractive to electric car manufacturers.

Li-ion conducting polymer

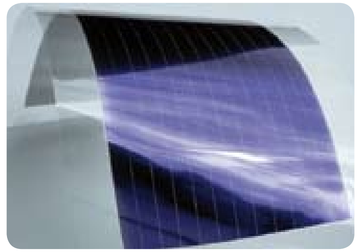
Electrovaya (Canada) provides a nanoporous Li-ion conducting polymer called SuperPolymer between the two electrodes instead of an electrolyte. This greatly improves the performance of Li-ion batteries, see figure on the opposite page. The superpolymer technology based on nanoporous polymers brings traditional Li-ion batteries in the 200-300 Wh/kg domain.

Battery technology Energy density (Wh/kg)

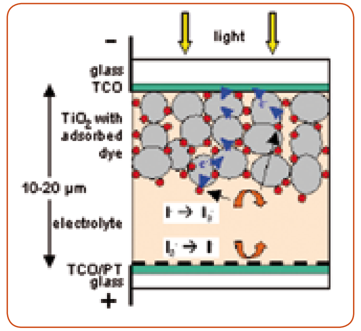
Old: Lead-acid	30-40
Mature: Nickel Metal Hydride	30-80
State of the art: Li-ion	150-300
-Li carbon/iron-phosphate	
-Li vanadium oxide/cobalt oxide,	
-Li polymer	
In development: Na-ion	400
Future: nano Li-ion	1000-2000
- Li-vanadium oxide aerogel	
- Silicon nanowire Li-ion	

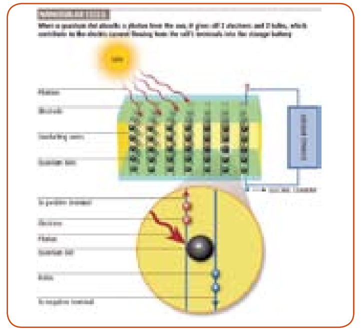


InP nanowire polymer solar cell



flexible photovoltaic cell





DSC working principle with nanoparticle TiO2

Nano for solar

Solar cells, or photovoltaics, convert the energy of the sun into electricity. In theory all parts of the visible spectrum from near-infrared to ultraviolet can be harnessed. The mainstay at present is the silicon solar cell which accounted for 90% of the market. However these are costly to manufacture and have limited efficiency (around 14% in most production modules, and up to 25% in the lab). At the other end of the scale, the state-of-the-art is a multi-junction group III-V semiconductor solar cell, which contains multiple layers (at present two or three) of different semiconductors and has a top efficiency of 34% (examples of such materials include gallium, indium, and germanium; and their compounds with arsenic, selenium, and tellurium). However the cost of such solar cells is sufficiently great that they are used primarily in niche applications (e.g. powering space satellite systems).

Nanowire solar cell

GE has demonstrated a scalable silicon nanowire-based solar cell with 18% efficiency and that can be produced at a dramatically lower cost than conventional solar cells via a roll-to-roll process. The nanowires are being grown on a flexible metal foil and the p-n junctions are conformally created around the nanowires. The cells can be processed in a roll-to-roll coater offering dramatic reduction in costs.

The UC SanDiego developed a solar cell based on InP nanowires on the metal electrode –indium tin oxide (ITO) – and then covered the nanowire-electrode platform in the organic polymer, P3HT, also known as poly(3-hexylthiophene). Once the electron and hole split, the electron travels down the nanowire – the electron superhighway – and merges seamlessly with the electron-capturing electrode. This rapid shuttling of electrons from the p-n junction to the electrode could serve to make future photovoltaic devices made with polymers more efficient.

Organic dye sensitised solar cell, upgraded with nanowires

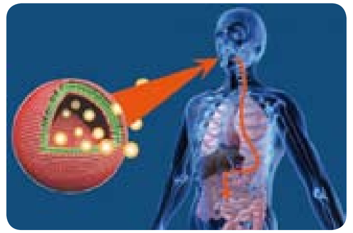
Nanotechnology advances are seen to offer solutions for both costs and efficiency. New devices such as organic dye-sensitised solar cells (so called DSC or Grätzel cells) exploit a similar process to photosynthesis such that the dye molecule absorbs a photon of light and as a result generates electrons, which are transferred to titanium dioxide nanoparticles (to which the dye is tethered) and on to electrodes. The costs of such devices are up to 60% lower than silicon based cells, however the efficiency is also low (a maximum of 10% in lab models, 7% industrial models). UC Berkeley realised that the electron diffusion length in the anode of the DSC could be improved by substituting nanowires for the random polycrystalline network represented by the nanoparticles of TiO2, with as much as several orders of magnitude. They worked with zinc oxide nanowires instead of TiO2, in the form of a dense array of oriented wires doped with the typical chromophore, a ruthenium-based dye. The nanowires are grown from deposited ZnO quantum dots by a simple decomposition process, resulting in 35 billion wires per square centimeter.

Quantum dot solar cells

In terms of efficiency, quantum dots are predicted to be the highest. This is due to the fact that quantum dots can be tuned to absorb any wavelength of visible light, by altering their size (or composition). As a result of this small size they are also more energy efficient, generating up to three electrons per photon, compared with one for existing silicon based technologies. By arranging multiple layers of quantum dots, tuned to absorb different wavelengths, an overall efficiency of 86.5% could be achieved.

Fullerene/carbon nanotube solar cells

Researchers at New Jersey Institute of Technology (NJIT) have developed an inexpensive solar cell that can be painted or printed on flexible plastic sheets. Mitra and his research team took the carbon nanotubes and combined them with tiny carbon Buckyballs (known as fullerenes) to form snake-like structures. Buckyballs trap electrons, although they can't make electrons flow. Add sunlight to excite the polymers, and the buckyballs will grab the electrons. Nanotubes, behaving like copper wires, will then be able to make the electrons or current flow.



nanoencapsulated ingredients

antimicrobial, UV-protective, high barrier packaging

RFID tag for identification

freshness sensor

farming using sensors

Nanofood

The potential benefits of nanofoods - foods produced using nanotechnology - are astonishing. Advocates of the technology promise improved food processing, packaging and safety, enhanced flavor and nutrition and increased production and cost-effectiveness. At the same time, the health concern is growing and there is an increasing need to identify the nature of the possible hazards associated with actual and foreseen applications in the food and feed area and to provide general guidance on data needed for the risk assessment.

Precision agriculture

In the future nanotechnologies will allow precision agriculture using distributed sensors in the field and crop. Smart pesticides or nanocides can be released autonomously on the desired location and time, upon a bio-activated trigger. The future expectations are focused on:

- single molecule detection for enzyme functionality
- nanocapsules for targeted delivery of pesticides, fertilisers, growth hormones, DNA
- nanosensors for monitoring soil, crop growth, pathogens

Nanofood and supplements

Worldwide commercial foods and food supplements containing added nanoparticles are becoming available. A major growth area appears to be the development of ‘nanoceuticals’ and food supplements. For example, if you squeeze an orange and drink it now, you will get vitamin C from it, but if you leave it a while, all the vitamin C will vanish. Putting the vitamin C in nanocapsules can allow it to be released only when it is drunk. Omega-3 fatty acids or tuna fish oil can be added to bread to provide valuable nutrients, while the nano-encapsulation prevents the bread from tasting fishy. The overall prospects are:

- nanocapsules to improve bioavailability of neutraceuticals and flavor enhancers
- nanocarriers that can mask specific flavors of ingredients
- nanocarriers to allow targeted delivery, better absorption, better stability of ingredients
- nanoparticles as gelation and viscosifying agents
- nanodroplets to form nano-emulsions
- nanoparticles for selective binding, removing chemicals and pathogens from food
- nanospheres to form porous fat, reducing the fat content of food

Smart packaging

Novel food packaging technology is the most promising benefit of nanotechnology in the food industry. Companies are already producing packaging materials based on nanotechnology that are extending the life of food and drinks and improving food safety via enhanced diffusion barriers, via antimicrobial and UV-protecting additives. Surface coatings that can identify and repel bacteria, that resist contamination, or can be more easily cleaned. In the future flexible displays, which are based on polymer light emitting diodes, on packaging and containers can offer better ways for displaying information on source, history since production, and nutritional status of products.

- self signaling labels and displays on packaging
- fluorescent nanoparticles to detect chemical or foodborn pathogens
- biodegradable nanosensors for temperature, moisture, time history
- nanoclays in films for better (oxygen) barrier properties and prolonged shelf-life
- transparant UV-protective films based on nano TiO_2 particles
- antimicrobial, antifungal surface coatings (e.g. silver, zinc particles)

self monitoring suit (MIT-ISN)

What are the prospects of nanotechnology for defence

While nanotechnology is in the “pre-competitive” stage, meaning its applied use is limited, nanoparticles are already being used in a number of industries. Nanoscale materials are used in electronic, magnetic and optoelectronic, biomedical, pharmaceutical, cosmetic, energy, catalytic and materials applications. Areas producing the greatest revenue for nanoparticles reportedly are chemical-mechanical polishing, magnetic recording tapes, sunscreens, automotive catalyst supports, biolabelling, electro conductive coatings and optical fibers. Source: NNI

The military use of nanotechnology should lead to higher protection, more lethality, longer endurance and better selfsupporting capacities of future soldiers. Nanoresearch for defence can be divided in various way in different categories.

Nanoresearch for defence can be divided in six categories:

- nano-assembly of materials and parts
- nano-optics
- nanochemistry
- nanoelectronics
- nanomechanics
- nanomaterials

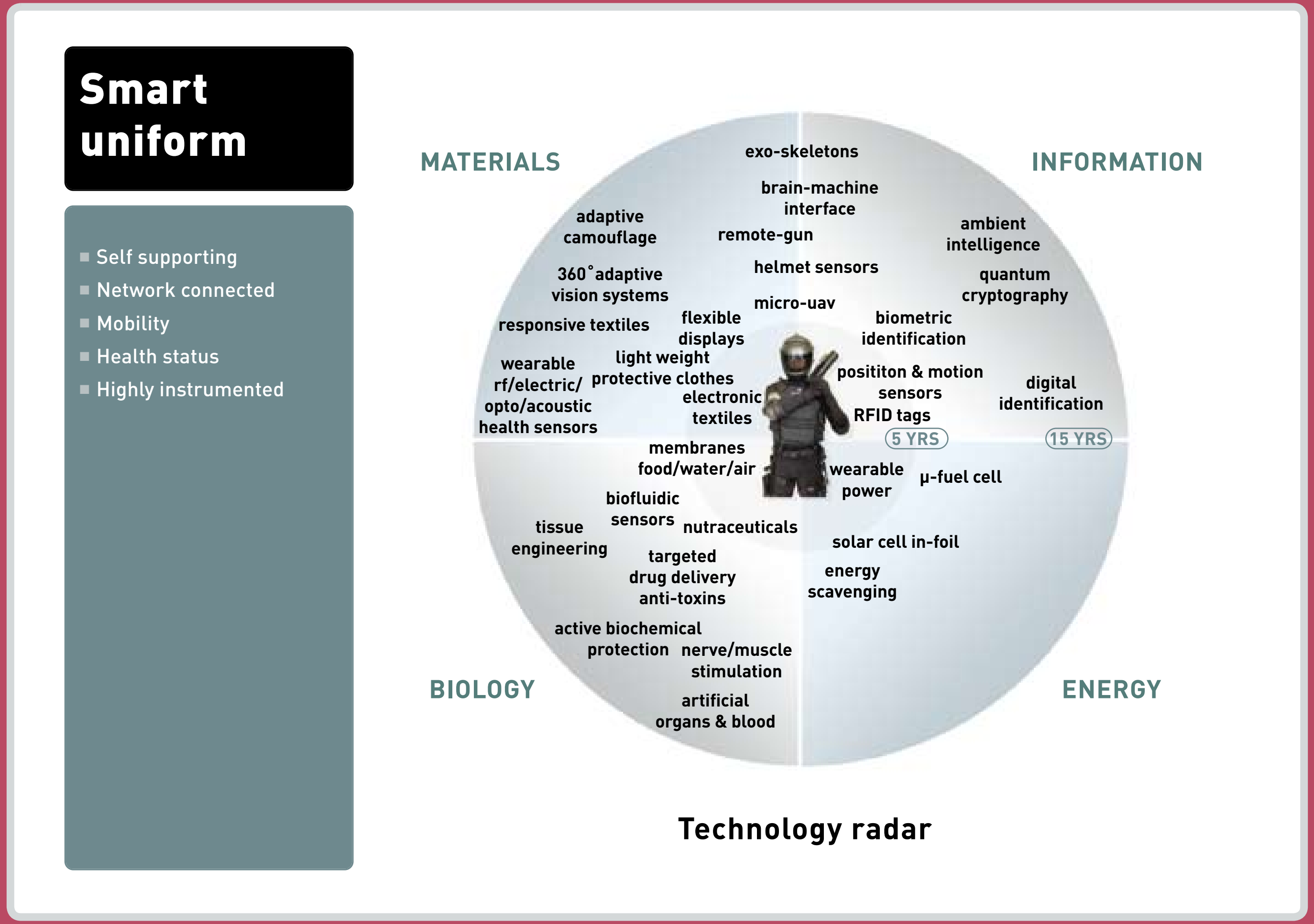
Another main division of nanotechnologies for defence is:

- nanoelectronics
- nanosensors
- structural nanomaterials (reinforced materials)
- nanofibers and nanoparticles

Nanotechnology for defence applications seems to concentrate mainly on five areas (according to NRL):

- the future warfighter or combat soldier
- information dominance
- weapons of mass destruction: CBNRE
- weapons / countermeasures
- platforms

Technological innovations in these five areas will provide the basis for the future defence capabilities.



Nanotechnology for the soldier

Human centric systems are in development in order to secure and optimize human performance and well-being. The systems provide monitoring and feedback functions of the human being in its environment plus protection and support tools. This approach is seen in top sport, medical care, revalidation, first responders, firefighters, police and the military. For military applications it enables better survivability, self supporting ability and mobility, improved group tactics and information intelligence. In practice such systems result in the ability to participate in a mobile information network, use of more comfortable, protective and functional suits, wearable intelligence such as sensors and displays for situational awareness and body condition monitoring. Nanotechnology is here crucial. Without miniaturisation such functionalities can not be adapted to lightweight, wearable systems.

Materials

Nanotechnology enables high strength, durable, sensoric and active materials. Nanostructures and nanocomposites are in development for the following functionalities:

- lightweight protective clothes: flexible antiballistic textiles, self BC decontaminating nanofiber fabric
- adaptive suit: switchable fabric for improved thermal control, switchable camouflage.
- microsensors for body & brain sensing, environmental and situational awareness, to be integrated into a smart suit or helmet
- wearable and/or flexible displays for visual feedback
- auxiliary supports: flexible/rigid textiles for additional
- strength, exoskeletons and robotics to assist the human tasks

Information

In order to operate in a safe and secure wireless network, the soldier will be equipped with:

- miniaturised hardware: sensors, readers, displays and radio transmitters, some of this already present in PDA's and mobile phones
- personal secured access to equipment (biometric id) and information (digital id)

Energy

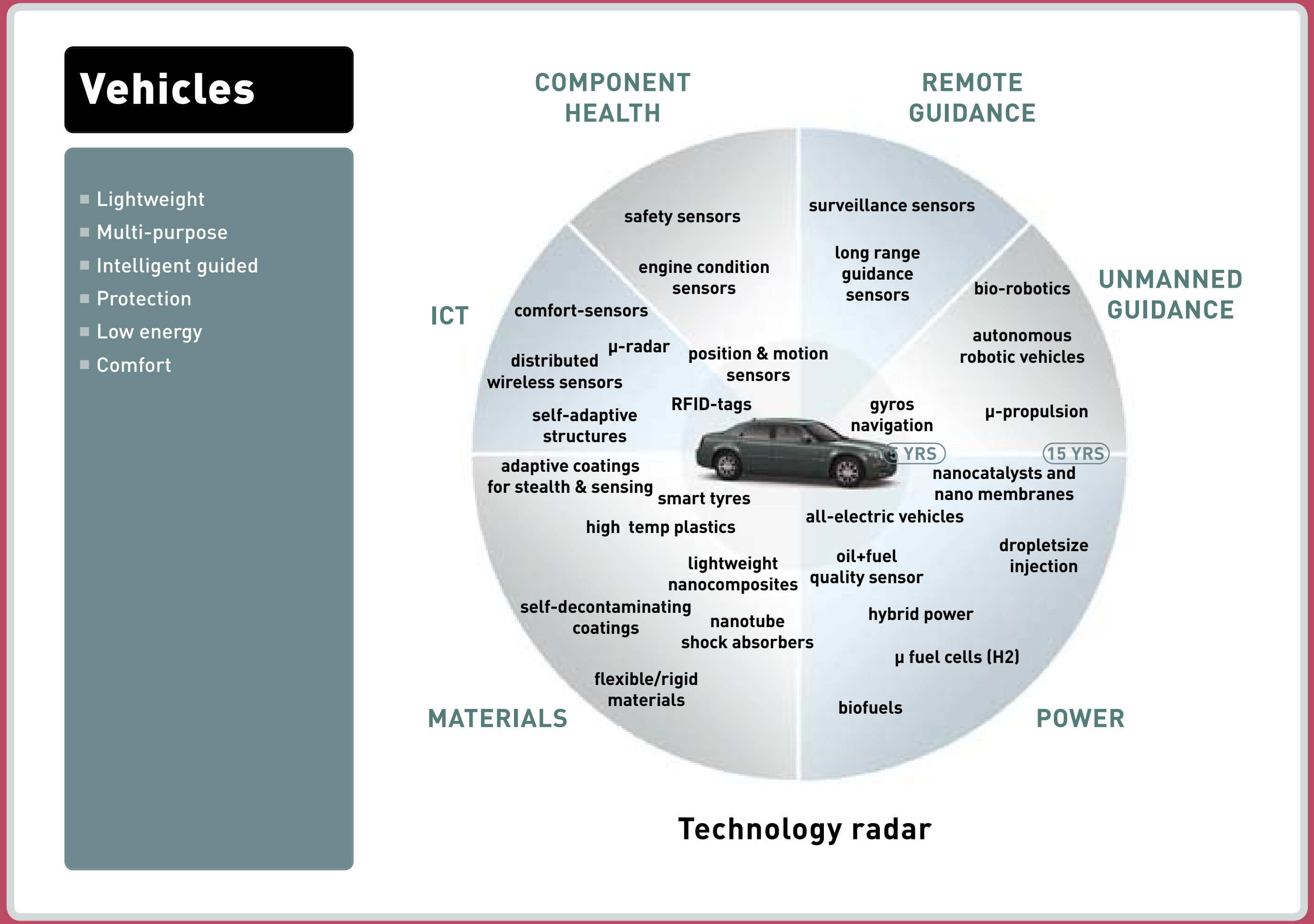
With the increase in wearable functionalities and electronics, the need for lightweight wearable electric power is very critical. The following developments are present:

- flexible solar cells to recharge batteries
- μ -fuel cell, preferentially to be operated by diesel or biofuel, μ-SOFC
- energy scavengers, e.g. electricity from vibrations, for low power applications

Bio

The nano-bio fusion is a booming area with high expectations that major steps in health treatment, body repair and body improvement can be made. It is regarded as the most innovative domain of this moment. Developments are in the field of:

- nanomedicine: targeted drug delivery by medically functionalized nanoparticles, for rapid cure without side effects or human stimulation
- regenerative medicine: DNA programmed tissue engineering for quick and efficient wound healing, rebuilt of organs and other body parts
- smart implants: biocompatible implants that can sense and actuate in order to repair or enhance a body function



Nanotechnology for vehicles

Future vehicles are expected to be lightweight, multipurpose, intelligent guided, low in energy consumption, safe and protective for the passengers and high comfort. This applies both to civil automotive vehicles as well as for military land vehicles. Military vehicles have additional requirements with respect to armour protection, specific detection and surveillance sensors and weapon systems.

Materials

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposite plastics are foreseen to replace metal and by this reduce weight and radar signature
- smart components: components with built-in condition and load monitoring sensors, on long term: self repairing or self healing materials
- adaptive structures: active structures that adapt to changing conditions such as adaptive camouflage, suspension, flexible/ rigid etc
- stealth: radar absorption coatings, camouflage
- armour: nanoparticle, nanofiber reinforced antiballistic structures, reactive nanoparticle armour, shock absorbing nanotubes

ICT

Vehicles are expected to be equipped with the following ICT features:

- position sensing and signalling: GPS for navigation and with EAS for tracking and tracing vehicles
- identification: RFID - tags for remote identification
- security: μ-radar
- wireless networks: vehicle internal sensoric network will become wireless; connection to distributed external network
- directional RF communication: micro antenna arrays enable directional radio communication with reduced power and signature

Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc sensor networks, enabling long range guidance of all kinds of vehicles. Advanced intelligence can be built-in thanks to the expanding μ-sensor capabilities, integration of sensor functions and information processing power. Especially for the military use, continuous effort is put in the development of unmanned and autonomous vehicles e.g. for surveillance. Nanotechnology is crucial here to minimize size, weight and power consumption, important for long range coverage.

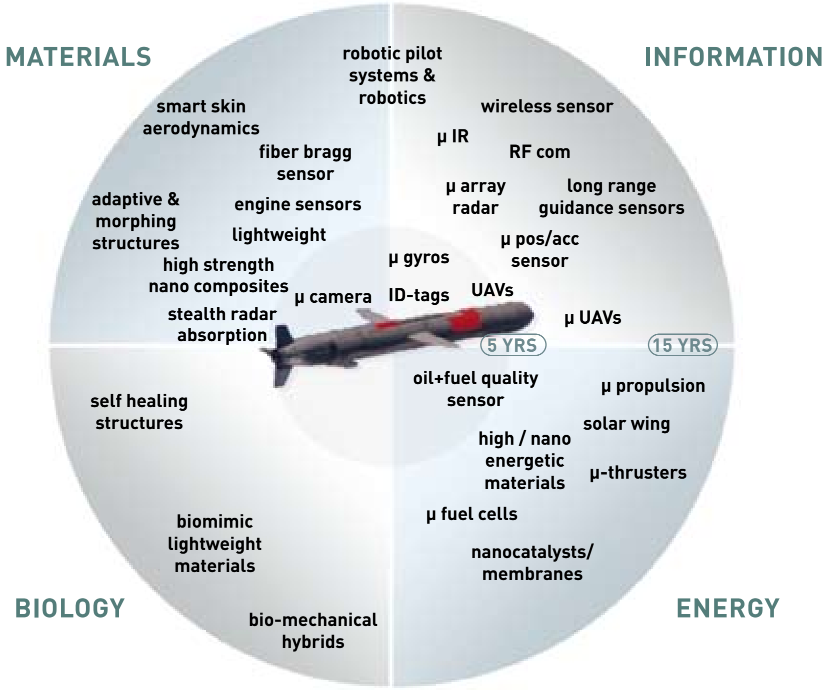
Power

Focus is on lightweight and energy efficient powering. Reduction of thermal, radar and acoustic signature is for the military an additional aspect. Main developments are:

- hybrid and electrical powering, driven by civil automotive, reduces consumption and signature
- hydrogen fuel cell, preferentially with diesel or biofuel (e.g. sugar) as hydrogen source via microreactor conversion
- for miniaturised, unmanned vehicles: μ-fuel cell

Aero-nautics

- Light weight
- Safety
- Intelligence-guided
- Protection / comfort
- Low energy
- High speed
- Adaptive



Technology radar

Nanotechnology for aeronautics

Future fighters and missiles are expected to be lightweight, intelligence guided, low in signature, high speed and manoeuvrable. The onboard intelligence will continuously increase, facilitating automated control and maintenance. Special attention goes to specific detection and surveillance sensors and weapon systems.

Materials

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposite plastics and biomimic (human bone type) structures to reduce weight and radar signature
- smart components: components with built-in condition and load monitoring sensors, such as fiber bragg, on long term self repairing, healing materials
- adaptive structures: active structures that adapt to changing conditions such as adaptive aerodynamics, adaptive skin
- stealth: radar absorption coatings, thermal camouflage
- high energetic propellants: e.q. nano dispersed aluminum as propellant agent

ICT

Aeronautic vehicles are expected to be equipped with the following ICT features:

- position sensing and signalling: position and acceleration sensors, long range guidance sensors
- identification: ID tags for remote identification
- security and guidance: μ-array radar, μ-bolometer (infrared)

Focus is on lightweight and high energy powering. Reduction of thermal signature is for the military an additional aspect. Main developments are:

- nanocomposite energetic material
- for miniaturised, unmanned vessels: μ-fuel cell, μ-thrusters

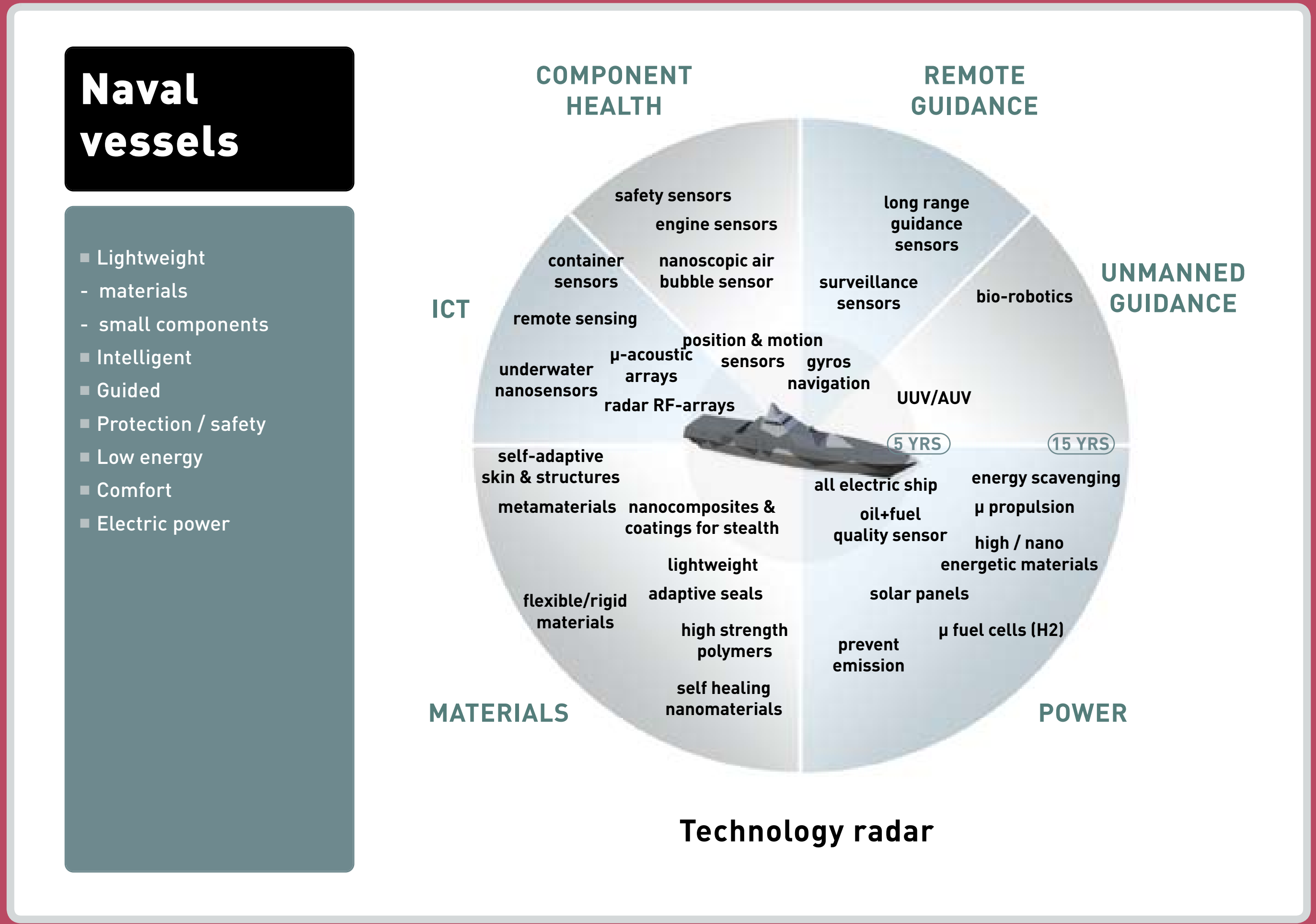
Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc satellite networks, enabling long range guidance. Advanced intelligence can be built-in thanks to the expanding μ-sensor capabilities, integration of sensor functions and information processing power. Especially for the military, continuous effort is put in the development of unmanned and autonomous flying platforms e.g. for surveillance. Nanotechnology is crucial here to minimize size, weight and power consumption, important for long range coverage.

Power

Focus is on lightweight and high energy powering. Reduction of thermal signature is for the military an additional aspect. Main developments are:

- nanocomposite energetic material
- for miniaturised, unmanned vessels: μ-fuel cell, μ-thrusters



Nanotechnology for naval vessels

Future vessels are expected to be lightweight, intelligence guided, low in energy consumption, safe and protective for the passengers and high in comfort. Also onboard intelligence will continuously increase, facilitating automated control and maintenance. Naval vessels have additional requirements with respect to detection and surveillance sensors and weapon systems.

Materials

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposite plastics are foreseen to replace metal and by this reduce weight and signature
- smart components: components with built-in condition and load monitoring sensors, on long term self repairing, self healing materials
- adaptive structures: active structures that adapt to changing conditions such as adaptive aqua dynamics, flexible/rigid etc

ICT

Vessels are expected to be equipped with the following ICT features:

- position sensing and signalling: nanoscopic air bubble, guidance and gyros navigation sensors for navigation and sensing
- identification: RFID - tags for remote identification
- security: μ-radar and μ-acoustic arrays for surveillance
- hydrogen fuel cell
- for miniaturised, unmanned vessels: μ-fuel cell (H2)

Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc sensor networks, enabling long range guidance of all kinds of vehicles. Advanced intelligence can be built-in thanks to the expanding μ-sensor capabilities, integration of sensor functions and information processing power. Especially for the military use, continuous effort is put in the development of unmanned and autonomous vessels e.g. for surveillance. Nanotechnology is crucial here to minimize size, weight and power consumption, important for long range coverage.

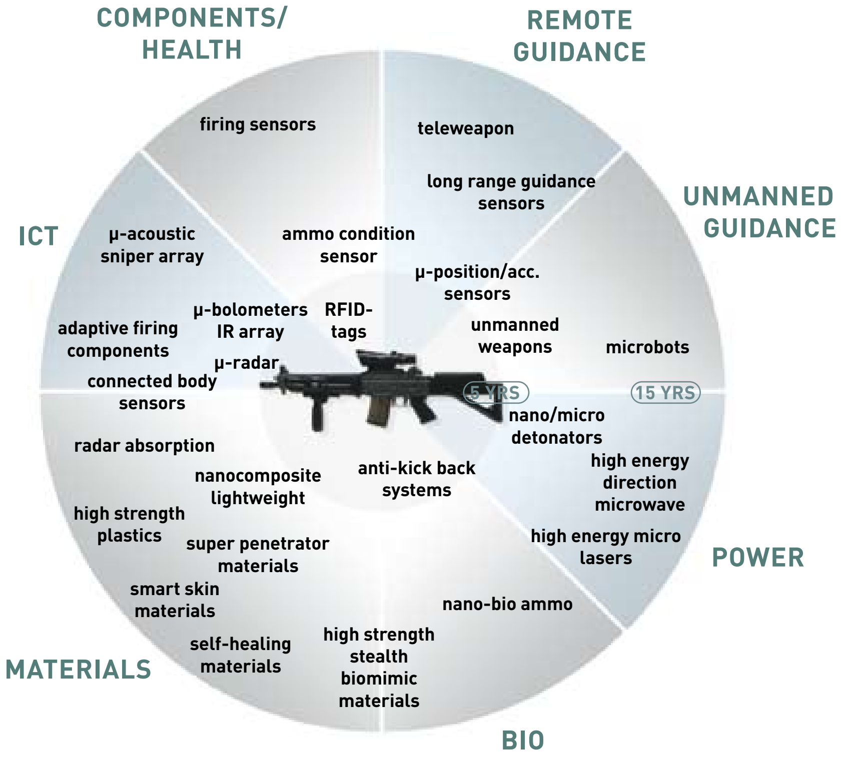
Power

Focus is on lightweight and energy efficient powering. Reduction of thermal, radar and acoustic signature is for the military an additional aspect. Main developments are:

- all electric vessel enabling very low signature
- hydrogen fuel cell
- for miniaturised, unmanned vessels: μ-fuel cell

Weapons

- Light weight
- Safety
- High impact
- Intelligent-guided
- High speed
- Adaptive



Technology radar

Nanotechnology for weapon systems

Developments in weapon technology take place both in the direction of more lethal as well as non-lethal weapons. For lethal weapons the focus is on precision targeting, minimum weight and signature, optimal impact damage. Cheap, onboard intelligence is needed. Non-lethal weapons, to neutralize the enemy temporarily, are relatively new and evolving. They usually make use of energy waves in different forms, directed by array technology. Non lethal weapons are also of interest to civil security services and the police.

Materials

Nanotechnology enables the following material functionalities:

- high strength plastics and nanocomposite lightweight materials: high strength (nanocomposite) plastics
- high strength stealth biomimic materials to reduce weight and radar signature
- radar absorption materials
- smart skin materials: materials with built-in condition and firing monitoring sensors
- super penetrator materials: nanostructured cone materials that sharpen upon impact or give additional damage
- high energetic propellants: e.g. nano dispersed aluminum as propellant agent
- quantum structures for small and efficient directed energy weapons such as directed microwave and high energy directed laser systems
- anti-kick back systems

ICT

Weapon systems are expected to be equipped with the following ICT features:

- sensors: μ-radar, μ-bolometers (infrared) and acoustic arrays for better targeting guidance,
- condition sensors for weapon and ammo
- identification: RFID tags

Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc distributed sensor networks. This enables new functionalities:

- teleweapons: expanding sensor capabilities and wireless communication enables remote operated weapons
- self adaptive targeting: based on feedback from previous impacts
- nano and microbots: miniaturised, autonomous or remote controlled robotic systems with firing capability

Power

Next to high impact weapon systems, non lethal weapons are in development in order to neutralize target groups for a certain time. This is also of interest to civilian law enforcement. Nanotechnology is important to reduce size and weight making these systems suitable as personal weapons. This accounts for: non lethal high energy μ-lasers, microwave, RF or acoustic waves generators

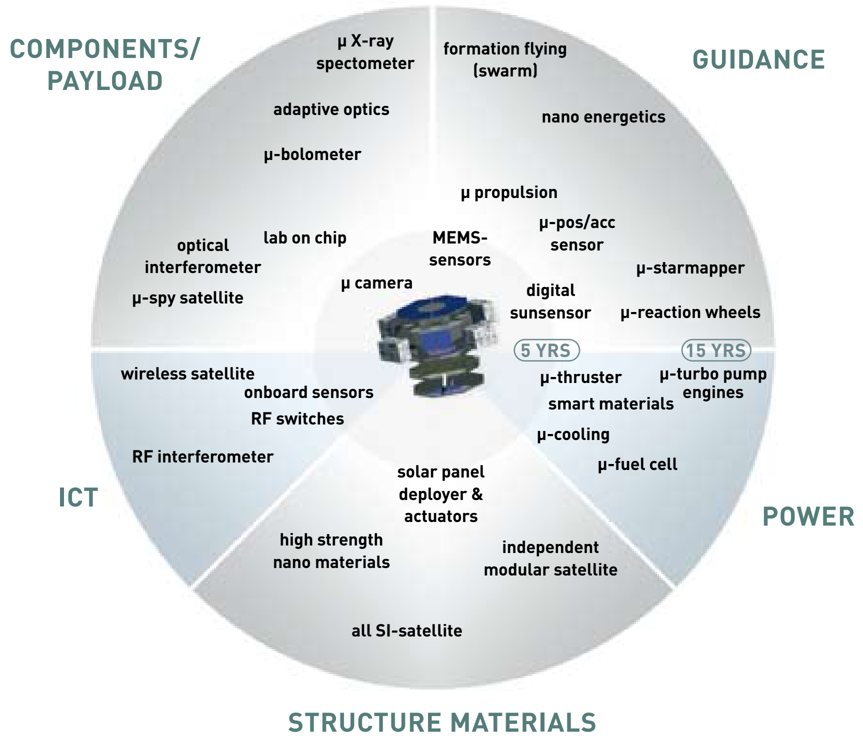
For high impact ammunition, nanotechnology can be used for the following developments: high energetic nanocomposite materials

active denial microwave skin heater

solid state laser on vehicle

Satellites

- Lightweight
- Distributed & redundant systems
- Wireless
- High integration of systems
- Low power
- Many small vs. one big
- Multi sensing



Technology radar

Nanotechnology for satellites

Nanotechnology and microsystems enable miniaturised components and very small satellites having significant lower weight and size than present satellites. This will make them cheaper to manufacture and to lift them into space orbit. Ideally one could launch into orbit a number of redundant micro satellites which can be wirelessly connected to each other. With a distributed network of small satellites instead of one big one, both functionality (multi aperture synthesis for better accuracy, formation flying) as well as redundancy is gained. Each micro satellite has his own power source/solar panels, dedicated sensor system, micro modular propulsion / thruster system, and navigation sensors. It can be expected, that the trend towards smaller satellites will continue in the coming years.

The following classification exists:

- minisatellite 50 – 500 kg
- microsatellite 10 – 50 kg
- nanosatellite 1 – 10 kg
- picosatellite < 1 kg

For military use the swarms of micro satellites can fulfill functions such as observation, inspection, anti-satellite, communication etc. and will be connected to the information gathering and control system. Advantages of small high integrated modular satellites for military purposes are that they can be used as destruction satellites, spy satellites and they can be part of a swarm of satellites, launched at the same time. Destruction (anti satellite) and spy satellites can stick themselves on large satellites without seeing and can destruct important parts of the satellite or it can intercept the communication or observations. Swarm formation flying can give high resolution observations.

Materials

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposites & structures to reduce weight
- nanomaterial enabled solar panels, deployers and actuators
- smart materials for energy solutions and strcuctures
- high energetic propellants: e.q. nano dispersed aluminum as propellant agent

Payload

All components in miniature satellites need to be integrated into microsystems. This accounts for:

- radio communication, position, motion and guidance sensors
- μ-instrumentation: x-ray, bolometer, optical and rf interferometer, lab-on-chip, camera
- security and guidance: μ-radar, μ-bolometer (infrared)

Power

Focus is on lightweight and high energy powering. Main developments are:

- nanocomposite and high energetic materials
- lightweight, flexible and efficient photovoltaic solar cells
- for mini to picosatellites: μ-fuel cell, μ-thrusters

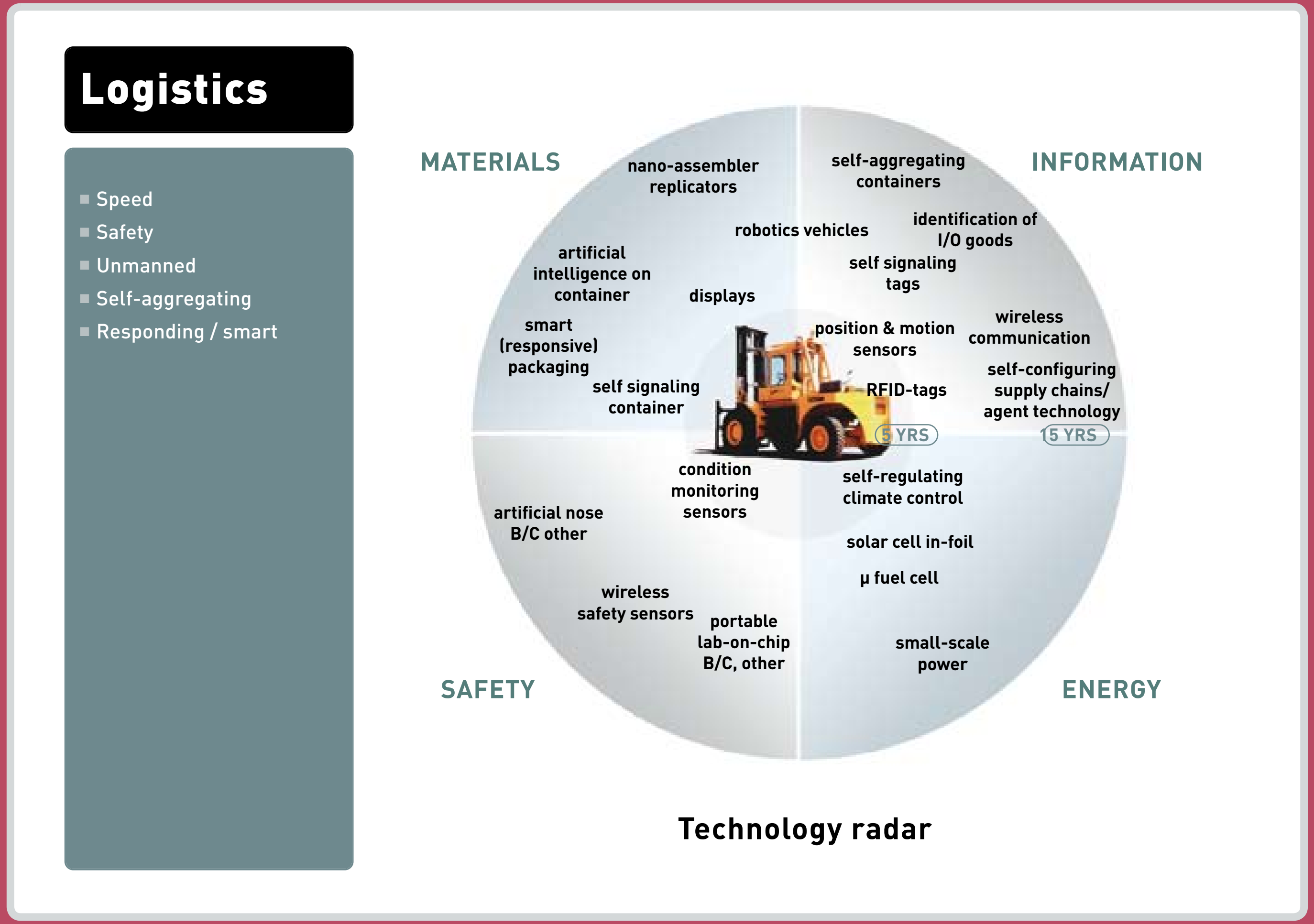
The ultimate goal is to develop a complete satellite-on-chip, the so called picosatellites. Microsatellites (appr. 10-30 cm) are in development in many countries: USA/NASA, UK, France, Germany, Sweden, Spain both for civil and defence applications.

Delfi C3 micro satellite

The Delfi-C3 is a 3 kg CubeSat measuring 10x10x30 cm which flies a new type of thin film solar cells, two autonomous wireless sun sensors and a miniaturized UHF-VHF transponder. It has been launched in 2008. Delfi-C3 is the first in a line of satellites intended for fast and relatively cheap testing of new technologies in space.

cube satellite concept (Swiss)

delfi C3



Technology radar

Nanotechnology for logistics

Technologies for logistics are focussed on two major issues: how to enhance the security and safety of transported goods and secondly how to improve the speed and efficiency of the logistic chain. It gets more and more involved with high tech such as unmanned operations, automated guidance, ict, identification for tracking, tracing and security. Nanotechnology will enable a host of other smarter, more efficient logistics operations.

It is not unrealistic to imagine in the period 15-25 years ahead an almost human-like anticipatory supply chain network that senses and responds in real-time to changes in supply and demand signals across the joint forces and which leverages robotics to accurately deliver critical payloads and materials to designated sites while being controlled by an operator half-way across the world or completely autonomously. A future system that can defend itself via fixed and mobile sensors, and unmanned ground and aerial vehicles, linked to high-precision, multi-platform, strike capabilities for protecting supplies in transit. A future system that employs manned leader vehicles with unmanned and disposable robot followers in convoys in order to automate sustainment and minimize casualties.

Materials

Nanotechnology can offer logistics the following advantages:

- lightweight containers: nanocomposite plastics can replace steel, shock absorbing STF materials reduce impact of G-forces
- self signaling containers: smart materials and sensors (chemical, integrity, vibrations, heat) to alarm for mechanical or chemical deficiencies, displays function
- nanoassemblers that can replicate products: would reduce logistics, at this moment still fiction

ICT

ICT sytems are used for tracking and tracing as well as for security reasons:

- positioning: miniature GPS modules for outdoor positioning, coupling with WIFI-nodes and RFID or UWB-tags for indoor positioning
- identification: RFID, in the future coupled to sensor tags
- condition and health monitoring: wireless sensor tags to monitor and log mechanical, thermal and chemical loads
- self aggregating containers: integrated robotic systems with autonomous logistic handling, futuristic long term development

Energy

Future packaging and containers will need on-board power for electronic and other functionalities. Options are:

- micro or miniature power (combustion) engines
- micro or miniature cooling and climate control devices
- (flexible) solar cells to recharge batteries
- μ-fuel cell, operated by diesel or biofuel (e.g. sugar)

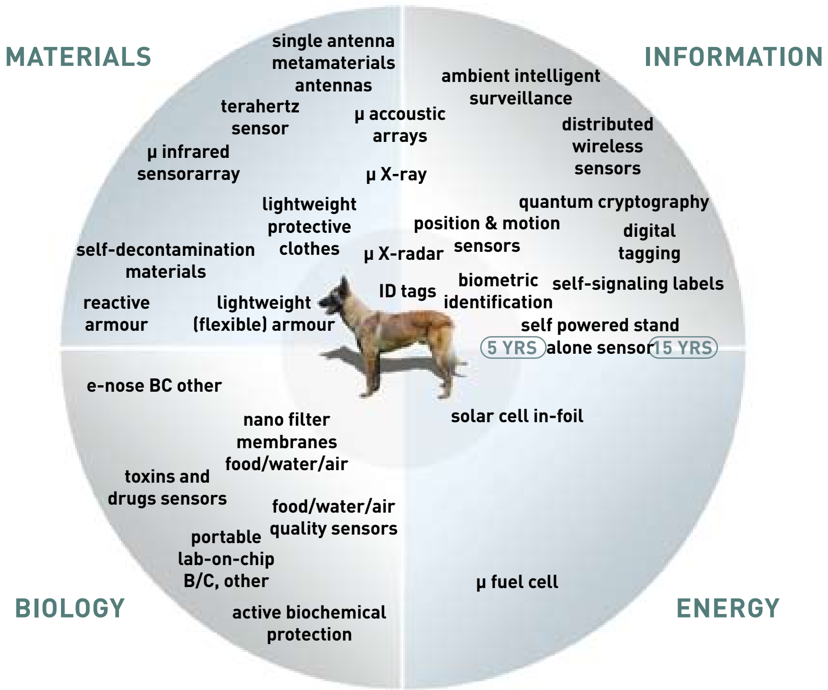
Safety

The safety of packaged and transported goods can be monitored with upcoming microsensors:

- sensor tags that monitor mechanical and temperature loads
- artificial electronic nose to detect gases and vapors
- lab-on-chip systems to detect bacterial or chemical toxins

Security

- Bio-chemical-radiological
- Explosive detection
- Automated scene understanding
  - Optical/infrared/terahertz
  - Acoustical
  - Radar
- Infrastructure protection
- Physical security



Technology radar

Nanotechnology for security

Both for social as well as national security reasons, technologies are in development that enable early detection of (potentially) hazardous conditions, goods and human behaviour. Sensing and detection, surveillance, situational awareness, interpretation, automated scene understanding are crucial aspects.

Materials

Nanotechnology related material developments are in the field of:

- lightweight protective clothes
- antiballistic and shatterproof armour
- advanced sensors and detectors: highly sensitive chemical sensors, high resolution vision systems, RF, infrared, acoustic arrays, terahertz & through the wall radar vision

Information

ICT technology is quite dominant in security systems and will further expand in the future:

- tags: physical identification tags (RFID) for goods, digital ID tags for documents and information
- biometric sensing for personal identification: fingerprint, face recognition, DNA identification
- ambient intelligence for surveillance: by means of distributed wireless sensor networks
- tracking & tracing with position and motion sensors
- secure data transfer with quantum cryptography, enabled by single photon sources and detectors based on quantum dots

Energy

Mobile security systems will need on-board power for electronic and other functions. The options are:

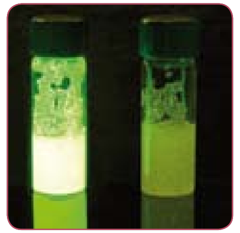
- micro power (combustion) engines
- (flexible) solar cells in foil to recharge batteries
- μ-fuel cells for methane and biofuels and μ-solid oxide fuel-cell (SOFC)

Biology

Microtechnology is in development to detect early hazardous conditions for the human biosystem:

- artificial electronic nose to detect gases and vapours
- lab-on-chip systems to detect and analyse bacterial or chemical toxins
- nanofiltration and photocatalytic decontamination in air, water and food
- B/C protection with catalytic nanofiber structures for filtering and decontamination

unattended remote ground sensor



luminescent explosives detecting polymers (Fido)

handheld sniffer

5.0 potential innovations for operations at land

electronic suit

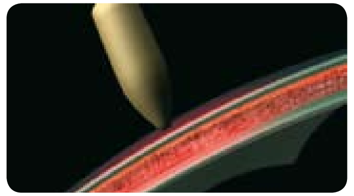
artificial muscles/hand

future force warrior concept Natick

mind controlled bionic arm

UAV launched by hand

solar power on helmet



nanoarmour with magnetic rheofluid

future camouflage

Land defence

Based on the evaluation criteria for future defence operations and the current nanotechnology developments in the civil domain, a short list has been made of the most important nanotechnologies we now foresee to have a foreseeable essential impact on future defence systems and applications.

Lightweight, high strength materials for vehicles and soldier

Nanomaterials offer high strength and ligthweight functionalities. Examples are: high strength carbon nanotube fibers, nanocomposites, nanocrystalline metals, porous and biomimic structures and materials with self healing capability. These materials can be applied for lightweight vehicles and can help to reduce the carry-on weight for the soldier. This is especially the case for lightweight and flexible armour systems for the soldier, featuring higher protection levels.

Tracking, tracing and remote

identification systems via RFID tags (goods, vehicles, people), identification of fellow and enemy soldiers via long range RFID-systems, localize their positions, identify and localize goods and vehicles, check ID, position and quality of preserved food packs.

Sensor systems for high intelligence, surveillance and awareness

A distributed network of sensors can operate autonomously, be self-learning and self-responsive and will evolve in an ambient intelligence system reacting to other elements on the battlefield (soldiers, equipment, environmental influences etc.). Tracking, tracing and remote identification systems via RFID tags (goods, vehicles, people), identification of fellow and enemy soldiers via long range RFIDsystems, localize their positions, identify and localize goods and vehicles, check ID, position and quality of preserved food packs. The RFID tags can be passive or active (able to transmit information without interrogation), can have an incorporated sensor function and can possibly have a radar reflection characteristic for positioning and identification on large distances.

Smart structures and robotics

Nanoparticles and nanofibers can perform specific sensor or actuator functions and can be responsive to certain influences. This enables smart structures that can be adaptive, sensoric, actuating, communicative or be stealthly. Applications are foreseen in unmanned μ-vehicles and robotics, both remote & autonomous, to reduce the risk of manned operations. Another aspect of these systems is the ability to identify fellow and enemy soldiers via integrated sensors. Also brain-machine interfaces for remote control of platform and robotic systems will get more dominant in the upcoming 15-20 years.

Small power sources

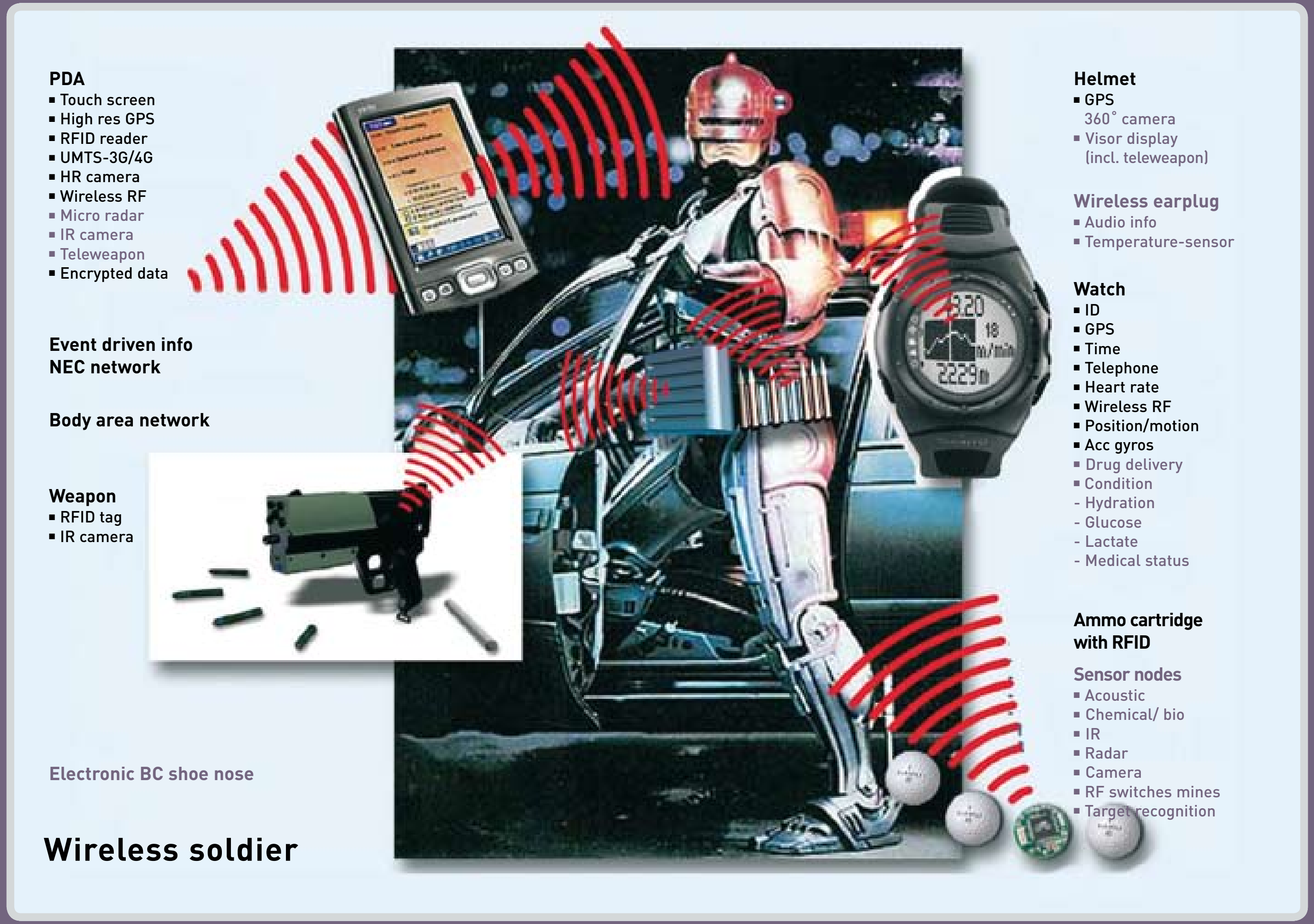
There is an increasing need for micropower that is lightweight and with minimum dimensions. Micropower is necessary to enable the future miniaturisation of devices and is needed as wearable power to energize the electronics and sensors systems of the soldier. Micropower systems will be used to power sensor systems in the combat suit, to recharge batteries of microsystems, to power communication and positioning systems, to power food preparation systems, to power robotic systems and small vehicles.

Nanoelectronics for advanced data processing

The technology roadmap in semicon is being governed by the adage of “more Moore”, saying that almost every two years the performance of semicon components (processor speed, memory capacity, number of active elements etc) is being doubled. This is only possible with subsequent progress in the nanostructuring technologies. At this moment semicon processors can be made in CMOS technology with nanostructures of 45 nm (submerged lithography). It is expected that in the next decade this can be shifted down to 15 nm (EUV technology) leading to a 10 fold increase in performance.

New and lightweight weapon systems

Nanoscaled energetic compounds and powders offer a significantly augmented reactivity and diffusion speed thanks to the high surface area and small interparticle dimensions. Very reactive and fast burning energetics can be made e.g. for ammunition. Also new materials with a high intrinsic energy/weight ratio come into the picture for energetics such as nanosized aluminum particles. This offers weight reduction and long range capabilities for e.g. missiles. By application of appropriate coatings on the nanoparticles, the stability and burning rate can be controlled.



Wireless soldier

Future soldier

Highly instrumented and protected but lightweight thanks to nanotechnology

Human centric systems are in development in order to secure and optimize human performance and well-being. The systems provide monitoring and feedback functions of the human being in its environment plus protection and support tools. This approach is seen in top sport, medical care, revalidation, first responders, firefighters, police and the military. For military applications it enables better survivability, self supporting ability and mobility, improved group tactics and information intelligence. In practice such systems result in the ability to participate in a mobile information network, use of more comfortable, protective and functional suits, wearable intelligence such as sensors and displays for situational awareness and body condition monitoring. Nanotechnology is here crucial. Without miniaturisation such functionalities can not be adapted to lightweight, wearable systems.

The future soldier concept wireless soldier is expected to be equipped with a Body Area Network consisting of a number of wireless products communicating with each other: PDA/mobile phone, helmet/visor with head display, watch, weapon, supplies cartridges, sensors on body or garment. All these systems can gather data, exchange data with each other and can give the soldier the essential info via his PDA, earplug, display, watch etc. The wireless soldier is via phone and PDA connected to the centric warfare system, his commander, the distributed sensor network on the battlefield and his fellow soldiers.

Ambient intelligence for better awareness

Essential part of the wireless soldier is the ability to monitor his position, his physical and mental condition, supplies and status of equipment. His watch or other personal device (PDA/Phone/Smart helmet) will have basic functions like positioning,wireless communication, RFID-reader, heartrate monitoring (wireless), accelerometers but in the future also enhanced body function monitoring can be expected such as dehydration level, glucose level and targeted drug and functional food delivery. The soldier can also distribute sensor nodes to gather and distribute information via micro IR-sensors, microradar, gas sensors, nanobiosensors which form adhoc networks and function as an ambient intelligence system. He will get info via his PDA, phone, watch and via flexible thin film displays on his uniform or in his visor.

Protective and sensoric suit

The future soldier will have an all impact suit enabled by nanomaterials combined with micro or macro fibers, offering protection against bullets, fragment of grenades, bioagents, chemical agents and the influences in combination with the physical status the body (insulation, ventilation, local cooling). The suit will have integrated BC sensors on label or credit card size for the first generation (4-6 years) and integrated nanofiber networks with absorbing, deactivation and decontamination capacity in the second generation (6-10 years).

Lighweight and remote operated weapons

His teleweapon is connected to his PDA and visor and also to his commander from a distance so that ultimate precision and lethality can be achieved.

Smart helmet

His smart helmet is lightweight and has superior anti-ballistic properties due to the use of nanoparticles (bucky CNT-paper, nanofibers) combined with high strength fibers in polymer composite. The helmet contains also a contactless EEG sensor, an air filtering system with gas and particle sensor and is of course part of the Body Area Network.

Auxillaries

In the backpack the soldier will have a basic wound treatment and therapeutics for BC exposure, a medicine and nutrition kit, a portable lab-on chip sampling and sensor system to test his own condition, water, environmental materials and a MUAV (Micro Unmanned Aerial Vehicle) to gather additional intelligence apart from the wireless sensor network on the ground.

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Materials

Nanotechnology enables high strength, durable, sensoric and active materials. Nanostructures and nanocomposites are in development for the following functionalities:

- lightweight protective clothes: flexible antiballistic textiles, self BC decontaminating nanofiber fabric
- adaptive suit: switchable fabric for improved thermal control, switchable camouflage.
- microsensors for body & brain sensing, environmental and situational awareness, to be integrated into a smart suit or helmet
- wearable and/or flexible displays for visual feedback
- auxiliary supports: flexible/rigid textiles for additional strength, exoskeletons and robotics to assist the human tasks

Information

In order to operate in a safe and secure wireless network, the human will be equipped with:

- miniaturised hardware: sensors, readers, displays and radio transmitters, some of this already present in PDA's and mobile phones
- personal secured access to equipment (biometric id) and information (digital id)

Energy

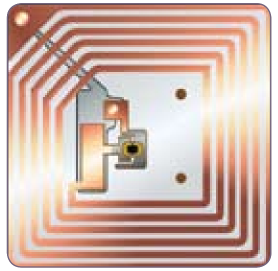
With the increase in wearable functionalities and electronics, the need for lightweight wearable electric power is very critical. The following developments are present:

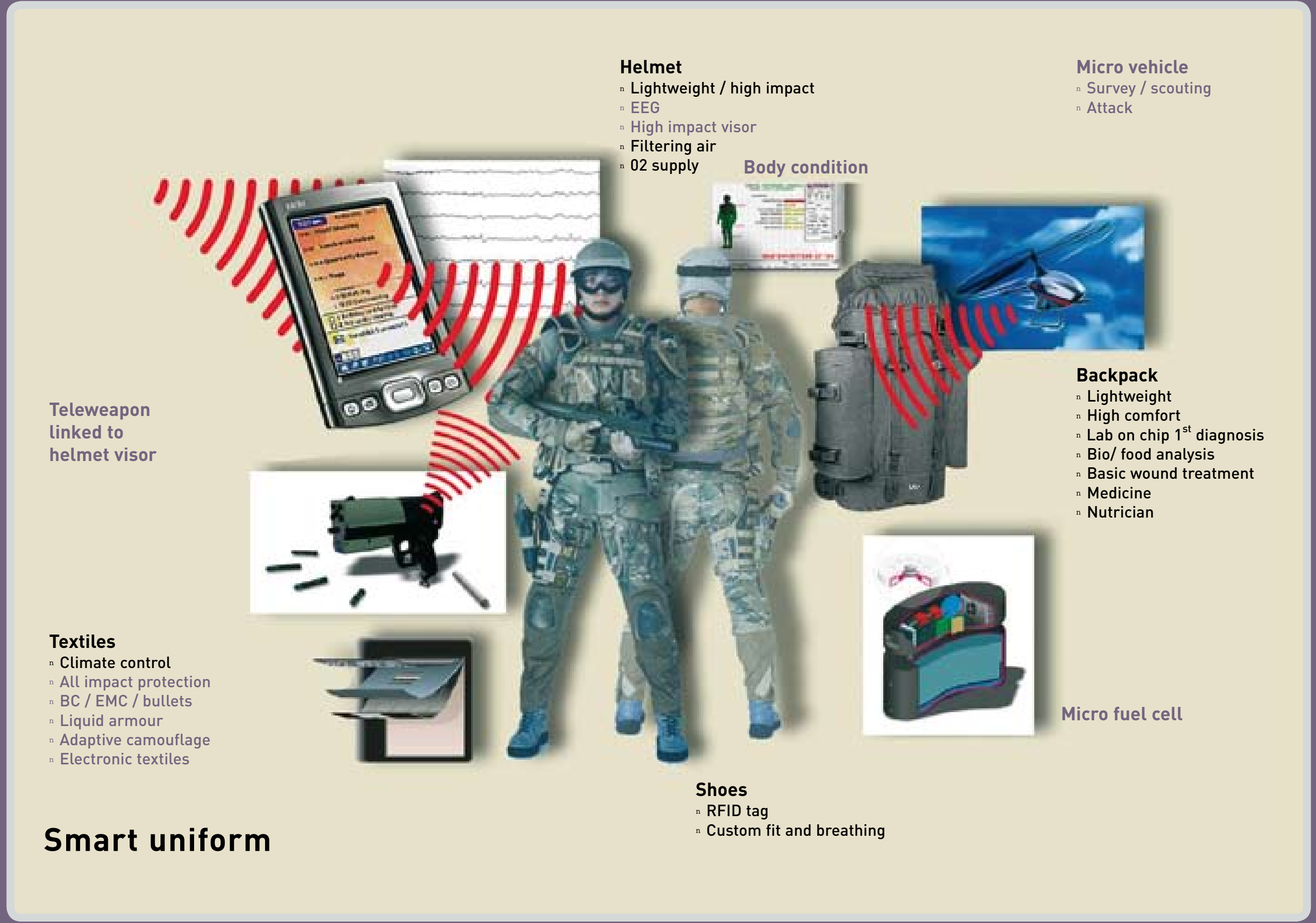
- flexible solar cells to recharge batteries
- μ-fuel cell, preferentially to be operated by diesel or biofuel (e.g. sugar)
- energy scavengers, e.g. electricity from vibrations, for low power applications

Bio

The nano-bio fusion is a booming area with high expectations that major steps in health treatment, body repair and body improvement can be made. It is regarded as the most innovative domain of this moment. Developments are in the field of:

- nanomedicine: targeted drug delivery by medically functionalized
- nanoparticles, for rapid cure without side effects or human stimulation
- regenerative medicine: DNA programmed tissue engineering for quick and efficient wound healing, rebuilt of organs and other body parts
- smart implants: biocompatible implants that can sense and actuate in order to repair or enhance a body function





Future combat suit: all impact protective and sensoric

The future combat suit of the soldier will protect him against various threats and will monitor and guard the physical and mental condition of the soldier. This all impact suit will be enabled by nanomaterials combined with electronic textiles and will protect him against bullets, fragment of grenades, bio-agents, chemical agents etc. It will consist of more layers with varying functionalities:

- flexible nano-armour textile: matrix of high strength polymer fibers (Dyneema+, Superthread) with a shear thickening binder fluid reinforced with nanoparticles
- intelligent undergarment with printed and embedded physiological sensors on textile (ECG- and heart rate sensors, respiration sensors, temperature sensor, dehydration sensors)
- power shirt: power grid and energy generating textile based on Zincoxide nanowires on textile fibers which act as piezo-electric powergenerators
- textile braces or garment with dry-electrodes to inject micro-current pulses for pain treatment, tissue recovery
- thermal management textile: use of nanofibers and CNTs for heat conductance, ventilation, insulation and local cooling
- BC-protective layers: use of nanofiber networks with absorbing, deactivation and decontamination capacity (catalytic breakdown of chemicals, blocking of larger molecules, venting of natural gases)
- outer layer with external sensors for communication and identification: printed RF and RFID-antennas on textile with ID-chip for positioning, identification and communication
- adaptive camouflage layer: absorption of radar and rf-signals via CNTs on fiber, optical illusion effects created by LED matrices, reduction of thermal signature via active body heat absorption and dissipation

Additional sensors to be integrated are motion and posture sensors embedded in clothing (2-3 axis MEMS accelerometers and gyroscopes) and integrated early warning BC sensors on label or credit card size able to detect biochemical hazards (reactive nanofiber pads) which can be coupled to the wrist watch or PDA of the soldier.

The backpack of the soldier will be light weight made from carbon fiber or polymer nanocomposite frame covered with a water tight fabric. In the rucksack the solider will have a basic wound treatment and therapeutics for BC exposure, a medicine and nutrition kit, a portable lab-on chip sampling and sensor system to test his own condition, water, environmental materials and a MUAV (Micro Unmanned Aerial Vehicle) to gather additional intelligence apart from the wireless sensor network on the ground.

His teleweapon is connected to his PDA and visor and also to his commander from a distance so that ultimate precision and lethality can be achieved. His smart helmet is light weight and has superior anti-ballistic properties due to the use of nanoparticles (bucky CNT-paper, nanofibers) combined with high strength fibers in polymer composite. The helmet contains also a contactless EEG sensor, an air filtering system with gas and particle sensor and is of course part of the Body Area Network.

His garment and or shoes have UHF RFID-tags incorporated for access control, positioning, custom fit application and a BC sensing device to gather and analyze BC agents from the ground.

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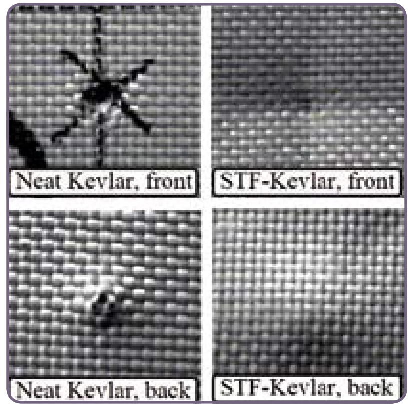
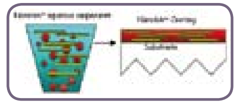
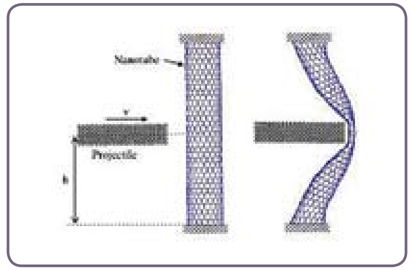
shear thickening fluid fabric as armor



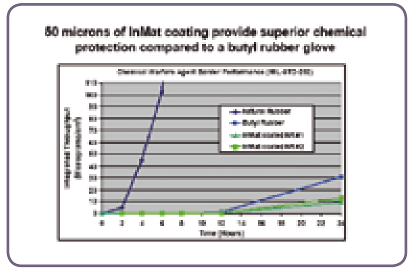
shear thickening fluid fabric as body armor





high impact absorption of CNT's

superthread (CNT technologies)



nanocomposites for gas protection

Flexible armour

At present, injuries of extremities have become the dominant factor in casualties, especially from bombings and subsequent shatter, resulting in loss of military power and high costs of medical treatment. Extremities require armour that is flexible. Flexible armour has become feasible thanks to nanotechnology, more over thanks to the shear-thickening binder technology. A shear thickening binder is made of a flexible matrix with a high load of silica nanoparticles. At low shear rate the binder is flexible, allowing fabric to bend and adjust to deformation, at high shear rate the binder and herewith the whole fabric becomes stiff and rigid. The nanoparticle filling allows deformation at low shear rate but inhibits deformation and sliding of the fabric at high shear rate: the particles are immobile and stick just as in hitting wet sand. Since the antiballistic strength is provide by the fibers in the fabric it is essential to use high strength fibers such as kevlar, aramide, dyneema or superthread (see below).

An alternative technology is based on a silliputty-type of elastomer, which is deformable and elastic at low shear rate and stiff at high shear rate, in combination with ceramic armour. It's similar to shear thickening fluids, but up until now less effective in anti-ballistics.

Lightweight armour

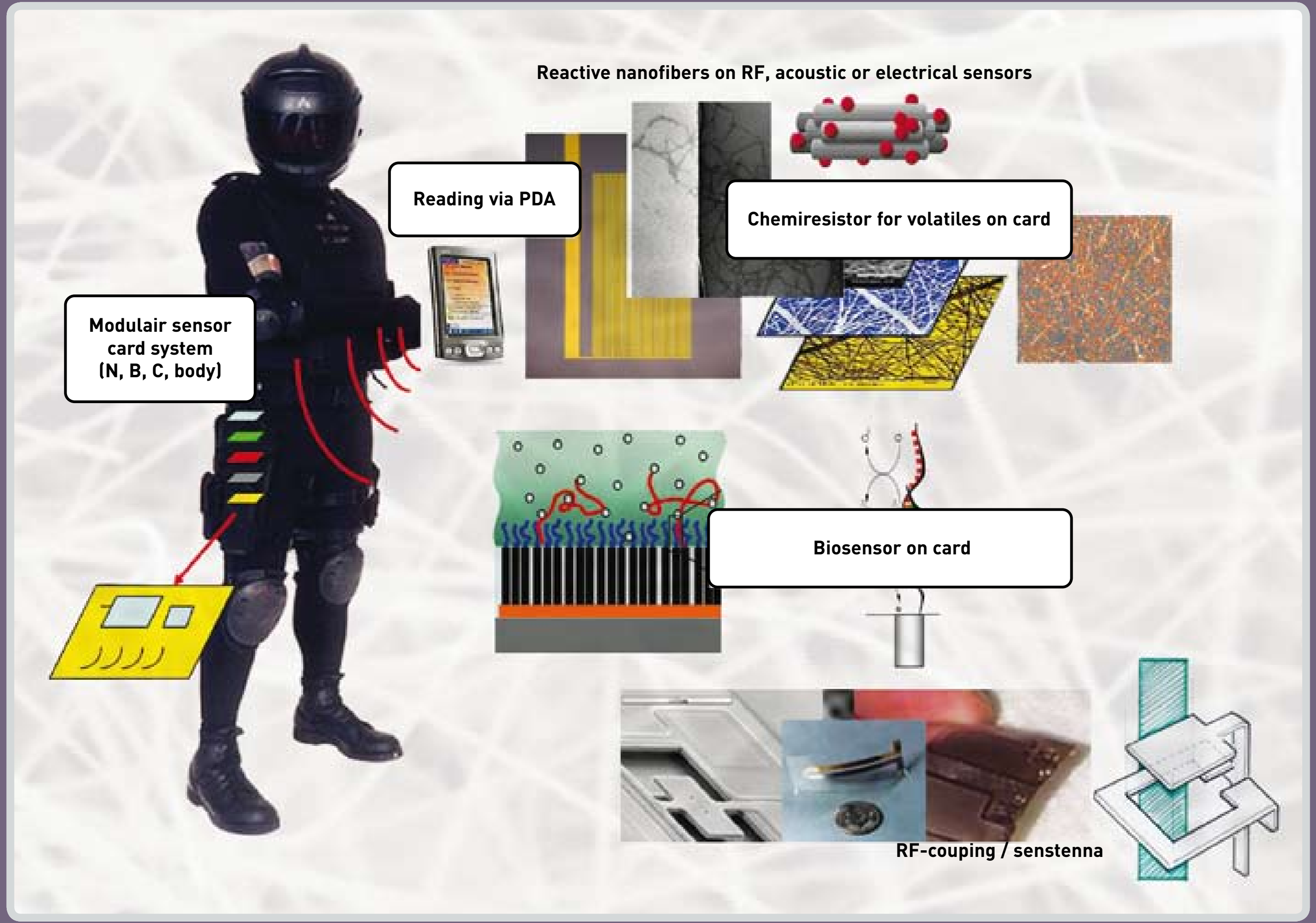
Carbon nanotubes (CNT's) show a very high intrinsic tensile strength of around 50-60 GPa. When spun into macroscopic fibers, a very strong fiber can be created. CNT Technologies (USA) report for their CNT Superthread a strength of more than 20 GPa. This is 6 times stronger that currently available carbon, aramide or HDPE/Dyneema fibers. With these fibers a very lightweight anti-bullet suit could be developed with properties comparable to Dragon Skin. Dragon Skin is currently made of laminated metal-ceramic tiles. A study of the University of Sydney indicates that body armour of 600 μm thickness made from six layers of 100 μm carbon nanotube yarns could bounce off a bullet with a muzzle energy of 320 J.

Other important progress is made with inorganic fullerene-like nanotubes and nanospheres made from inorganic compounds such as WS_2, MoS_2, TiS_2 and NbS_2 (ApNano, Isr) showing extremely high degree of shock absorbing ability such as for body armour.

BC protection

A high BC barrier can be achieved by a coating with hundreds of dispersed nanoclay platelets per micron of coating thickness. These platelets form a tortuous path for molecules such as oxygen and aromatics, dramatically increasing the barrier properties of the substrate. Such a coating (e.g. Inmat USA) forms an extremely efficient barrier which can be 100's of times less permeable than the uncoated substrate. In addition, these coatings are transparent, thus useful for see-through packaging applications. For application in chemical protective gloves and suits:

- thinner, more dexterity
- more comfortable
- improved chemical protection
- less flammable



Bio sensing and health monitoring

For medics it is essential to know which soldier needs immediate care and which soldier is not directly in danger whereas the commander has particular interest to monitor the physical and mental condition of a soldier in combat in order to decide on its operability. The following health information is desirable:

- heart rate and heart rate variability (ecg, stress monitoring)
- activity level and body temperature
- respiration rate
- blood pressure
- hydration level

On-body health sensors

Already on the market is a wearable, wireless ECG sensor tag with temperature sensor and accelerometer that can RF transmit these data to a PDA and to the medic and commander (e.g. RF-ECG from Micro Medical Device inc). Additional RF-sensor tags could give data on hydration, stress, shell shock or bacterial contamination. Acoustic sensors (ultrasound sensors) could detect bullet hits, bone fraction and can detect noises in the body of breathing, movement etc and via an array setup even info on sniper locations could be gathered. Wounds can be dressed with intelligent band aids which monitor the moisture level, the bacterial activity and which release antimicrobials on nanoclay particles to kill bacteria.

Such a health monitoring system can also include a portable lab on chip analysis kit enabling the soldier to test his own body fluids. The use of early biomarkers via the system biology approach to gather in an early stage relevant information about the body is of great interest. Ideally this analysis system will be built in his smart suit and will be able to detect bioagents and to apply anti-dotes to the soldier (vision of MIT/ISN). This however seems still far away.

Sub-skin biosensors

In the future, biosensors can be expected to be integrated subcutaneously in the body of combat soldiers. NASA is already working on implanted (sub skin) passive silicon sensors which can be read wirelessly from outside the body. Core temperature measurement with a swallowable passive RF-sensor is one of the solutions for accurate and low cost core temperature measurement of soldiers in combat.

Wearable BCNR sensors

For soldiers in the field it is essential to get an early warning when they are under a bio, chemical, nuclear or radiation threat. For immediate detection and response, a mobile and preferentially wearable system is needed. Chemical species to be detected are:

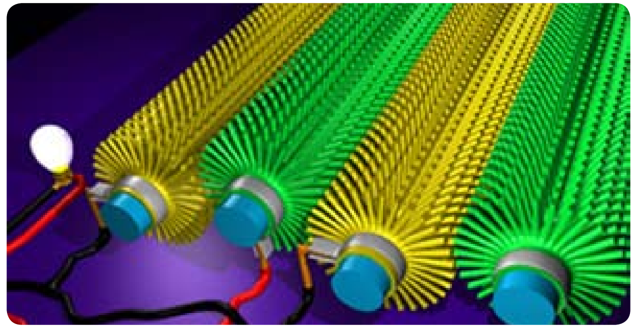
- VX
- Soman
- Musterdgas
- Lewisite

Ideally these sensors should be integrated in the suit as woven or non-woven structures of functionalized nanofibers which sense, absorb and deactivate bio and chemical agents and block of the ventilation of the suit when needed by creating an adaptive BC protection suit. This concept is to be expected in 10-15 years.

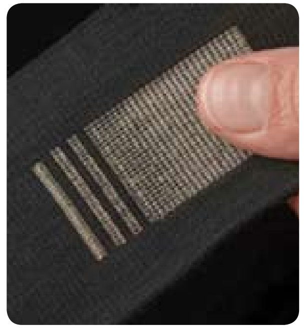
Replaceable sensor cards

The next generation of B/C and health status sensing is supposed to be put on credit card sized semi-active or passive sensor tags. These sensor cards communicate wirelessly with the soldiers PDA or watch. Severa configurations of sensor cards can be put in the suit or helmet. A combination of a silicon RFID-chip, a nanobiosensor and a rf-antenna is a feasible configuration.

vital Jacket (Biodevices)


ZnO nanowires for power generation in a suit


textile printed electrodes


Textronics sensor


key pad in textile


Numetrex cardio shirt


MP3blue


Lumalive signage


MyHeart


Lifeshirt


Adidas/Polar heartrate shirt

Electronic textiles for a smart suit

Textiles with integrated electronics have entered the market for various applications: key pads for mobile phones, MP3-players and camera’s, music systems built into coats, specialty clothing with integrated sensors for monitoring vital life signs of patients and even light emitting textiles for display, communication, advertising and fun. It allows for a new smart soldier suit. Even an adaptive camouflage suit seems feasible now.

Multimedia suit

Interactive Wear developed the new Rosner’s multimedia-lifestyle-jacket. Functions like “mobile phoning via Bluetooth” and “MP3 player” are built right inside the men’s jacket, a combination called “mp3blue”. The electronic system is controlled by buttons printed on the sleeve.

Sensor suit

Constructed of an advanced wicking fabric with special sensory fibers integrated directly into the garment, the Cardio Shirt allows men and women to wear a heart rate monitor without knowing it is there. The sensing fabric moves comfortably with the body, picking up the heart’s pulse and sending it to a compatible heart rate monitor watch or cardio machine via a tiny transmitter that is snapped into a pocket on the shirt. The transmitter can communicate with the outside world (Numetrex) . Other shirts have integrated also ECG-electrodes and an 3D-accelerometer for activity measurement (Lifeshirt). Common in sports is the Adidas/Polar heart rate shirt with Clothing+ electrodes (coated conductive fiber pads) connected to a 2.4 GHz wearlink module enabling presentation of data on a wristwatch.

Light emitting suit

Textile can be made light emitting by adding small, square millimetre size, LEDs in or behind the textile (Lumalive). The LEDs and wiring or small enough for flexible and confortable wearing. It can be programmed and turned on to create a moving panel of glowing shapes, colours, graphics, messages on shirts, jackets, backpacks, upholstery or curtains. Another techniques makes use of luminescent fibers by weaving fibre-optics into fabric (Luminex). The fibers are attached to super bright LEDs that are controlled via a microchip. By adding an optical sensor, the clothes can glow by constantly changing the colors to match the surroundings.

Power generating suit

Former Eleksen Group and O’Neill Europe developed a solar backpack with two flexible solar panels. In optimum light conditions, the solar cells provide charge to the user’s iPod, mobile phone (and Bluetooth module or health monitoring sensors) via a USB recharging system. Power from the solar cells travel through conductive fabric layers within the backpack, to the fully integrated communication and entertainment systems. In the future, the garment itself could generate piezoelectric power via integrated zincoxide nanowires. These nanowires are being bent due to movement of shirt and generate electric power (Georgia Tech).

Electro-active suit

Another functionality can be to provide, via an electrode array on textile, injection of micro-currents into the body that can treat pain, heal tissue, or activate nerves and muscles. During the operation the soldier can then recover more quickly from minor injuries, anaerobe effects in muscles, pains in joints etc. This conductive electrode array on textile can direct microcurrent pulses precisely to the injured spots and areas for recovery. This technology can be part of the in intelligent undergarment and can even be applied in the inner soles of the soldier’s boots.

Work- and Perspiration Rates Under different Activities

Activity	Work Rate (W)	Persp. Rate (L/hour)
Gentle walking	200	0.32
Active walking with ligtht pack	400	0.63
Active walking with heavy pack	500	0,79
Mountain walking with heavy pack	600 - 800	0.95 - 1.3
Maximum work rate	1000-1200	1,6-1,9

Electric powered breathable textiles are capable of transporting more than 1 liter per hour with energy from a small battery.

Performance of Waterproof Breathable Fabrics

	WVT (L/m2h) - dry	WVT (L/m2h) - rain
Electrical powered breathable textile	5.0	5.0
Microporous PU coated fabric A	0,142	0,034
Microporous PU coated fabric B	0,206	0,072
2x layer PTFE laminate	0,205	0,269
3x layer PTFE laminate	0,174	0,141
Hydrophilic PU laminate	0,119	0,023
Microporous AC coated fabric	0,143	0,017
Microfibre fabric	0,190	0,050
PU coated fabric	0,018	0,004

Passive ventilation control

This concept consists of a switchable insulation and ventilation fabric for use in future combat uniforms. The soldier will generate heat during exercise and practice, and to maintain his optimal performance level he has to reduce his body temperature by adjusting the ventilation systems of the suit. This can be done with electroactive polymers which can be contracted or elongated at low voltages. MIT and UCLA are currently working on these polymers. Key research question is to make them stable and contractive at low voltages.

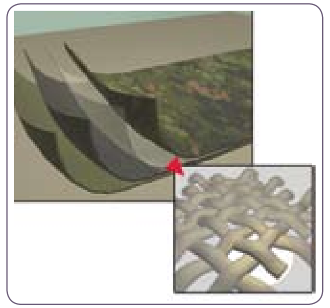
Ventilation can also be provided by using nanofiber fabrics which let pass water vapour and air but block water and other liquid or vapor-type materials. Possibly extra ventilation can be provided by micro flaps and rotors integrated in the fabrics. For insulation the use of densely woven fabrics will lead to wind-proof insulating fabrics. These can possibly be combined with cross-linked aerogels, carbon nanotubes which have a high heat dissipation. X-aerogels have potential for use as high-insulation materials, require simplified processing, have an improved machinability, are flexible and have a higher strength than aerogels. This material will probably be developed further for astronaut suits and other space applications first, but has potential as filler in future fabrics for a combat suit.

Carbon nanotubes can easily dissipate excess heat and are therefore an interesting option to be researched further as filler or additive in fabric structures for cooling purposes. Also CNT composites and nanofibers have potential in this area. They are flexible, have a high strength and a high thermal conductivity. Electrospun nanofibers offer good potential as insulating materials, thanks to low mass, high strength and a high surface / volume ratio.

Active ventilation control

A new development is the electric powered breathable membrane (Osmotex). Water or liquid transport through the membrane is controlled by an electric signal, and almost any desired amount can be transported. As part of a microfluidic system, the Osmotex membrane can be used for pumping or sieving. The membrane can also be laminated as part of a textile, which can be used in a host of cases where water (condensation, perspiration, rain, groundwater etc) needs to be removed

Present breathable clothing can only transport 1-3 dl of water per hour, depending on weather conditions. Given relatively warm climate and humid conditions, the water transportation is greatly reduced. Perspiration rate is around 10 dl per hour for hard work and active sports. Lack of an effective water vapour removal greatly reduces performance and durability. Furthermore, the risk of hypo- and hyperthermia increases in extreme situations. Without fast water vapour removal in clothing and protective material, endurance in sports, military activities, fire fighting etc., must be insufficient.



electrical powered breathable textile (Osmotex)


dream phone concept polymer vision

foldable phone concept NOKIA


flexible phone concept NOKIA


readius


polymer vision readius

Flexible display and communication devices

Nanotechnology enables materials and components that are flexible, stretchable, transparent and remarkably strong. Fibril proteins are woven into a three dimensional mesh that reinforces thin elastic structures. Using the same principle behind spider silk, this elasticity enables the device to literally change shapes and configure itself to adapt to the task at hand.

A folded design would fit easily in a pocket and could lend itself ergonomically to being used as a traditional handset. An unfolded larger design could display more detailed information, and incorporate input devices such as keyboards and touch pads.

Even integrated electronics, from interconnects to sensors, could share these flexible properties. Further, utilization of biodegradable materials might make production and recycling of devices easier and ecologically friendly.

Self-Cleaning

Nanotechnology also can be leveraged to create self-cleaning surfaces on mobile devices, ultimately reducing corrosion, wear and improving longevity. Nanostructured surfaces, such as “Nanoflowers” naturally repel water, dirt, and even fingerprints utilizing effects also seen in natural systems.

Advanced Power Sources

Nanotechnology holds out the possibility that the surface of a device will become a natural source of energy via a covering of “Nanograss” structures that harvest solar power. At the same time new high energy density storage materials allow batteries to become smaller and thinner, while also quicker to recharge and able to endure more charging cycles.

Sensing The Environment

Nanosensors would empower users to examine the environment around them in completely new ways, from analyzing air pollution, to gaining insight into bio-chemical traces and processes. New capabilities might be as complex as helping us monitor evolving conditions in the quality of our surroundings, or as simple as knowing if the fruit we are about to enjoy should be washed before we eat it. Our ability to tune into our environment in these ways can help us make key decisions that guide our daily actions and ultimately can enhance our health.

Origami Cell Phone

This is a future cell phone concept developed at Inventables. The concept was inspired by the e-paper developed by Mag-Ink (Israel) and the Popout Map. The map uses origami paper folding technique to expand and collapse automatically as it is opened and closed. This concept addresses the need for larger displays on cell phones without sacrificing a small form factor.

Flexible and rollable displays

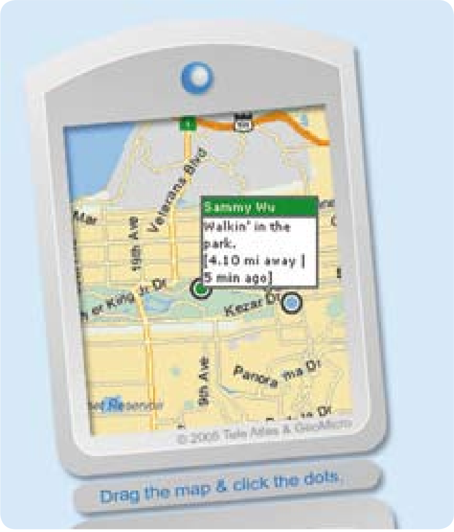
Readius (Polymer Vision)
Current mobile displays available in the market all have one thing in common: they are rigid and cannot bent. Although existing display technologies like LCD have served well in mobile devices a major dilemma arises when consumers demand for larger displays in combination with small pocket size devices.
With the introduction of rollable displays in mobile devices this is going to change: the display is large when in use and can be rolled up into a small device when not in use.

Polymer Vision is the first company in the world showing the capabilities of rollable displays. The characteristics of Polymer Vision’s rollable display technology are:

- fully rollable to the thickness of a finger
- low power: no power required to maintain the image on the display
- light weight
- robust, unbreakable
- enabling revolutionary product designs and form factors

Other flexible displays

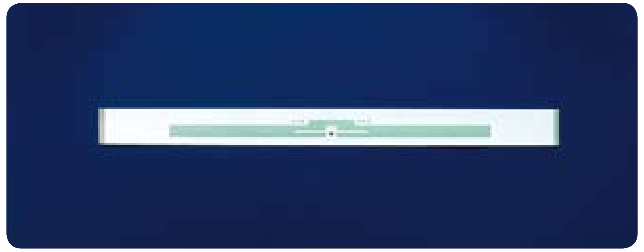
- Sony organic LED colour display
- UDC oganic LED colour display (FOLED)
- Smart card with flexible display



friend tracker with your phone


speedmonitor display in O'Neills Navjacket


UHF RFID tag on body


printed UHF RFID tag


keypad Nav-jacket


nav-jacket


PDA with built in GPS

Friend tracking using the GSM network

Sniff is a mobile phone service that lets users track the location of friends. A user can text Sniff to find the location of a friend and will receive a reply message that shows their location and a map. Sniff is available in Scandinavia and the UK. Mologogo is a free service the US that will track you and your friends using GPS-enabled mobile phones. If you are on the go, Mologogo can alert you when friends are close, search around for points of interest, and keep you updated with local traffic and weather. If you are on your PC, you can see all of your friends - locations, sign up new friends, bookmark locations, and show your Mologogo location on your own web page or blog.

3D navigation with a GPS phone

O'Neill and Satski both have launched ski gadgets enabling skiers and boarders to navigate the piste, record their day on the slopes and speed levels all from their pocket. At has the following features:

- to plan a full day out on the piste avoiding e.g. black runs
- measure speed, distance, ascent, descent, statistics
- buddy tracking, see where their friends and family are
- emergency messaging with GPS coordinates
- instant messaging

O'Neill has integrated the GPS and mobile phone functions into a jacket, the Nav-Jacket.

Soldier PDA or smart phone system

Similar applications for the soldier are in development, such as the SIM for the Dutch defence organisation: the SIM is a personalised PDA system for the soldier. Of course soldier systems need to be very robust and will require a sophisticated data security system.

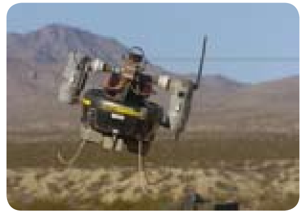
RFID tracking

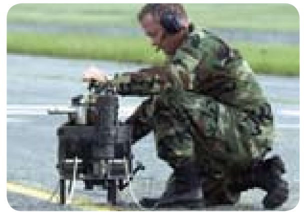
RFID-technology is available for identification and positioning applications. Passive and low cost UHF RFID-tags at 868 MHz and 2.4 GHZ are useful for identification of soldiers and equipment on short ranges in the field and in indoor environments. These tags can be incorporated in clothing, shoes or removable smart cards, combined with portable readers. This feature allow soldier users to track and see where their companions are on limited distances. For longer range identification active RF(ID) and radar ID system will become available. Examples are nowadays: WIFI nodes for ID and positioning, active 5.6-5.8 GHz tags for indoor and outdoor positioning, future and upcoming UWB-tags at 3-10 GHz and GSM tri-anular beacon positioning with present telecom networks. Use of third harmonic waves reflecting from UHF RFID-tags or chipless RF-antennas with a diode can result in very accurate positioning applications. This last principle is already practisized for finding of skiers underneath snow.


UAV from Honeywell


commercially available microdrone


commercially available microdrone


honeywell micro UAV system


honeywell micro UAV system


flying fish UAV

Honeywell micro UAV system

Honeywell has developed a backpack-sized Miniature Air Vehicle (MAV) designed to gather and transmit battlefield Information in support of small units operations. Once matured, the micro air vehicle will become become the smallest unmanned aerial element of the U.S. Army's Future Combat Systems program, providing "hover and stare" capability at the platoon level. Class I is one of four UAV systems organic to platoon, company, battalion and brigade echelons that form the aerial component of the FCS networked system-of-systems, providing protection and information to soldiers on the ground.

The system consists of two air vehicles with support equipment of fuel, batteries, an observer/controller unit, remote video terminal and starter. Each vehicle weighs about 17 pounds fully fueled, is 13 inches in diameter and designed to be transported in a back pack. The vehicle operates at altitudes of 100 to 500 feet above ground level, and can provide forward and down-looking day or night video or still imagery. The vehicle will operate in a variety of weather conditions including rain and moderate winds.

Soldiers can be trained on vehicle operation in less than 24 hours and then can immediately begin to operate the vehicle for proficiency training. Unlike other unmanned aerial systems, no specialized military training is needed to operate the MAV or exploit its data and imagery.

Microdrones: commercially available UAV's

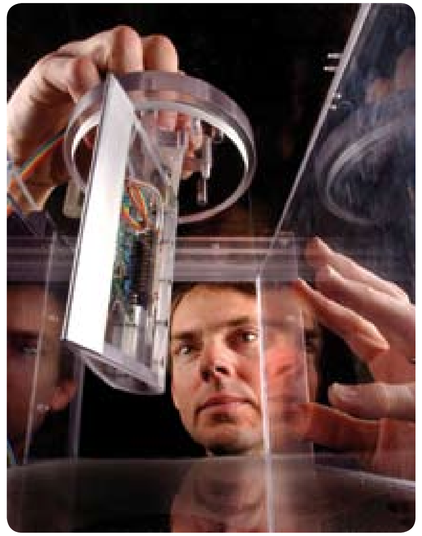
The MD4-200 is a vertical take off and landing, autonomous unmanned micro aerial vehicle. For lowest weight and highest robustness we have designed the drone completely in carbon fiber reinforced plastics. This carbon mono frame is also a perfect shield against electromagnetic interferences. Their outstanding AAHRS (Altitude and Attitude and Heading Reference System) uses the following sensortypes: Accelerometers, Gyroscopes, Magnetometer, Airpressure, Humidity, Temperature.

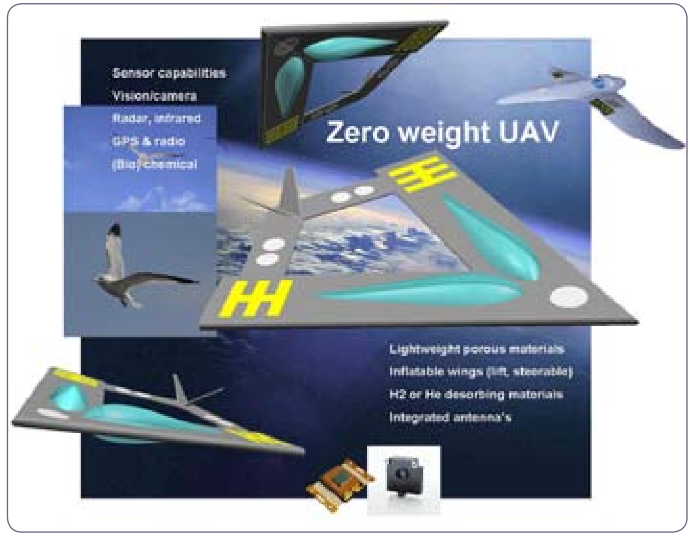
By means of our synchronized, brushless direct drives (transmissionless) the noise level is very low (rpm < 2000, noise < 63dBA @3m). These propulsions recover from stall and overload conditions even at flight time.

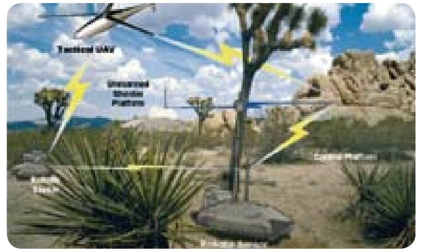
The optional GPS provides position hold and autonomous waypoint navigation. The onboard flight recorder (microSD card) permits a post-flight analysis in real-time. With our downlink decoder we provide all important data at the base station (battery state, altitude, attitude, position, flighttime etc.). For best pilot support they have implemented a talking audio response system (no need to look at a display). Security features prevent from crashing - autonomous landing on low battery or missing radio signal. Depending on payload, temperature and wind the vehicle achieves up to 20 minutes of flight time.

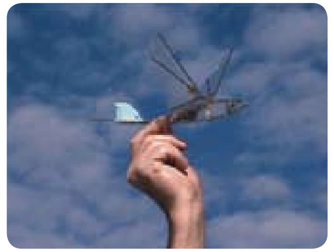
Flying fish UAV

On the opposite page is depicted a new seaplane UAV made at the University of Michigan. They've called it the 'flying fish' - not entirely accurate since it can only land on, not swim in, water. It has a seven foot wingspan - making it "about the size of a large pelican" according to one of its builders. During sea trials in California it successfully showed off in front of DARPA officials, taking off from and landing on the water 22 times. It has been programmed to use GPS to take off after drifting a certain distance, and to land at another GPS location.


sensor platform Snifferstar

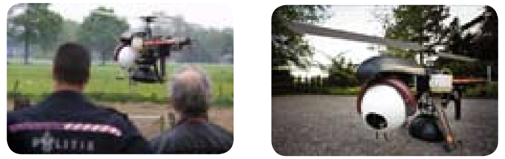



network centric approach for robotics


caltech's/UCLA's MUV ornithopter for DARPA


zero weight radar plane


sniffer STAR system


cannachopper detecting illegal cannabis farming

Snifferstar detects possible gas attacks

A half-ounce 'sniffer' intended to ride on small aerial drones to detect possible gas attacks on cities and military bases has been created by researchers at Sandia National Laboratories in partnership with Lockheed Martin Corporation. The device, which detects nerve gases and blister agents, operates on only half a watt of electrical power. While other gas monitors exist, this is small, lightweight, low power, and offers rapid analysis. Rapid analysis currently is not possible with any other package near this size.

Material in the sampled air is absorbed and concentrated. It is then thermally released (desorbed) to pass over thin stripes of coating materials, to which it temporarily sticks. The sampling process is repeated every 20 seconds, with 15 seconds intake and five seconds for analysis. The inrush of air then clears the device sensors for the next reading.

The on-board gas sensor consists of a series of tiny sensors (vibrating quartz sensors) on a small platform, the forward motion of the vehicle forces air through the device.

Cannachopper detects illegal cannabis farms

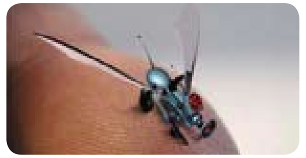
The Cannachopper is a new tool in fighting illegal cannabis farms in the Netherlands. This micro chopper is fully GPS and computer controlled and can follow prescribed GPS coordinates. It can fly for 8 hours. It has been equiped with a daylight and infrared camera and has a selective sniffer for cannabis: the "canna sniffer". On demand it can suck air through a small air-inlet cap, e.g. air that is being release from a ventilation duct or chimney. This air is then being analysed on cannabis gases on board of the chopper via its cannasniffer.

Zero weight UAV for continuous surveillance

This concept from TNO concerns a sensor UAV that combines radar for air and ground for moving target identification (GMTI), imaging and foliage-penetration applications. Also electro-optical/infrared sensors can be used. The UAV is close to zero weight to ensure long endurance in the air. This is achieved by using Helium inflatable nanoporous materials in combination with lightweight sensors, integrated into the wing structure. The wing structure also integrates the antenna's for the radio frequency (RF) side.

The active, electronically scanned radar must be lighter in weight, in the thousand-fold range, and much lower in cost than today's technology. Using lightweight materials would enable affordable radars that are five to six times bigger in area than what we have today. Key are the load-bearing antennas, where the sensor becomes part of the wing, rather than a "parasitic" load bolted onto the airframe.

spy plane “the bat”



nano insect

silverlight RF toy plane

solar powered MAV

flyhand

Delfly

Mini/micro aerial vehicle: Delfly

The Delfly, developed at the Technical University of Delft and Wageningen University, is able to transition between hovering and forward flight. These ornithopters also carry a small video camera. The live images are analysed by a computer on the ground, giving Delfly the capacity for autonomous navigation.

Silverlite micro helicopter (25$ toy)

Small just got a whole lot smaller with the PicooZ Mini Micron. No bigger than the length of a credit card the tiny remote control helicopter is even small enough to fit into a compartment under the remote!

It has super wide infrared control, a built-in Li-Poly battery, trim control and durable body. It is two channel helicopter which means you control the height with the left stick and direction with the right. Its design means that it is always flying forward. The miniature helicopter is easy to fly so is great for beginners and its size means it is suitable for small rooms.

A normal charge of 20-25 minutes should give you a flight time of around 10 minutes, and this is done directly from the remote control (requires 4xAA batteries)

Spy plane concept

The US Army is sponsoring research to build a bat-like, six-inch robotic spy plane dubbed “the bat” that will use quantum-dot solar cells for power and have an autonomous navigation system that’s 1,000 times smaller and more energy-efficient than current systems.

The bat will use low-power miniaturized radar and a very sensitive night navigation system. It will recharge its lithium battery by energy-scavenging from solar, wind, vibration and other sources.

The next time you see a pair of shoes suspended from a wire …
It could be a spy plane being recharge your batteries.

The United States military is experimenting long mini-robotic aircraft that can be carried in a backpack and then reassembled. But they could not put autonomy of only 45 minutes. The Research Laboratory of the Air Force in Dayton (Ohio) is therefore developing a micro air vehicle, which could be recharged by plugging itself in a power line. To avoid attracting suspicion, it would have folded its wings and its designers work is to draw a fuselage that resembles harmless debris rejected by the wind…

Smart helmet

Essential part of the future soldier's combat gear will be the smart helmet. This smart helmet consists of a helmet as a platform system equipped with an intelligent multi sensor system for various tasks:

- surveillance
- positioning and identification
- RF and audio communication,
- B/C sensing
- acoustic sniper detection,
- lifesign monitoring
- digital signal processing.

The use of micro system and nanotechnology for these sensors will reduce weight of the equipment which is now attached or mounted on the helmet, creating lesser physical loading on the head. The technologies will enable more accurate sensors in smaller, flatter dimensions. The helmet is a form stable object so therefore creates a good base for integration of various sensor arrays. In general, it is even the only firm base, the garment is usually flexible. The second advantage of using the smart helmet as base for the sensors is its position, it is usually the highest point of the soldier. Suitable sensors for the helmet are:

- optical/IR camera (360° vision)
- RF array antennas for positioning, friend or foe RFID and directed low power and efficient communication
- B/C sensor arrays as early warning system
- acoustic arrays (microphones)
- lifesign sensing: EEG, heart rate, respiration sensors

Optical/IR camera array

The optical and infrared camera array will give a 360° coverage (6 camera's). It's useful for detection of laser designators, night vision, surveillance. The cameras are already available in small sizes. Applications requiring simple signal processing, like laser detection, can already be integrated in the helmet. Examples of a micro IR camera can already be found integrated in a device similar to a mobile phone, showing the further miniaturization of these types of camera systems

Array antennas

The helmet can take advantage of conformal array technology. Using conformal array technology, antennas no longer need to be "flat" but can follow the curvature of the helmet. For popular frequencies on the battlefield, for example 60 GHz, conformal arrays can be of great added value in beam forming. Communication beams can be directed to the conversation partner of interest. Used as radar antenna, they eliminate the need for a mechanically steered antenna. Furthermore the antenna array can be used for indoor identification and positioning which is becoming more important for urban warfare. This can be based on RFID-available frequencies (868-962 NHz-2,4 GHz) up to higher frequencies.

Acoustic array

For frequencies higher than 1000 Hz, acoustic array technology can be applied. There are two applications: beam forming, a "listening beam" and direction finding, the direction from which a gunshot is detected can be determined. Acoustic detection is greatly improved when soldiers share each others acoustic detection information, which requires mutual communication links. The technology can be adapted to enable communication between soldiers not directly on the ear but via the jaw or skull bones. This is already demonstrated by SAGEM on a micro scale in the Osteo microphone and loudspeaker of the FELIN system.

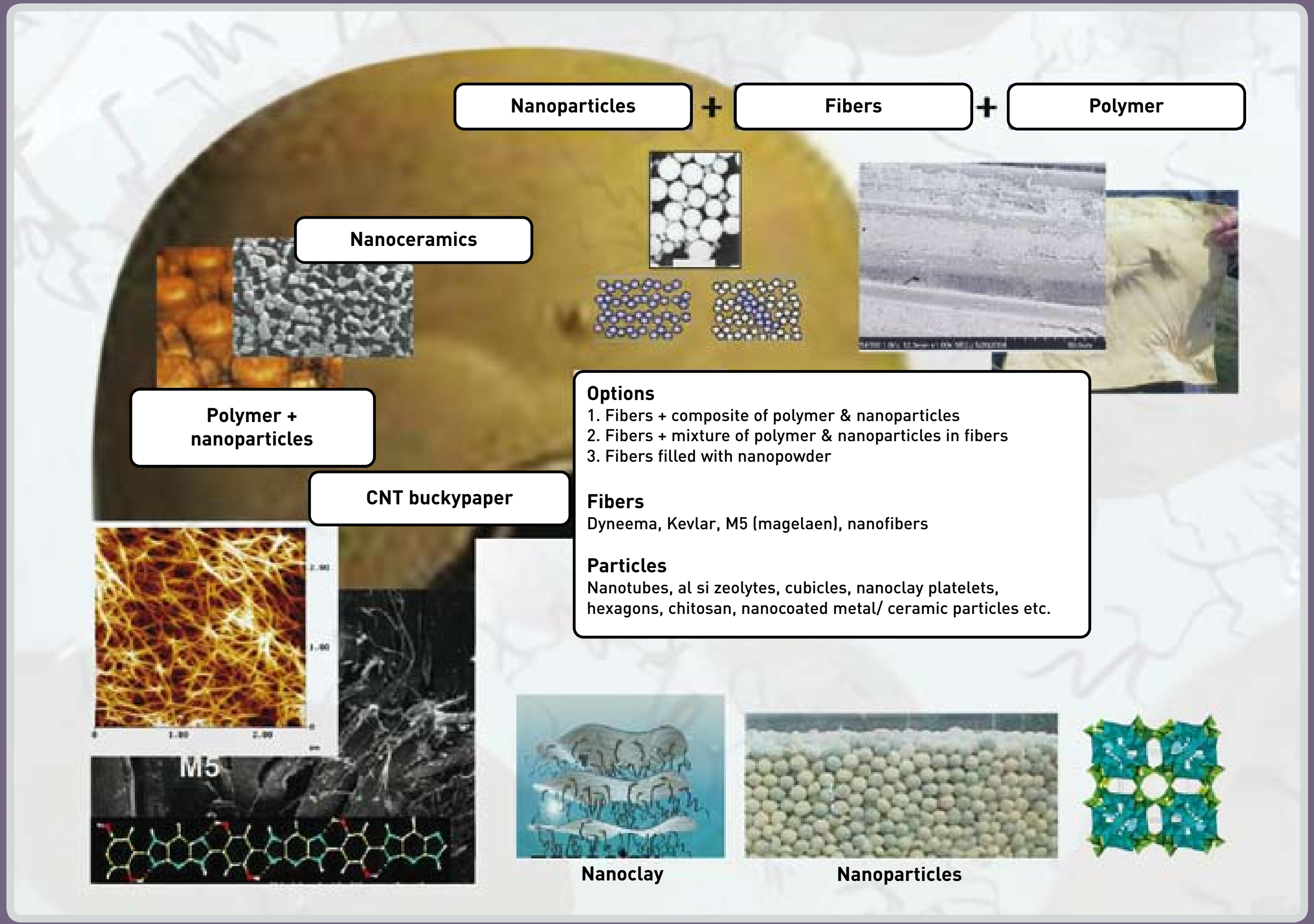
B/C sensor array as early warning system

The B/C sensor array on the helmet could consists of small semi-active or passive sensor elements with reactive large area surfaces (electrodes with carbon nanotubes, nanofibers, conductive polymer SFET sensors etc.) which react to chemical volatiles in the air and to certain bio-organisms and give an early warning to the soldier to put on protective clothing and breathing gear.

Lifesign sensing

The smart helmet will also contain a lifesign sensing system able to assess the physical and mental condition of the soldier, consisting of:

- EEG-sensors: contactless EEG sensors via GMR-chips technology or dry EEG-electrodes with CNT's able to measure concentration, stress, alertness levels of the soldier
- heart rate, respiration and SpO2 sensor on the earlobe, in the ear or on the forehead: spectroscopic IR and NIR measurement of these vital signs via MID-led and in the future polymer LED's and diodes.



Bulletproof helmet

Closely connected to the concept for the smart helmet is the concept for anti-ballistic protection via a lightweight helmet consisting of a combination of polymers, fibers and nanomaterials. This new nano-composite should have a higher impact resistance than present fiber composite systems and should have a significantly reduced weight.

Most promising seems to be the application of nanofibers and bucky-paper in combination with present high-strength fibers and polymer material to create new composite material. For the next generation of helmets the use of present fibers such as Kevlar, Dyneema or M5 is most realistic in combination with nanomaterials which can enlarge the strength of the composite and which can keep the fibers closely packed in the composite structure at impact. M5 is the newest type of fiber in this category and product applications of this fiber are expected in the next few years. Nanoclay in a silliputty type of polymer matrix combined with fibers is a possible alternative. These high-strength fibers can, in theory, bring significant improve-ment. The same applies to metal nanoparticles coated with a multiple-layered ceramic nanocoating. These coatings have originally been developed for turbine blade protection but the extreme hardness is also of use for anti-ballistic nano fillers in composites.

In the long term (10-15 years) a more dominant use of electrospun nanofibers to create the basic fiber strength in the composite can be expected. These CNT fibers and other nanofibers have a theoretical strength of 130-180 GPa.

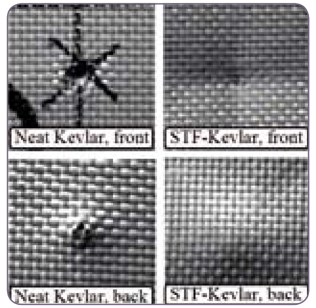
Flexible antiballistic helmet

With the development of flexible armour such as shear-thickening fluid systems (see future combat suit) , the helmet could become both bullet resistant as well as offering some flexibility for optimal matching and comfort. A shear-thickening fluid system is based on a nanoparticle filled binder for high strength textile that is flexible under low shear rate and that becomes rigid under high shear rate impact. This nanoparticle filled system inhibits deformation and sli-ding of the high strength fibers in the fabric at high shear rate.

Anti-ballistics with nanotubes

A study of the Centre for Advanced Materials Technology, University of Sydney, shows that the ballistic resistance capacity of a carbon nanotube is highest when the bullet hits its centre and a larger tube withstands a higher bullet speed. On a subsequent impact after a small time interval, a nanotube could withstand almost the same speed as in the first impact, indicating that carbon nanotube body armour can have a constant ballistic resistance even when bullets strike at the same spot. This study estimates roughly that body armour of 600 μmin thickness made from six layers of 100 μm carbon nanotube yarns could bounce off a bullet with a muzzle energy of 320 J.

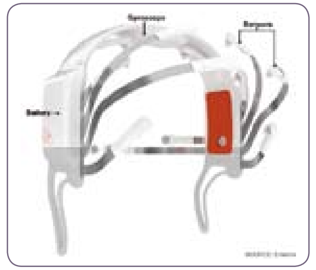
The Israeli company ApNano found out that certain inorganic compounds such as WS2, MoS2, TiS2 and NbS2 that normally occur as large flat platelets can be synthesized into much smaller nano-spheres and nano-tubes which they named inorganic fullerene-like nanostructures or IF for short. One of the most interesting new IF properties discovered by ApNano is its extremely high degree of shock absorbing ability such as for body armour.



flexible anti-ballistic armour for helmets

cnt based bucky paper for future bulletprof helmet


mind controlled bionic arm


16 channel BMI + gyroscope headset

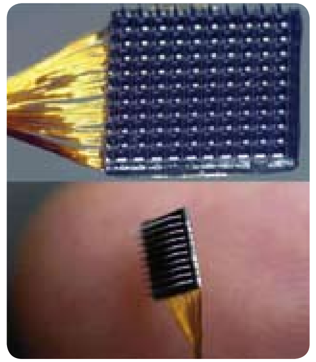

bmi game


brain computer interface


Neurosky starwars toy


Neurosky connected to a phone


brainremote machine interface


brain implant chip (BrainGate)


braingate controlled arm


one-electrode headset


EPOC headset

Brain machine interface

A brain-machine interface (BMI), sometimes called a direct neural interface or a brain-computer interface, is a direct communication pathway between a human or animal brain and an external device. In one-way BMI's, computers either accept commands from the brain or send signals to it. Brain machine interfacing is an upcoming technology in the gaming industry.

Two-way BMIs would allow brains and external devices to exchange information in both directions but have not yet been successfully implanted in animals or humans.

The following BMI techniques are in development:

- Invasive: direct implants of tiny electrodes into the brain e.g. to restore vision capabilities or to restore the motion control after paralysis such as arm control (Brain-Gate, a 96 channel implanted chip)
- Partially invasive: implanted electrodes inside the skull but rest outside the brain rather than within the grey matter for capturing the brain signals (electrocorticography ECoG). This has a much better resolution and less noise than EEG.
- Noninvasive: a headset with electrodes attached to the skin, detecting brain activity using electroencephalography (EEG) from in various parts of the furrowed surface of the brains cortex.

Brain activity measurement

Electroencephalography (EEG) is the most studied potential non-invasive interface, mainly due to its fine temporal resolution, ease of use, portability and low set-up cost. Specialized companies like Emotiv sell headsets (EPOC, 16 channels, 1 gyro for movements) for the consumer market (300$) in combination with a software suit to analyse EEG's and to control a PC, avatar or other devices.

Somewhat different is the neural impulse actuator (OCZ Technologies, game industry) capturing, via a headset, a mixture of signals of muscle, skin and nerve activity including sympathetic and parasympathetic components that have to be summarized as biopotentials rather than pure neural signals. Individual signals that are isolated comprise alpha and beta brain waves, electromyograns and electro oculograms.

Meaurement of emotions

Neurosky has publicly demonstrated two emotions reading with their brainwave sensors: attention meters is a reading of how attentive the user is feeling and the meditation meter is a reading of how relaxed the user is feeling. Other emotions, including anxiety and drowsiness were also in the work. Neurosky uses their patented dry-active sensor technology to read the brain signals. The electrodes of standard medical electroencephalography use a conductive gel to facilitate the reading of the signals. Neurosky is working to include also head and eye tracking plus stereo sound.

Although brain-machine interface technology has traditionally focused on medical uses, makers like Hitachi and Japanese automaker Honda Motor Co. have been racing to refine the technology for commercial application. Hitachi's scientists are set to develop a brain TV remote controller letting users turn a TV on and off or switch channels by only thinking. Honda, whose interface monitors the brain with an MRI machine like those used in hospitals, is keen to apply the interface to intelligent, next-generation automobiles. The above mentioned companies Emotive, Neurosky and OCZ have their primary market in the game and consumer market.

For military, the first applications can be expected for personel operating in very complex situations such as pilots and special forces.

Nanotechnologies for the next generation weapons

We can expect that nanomaterials can be used in polymer compound to create lightweight structures for guns, rifles and automatic firing systems. It would very interesting if nanomaterials could create a corrective guidance structure to correct the movement and trembling of the body of the soldier. Ideally this would be a smart adaptive material in the shaft of the gun or on the grip.

Other technologies which can be integrated in future weapons for the soldier are: RFID-tags in gun, cartridge, target positioning/ recognition (via micro IR camera on gun or PDA, microradar, RF-array, through the wall THz radar), wireless link to PDA and smart helmet to pull trigger from a distance (teleweapon), various ammotypes (shaped ceramic materials, softer bullets, high penetration bullets, sensor modes/ smart dust, insensitive tailored explosives to limit collateral damage).

The gun will be equipped with a non-mechanical trigger which can be wireless linked to PDA, phone or smart helmet of the soldier. An example of the use of present wireless technology to detonate explosives is the use of GSM-technology by terrorists in Iraq. A high power laser for hand guns is still far away but not unthinkable.

Cornershot

CornerShot is a special-purpose weapon that can fire around corners. It was designed in the early 2000s for SWAT teams and special forces in hostile situations usually involving terrorists and hostages. The CornerShot is available in several variations. A standard pistol version is available, along with a 40 mm grenade launcher. Because they are fitted with high-resolution digital cameras, any variant can also be used as a surveillance tool. All the models come with the same stock camera and 2.5 in. color LCD monitor, providing a video observation and sighting system with transmission capability. The flashlight and camera let it operate in either day or night. A variety of optional interchangeable cameras, as well as a folding stock, are available, and a universal accessory rail is standard.he standard CornerShot mounts a normal semi-automatic pistol in the front part of the weapon, with a remote linkage to the trigger mechanism in the rear part, it has a trigger pull of 21 newtons. It is 820 millimetres long, with a weight of 3.86 kilograms.

Nanotechnology can offer weight reduction in the future via high strength, nanocrystalline metals and lightweight nanocomposites. Also more advanced sensor systems (infrared, acoustic sniper array) can be expected to arrive.

Laser guided weapon

The S-Korean XK11 gun is supposed to have laser guided target assesment, explosive projectiles and a mini missile launcher. The one intersting part is the multi-function XK11 rifle is already shown on video able to fire NATO 5.56mm rounds and 20mm grenades!

Bullet camera (TNO concept)

The bullet camera can be considered as a cross-over between a bullet and a UAV. Thanks to the miniaturisation enabled by nanotechnology a bullet can be transferred into an intelligent monitoring “node” that can perform detection and surveilance tasks. The bullet can be fired by a traditional weapon into the area (or building) where inspection or surveilance is needed. The bullet can carry the following functional components:

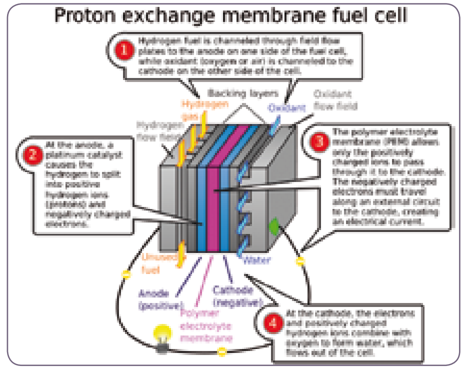
- microphone
- camera
- infrared or radar array
- acoustic detector
- chemical sensors
- radio for rf-communication
- small battery
- explosive charge

It is expected that the bullet will consist of two individual parts: one part that carries the sensor system (payload) and a second part, the point of the bullet, that will consist of an impact absorbing material offering crash protection for the payload during the impact or landing.


electronic laser gun

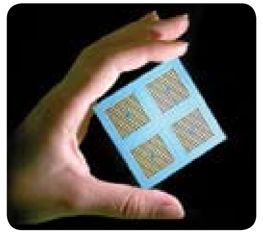

corner shot automatic rifle

devices needind portable power



20 W Ultracell methanol fuel cell

50 Watts fuel cell running on propane



nanomembrane for fuel cell

Power sources

The future of wireless (nano or micro) sensor devices will very much depend upon the progress in miniaturization of the power or energy supply. It is supposed to be one of the most critical issues for opening the high volume market for wireless sensors. Research in this area goes into various concepts depending on the required peak power and required long term endurance of the energy pack. The following small scale energy systems are in development:

- high peak power, short endurance
  - advanced flywheels (not nano)
  - super capacitors
- medium endurance, medium peak power
  - various battery systems, nanotechnology assisted
  - flexible thin film batteries
- long endurance, low peak power
  - H2 fuel cells
  - μ-nuclear battery
- long endurance, medium peak power
  - micro combustion engines

More and more effort goes in to hybrid systems of recharchable batteries and energy harvesting such as:

- solar battery power pack: combined thin film battery with thin film solar cell
- remote charging with RF

Hydrogen fuel cell

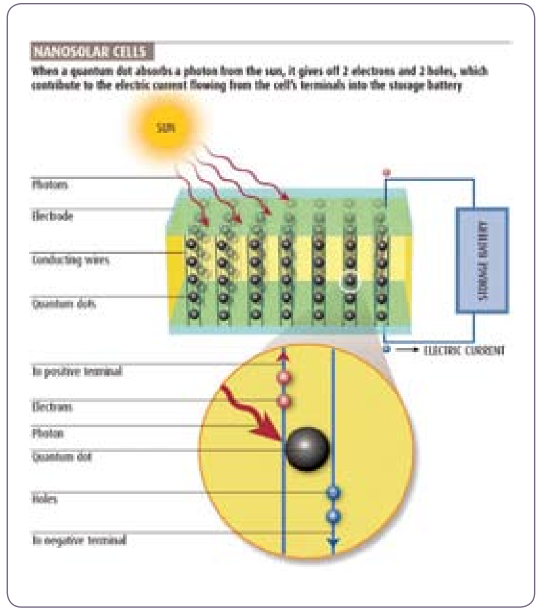
Hydrogen fuel cells use hydrogen and oxygen gas to create electrical energy. They differ in their internal chemistries but the reaction is always basically the same: hydrogen+oxygen=water, the basic reason for their eco-friendly reputation. As shown in the figure, flow plates are used to bring hydrogen gas to one side of the fuel cell while oxygen is brought to the other. A catalyst (usually platinum) breaks the hydrogen gas into positive ions (protons)and electrons. The central membrane, the protron exchange membrane, allows only positive charges to pass through. The positive ions pass through the central membrane while the electrons are stuck and flow away through conductors that provide the electrical current that provides the useful power. Once the positive ions and electrons reach the other side of the fuel cell, where the oxygen is, another catalyst (usually platinum) combines the positive ions, electrons and oxygen yielding water and releasing heat. Nanotechnology is helping fuel cells by making them more efficient.

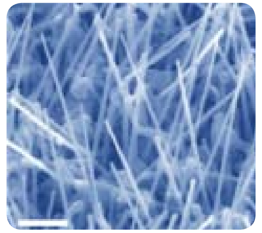
Methanol fuel cell

The UltraCell company's XX25 prototype being designed for the military, as well as a commercial version called the UC25, promise to as much as 9 hours of power within the 20 watt envelope - about double the capacity of current laptop batteries - while weighing up to 70% less. UltraCell's fuel cell systems use replaceable cartridges that contain a mixture of 67% methanol and 33% water. The power adapter into which the cartridges fit weighs about one kilogram, while the military versions of the cartridges themselves - which contain 500 wh/kg of energy - weigh 625 grams each. Commercial versions of the cartridges will contain 300 wh/kg of energy and weigh 260 grams each.

Portable fuel cells, SOFC type

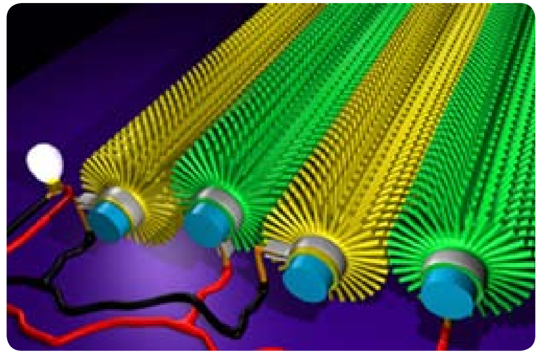
An example of the state -of-the-art in fuel cells is offered by Nano-dynamics Energy (USA) with the 50-watt solid oxide fuel-cell proto-type, roughly the size of a loaf of bread, and being composed of roughly 20 percent nanomaterials (membranes, electrodes, catalysts). It can generate some 3 kWh (10 MJ) from 2,5 kg propane. The prototype, originally designed for a combat soldier, could replace about 17 kg of batteries. Unlike conventional fuel cells, which use hydrogen gas, this prototype uses propane gas. the kind you find at camping stores. The amount of nanomaterials will increase in the near future, to make it possibel to run the SOFC fuel cell on diesel.

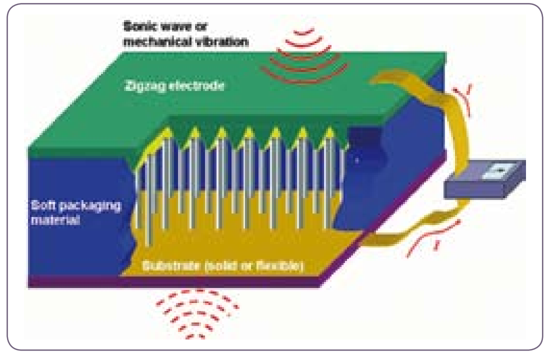



nano wire polymer USCD


violetta Solar Gear Charger Battery


voltaic backpack


microfibre nanogenerator



ZnO nanowire energy scavenger (Wang)

Energy from the sun

Nanotechnology is a strong enabler for future solar cells offering significant improvement in efficiency. The main developments in this field are:

- nanowire electrodes for silicon and organic dyes solar cells
- solar cells based on nanotube-bucky ball interfacing
- quantum dot solar cells with very high efficiency potentials

More background information is given in section 3.14 and 3.16

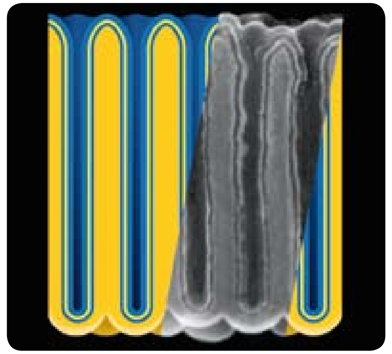
Energy harvesting from human motion

"If you want to get power from the body, go where the muscles are" says prof. Donelan of the Simon Fraser University (Canada) and cto of the company Bionic Power. He developed an energy harvesting device capable of harvesting energy from the motion of the leg (knee-device) generating 5 J from each single footstep (5 W at normal walking speed). This is much more efficient than devices such as piezo-electric footsoles, generating only 1 W per footstep.

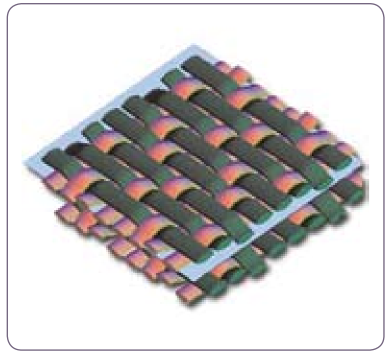
ZnO nanowire energy generator from vibrations

Georgia Tech (prof Wang) has developed a nanowire nanogenerator that is driven by a sonic wave to produce continuous direct-current output. The nanogenerator was fabricated with vertically aligned zinc oxide nanowire arrays that were placed beneath a zigzag metal electrode with a small gap. The wave drives the electrode up and down to bend and/or vibrate the nanowires. A piezoelectric-semiconducting coupling process converts mechanical energy into electricity. The zigzag electrode acts as an array of parallel integrated metal tips that simultaneously and continuously create, collect, and output electricity from all of the nanowires. The approach presents an adaptable, mobile, and cost-effective technology for harvesting energy from the environment, and it offers a potential solution for powering future nanodevices and nanosystems.

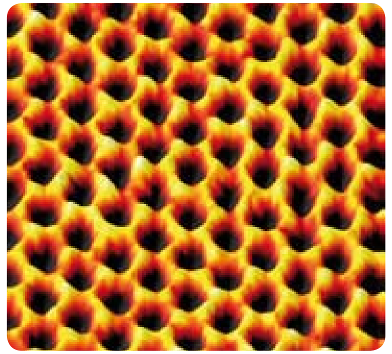
A layer of zinc oxide is grown on top of substrate to collect the current. The electrode is then lowered on top of the nanowire array, leaving just enough space so that a significant number of the nanowires are free to flex within the gaps created by the tips. Moved by mechanical vibration, the nanowires periodically contact the tips, transferring their electrical charges. By capturing the tiny amounts of current produced by hundreds of nanowires kept in motion, the generators produce a direct current output in the nano-Ampere range. The nanogenerator could produce as much as 4 watts per cubic centimeter – based on a calculation for a single nanowire. That would be enough to power a broad range of nanometer-scale defense, environmental and biomedical applications, including biosensors implanted in the body, environmental monitors – and even nanoscale robots.



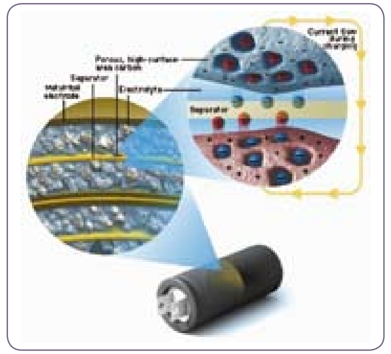
nanocapacitor for electrical energy storage



ultracapacitor fabric



graphene ultracapacitor



ultracapacitor structure

Energy storage

Rechargeable batteries and supercapacitors are both forms of portable energy supply. Rechargeable batteries store electrical energy in a chemical form, with the top end of the market dominated by lithium. While there is work on other metals (such as magnesium), this is likely to remain the case for the foreseeable future, as lithium is the lightest and most electropositive metal. In such rechargeable batteries current is generated through the migration of lithium ions between electrodes. Supercapacitors differ from rechargeable batteries by storing electrical energy directly as charge on sets of electrodes, which are separated by an insulator and covered with a thin coating of electrolyte. One common theme links both types of energy supply- the requirement for more power from portable devices, which translates into higher energy densities. However, allied to this is the need for materials to be robust (to withstand many hundreds of charge/discharge cycles), and the ability to deliver power rapidly when required (i.e. faster charge/discharge rates). Achieving this is dependent on the production of new electrode materials.

Rechargeable batteries

Rechargeable batteries require different materials for the cathode (where the majority of lithium resides when the battery is in a discharged state) and the anode (where the lithium migrates to when the battery is charging). As power density is proportional to the available lithium, then the volume changes at each electrode can be large during the charge/discharge cycle. Nanocomposites of metal oxide nanoparticles are being developed for the cathode, which offer higher density lithium intercalation, improved diffusion and excellent electrical conductivity. For the anode, carbon-based materials and metal alloys offer the tensile strength to cope with the increase in volume changes during the charging cycle. New developments have shown that electrode materials can be nanostructured in situ during the first charging cycle, a process known as “conversion”. Although at an early stage, this has the potential to provide higher energy electrode materials (by increasing the electron output per component electrode atom from approximately 0.6 to 2 or even higher).

Supercapacitors

Supercapacitors make use of the high surface area of nanomaterials, usually nanoporous carbon, to store electrical charge. A thin layer of an electrolyte dielectric medium is used to separate the capacitive electrodes. Because of the relative high power density (however still below Li-ion batteries), supercapacitors fill the gap between capacitors and batteries. Current nanoporous carbon and carbon aerogels can store upto 200 F/gram. The self discharge is relatively high and therefore their use is limited to short term storage.
For supercapacitors, the electrode surface area determines the power density. Therefore nanocrystalline materials, carbon nanotubes and aerogels, are all being developed, as they have a large surface to volume ratio. However as supercapacitors utilise a small volume of electrolyte the surface of each electrode must be tailored to ensure that interactions between the electrode and the relevant electrolyte ion are optimised. Many supercapacitors employ organic electrolytes and there is usually a large difference in size between anions and cations, thus the surface of each electrode must structured to have nanopores of different dimensions.
R&D in this sector is very near to market with most experts believing that nanotechnology will have a major influence by 2014. As there is such a large demand for powerful and portable energy supplies, it is expected that advanced batteries and supercapacitors will be able to command a premium price.
A research team of the University of Maryland research develops new devices for electrical energy storage, electrostatic nanocapacitors which dramatically increase energy storage density of such devices - by a factor of 10 over that of commercially available devices - without sacrificing the high power they traditionally characteristically offer. This advance brings electrostatic devices to a performance level competitive with electrochemical capacitors and introduces a new player into the field of candidates for next-generation electrical energy storage. Electrostatic nanocapacitors are formed in nanoporous anodic aluminum oxide (darker yellow) film by sequential atomic layer deposition of metal (blue), insulator (yellow), and metal. Insert in picture on page 68: cross-section of actual structure, represented as rescaled scanning electron micrograph.

Graphene ultracapacitors

Researchers from the University of Texas have developed a new carbon-based material called graphene which can be used as ultracapacitor for electrical energy storage. The graphene has an one-atom thick structure which enables high storage capacity. Electrical charge can be rapidly stored on the graphene sheets, and released from them as well for the delivery of electrical current. There are reasons to think that the ability to store electrical charge can be about double that of current commercially used materials.

Combat vehicle

The future tank or land vehicle should be lighter and will have to fit in larger quantities in the available C-130 like transport planes of the NATO countries. Secondly the tank should be faster and more lethal. The basic question is whether the future tank should have a traditional large caliber gun in a turret or will be equipped with micro cruise missiles. This will determine the weight together with the armour materials being used.

The aim should be to develop lightweight nano-armour skirt or composite plates to cover the vital part of the tank or land vehicle. This armour could also consist of magneto-rheofluidic systems. The outer layers of the vehicle should have a coating with B/C absorbing and deactivation capacity and will ideally in the long term also have a switchable nanodot polymer camouflage display. Another use of nanomaterials can be found in the bearings, the sealants, and the ammo. Vital microsystems in the future tank will be the microradar, a large polyled command display in the turret and various machine condition sensors for the components which need maintenance (engine, wheels, tracks).

Of course the tank will have to have the latest stealth shape and nanocoatings combined with materials which limit the IR-visibility. With the increase of computing power of nano-electronics unmanned land vehicles (microrobots) with sensors and weapons can be anticipated for surveillance in hostile urban environment, reconnaissance missions and logistics supply.
Future vehicles are expected to be lightweight, multipurpose, intelligent guided, low in energy consumption, safe and protective for the passengers and high comfort. This applies both to civil automotive vehicles as well as for military land vehicles. Military vehicles have additional requirements with respect to armour protection, specific detection and urveillance sensors and weapon systems.

Materials

Nanotechnology enables the following material functionalities:
- lightweight: high strength nanocomposite plastics are foreseen to replace metal and by this reduce weight and radar signature
- smart components: components with built-in condition and load monitoring sensors, on long term: self repairing or self healing materials
- adaptive structures: active structures that adapt to changing conditions such as adaptive camouflage, suspension, flexible/rigid etc
- stealth: radar absorption coatings, camouflage
- armour: nanoparticle, nanofiber reinforced antiballistic structures, reactive nanoparticle armour, shock absorbing nanotubes

ICT

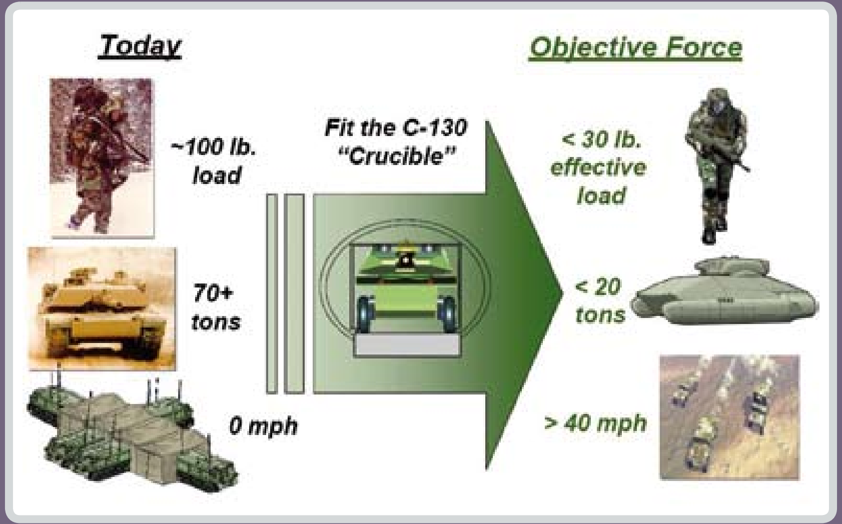
Combat vehicles are expected to be equipped with the following ICT features:
- position sensing and signalling: GPS for navigation and with RFID-systems for tracking and tracing vehicles
- identification: RFID - tags for remote identification
- security: μ-radar, μ-bolometer (infrared) for surveillance - acoustic arrays for sniper detection
- wireless networks: vehicle internal sensoric network will become wireless; connection to distributed external network
- directional RF communication: micro antenna arrays enable directional radio communication with reduced power and signature

Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc sensor networks, enabling long range guidance of all kinds of vehicles. Advanced intelligence can be built-in thanks to the expanding μ-sensor capabilities, integration of sensor functions and information processing power. Especially for the military use, continuous effort is put in the development of unmanned and autonomous vehicles e.g. for surveillance. Nanotechnology is crucial here to minimize size, weight and power consumption, important for long range coverage.

Power

Focus is on lightweight and energy efficient powering. Reduction of thermal, radar and acoustic signature is for the military an additional aspect. Main developments are:
- hybrid, electrical/combustion, powering, driven by civil automotive, reduces consumption and signature
- hydrogen fuel cell, SOFC
- for miniaturised, unmanned vehicles: μ -fuel cell



Unmanned weaponised robot

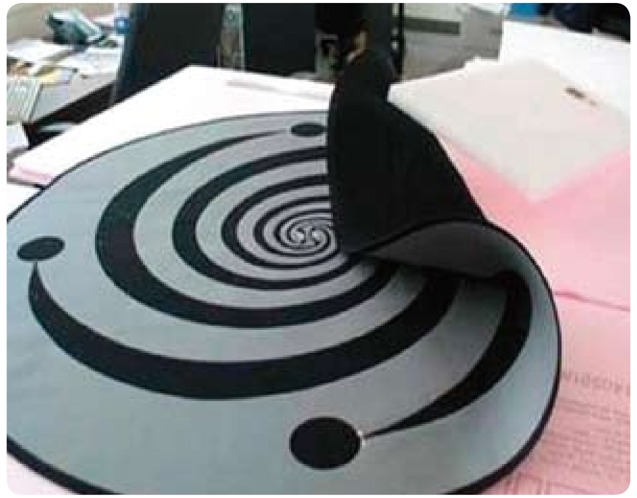
Talon robots are a family of powerful, durable, lightweight, remotely operated, tracked vehicles that enable the operator to be positioned up to a kilometre away from the danger point. Talon robots are widely used for EOD, reconnaissance, communications, sensing, security, defence and rescue operations. They have all-weather, day/night capabilities and can navigate virtually any type of terrain. The flexibility of the Talon architecture facilitates straight forward integration of sensors and accessories making it a highly versatile platform and one which requires a low logistic footprint.

The SWORDS (Special Weapons Observation Reconnaissance Direct-action System) variant can be configured with either an M240 or M249 machine gun or a Barrett .50 calibre rifle for armed reconnaissance missions. Of significant importance is that the operator remains in direct control of the SWORD at all times and a person has to make the final decision to engage the target."

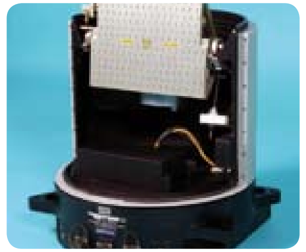
Principal characteristics of Talon Swords:

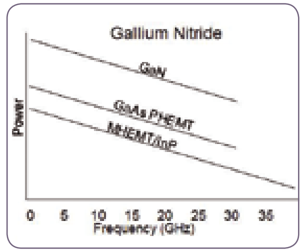
- rugged all-terrain, all-weather tracked vehicle with day/night capability
- weighing around 200 lb (90 kg), it's man-portable, easily transported and instantly ready for use
- US Army safety confirmation for M249 Squad Automatic Weapon and M240 Medium Machine Gun (pending).Can be equipped with mounts for M16 rifle, Barrett .50 calibre, 40 mm grenade launcher and M202 anti-tank rocket systems
- high flotation and traction for operations in soft sand, mud, snow or heavy brush and can climb stairs, negotiates rock piles, and can traverse concertina wire
- controlled by RF from an attaché-sized operator control unit (OCU)– the TALON is widely regarded by user community as being amongst the easiest robot to operate, particularly in a hostile environment
- vehicle speed of up to 5.5 mph (8 kmh)
- with a four hour battery run time, Talon robots have the longest battery life of all man-portable robots.

Talon Sword

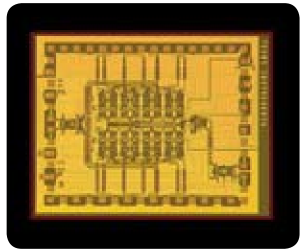

flexible radar antennas made from LCP's

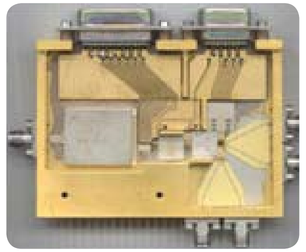

NanoSar synthetic aperture radar (Imsar USA)

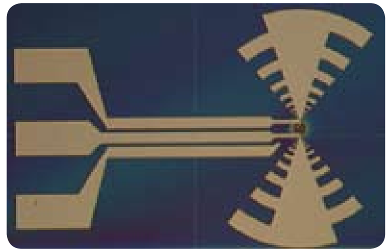

small phased array radar system (Thales)



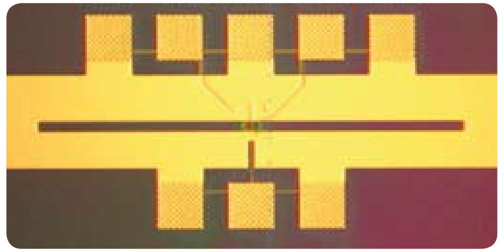
more power output with GaN technology


high speed ADC of TI


AD for digital TR nodes


passive pixel detecor 70-600 GHZ 06mm


radar phased array self defense


RFantenna 78-330 GHZ 10GHz bandwidth with quantum ADC

Nanomaterials for small radar systems

Nanotechnology can contribute to development of more accurate, faster, lighter and more stealthy radar systems for defense vehicles by:

- denser memory, faster processors, rf-switches and electronic devices needing less power
- conductive materials capable of emitting RF-waves at high frequencies, embedded in the structure of vehicles to enhance recognition capacities
- reduction of radar and visual signature (stealth)

Nano synthetic aperture

A good example is the NanoSar system (Imsar USA). NanoSAR is a revolutionary SAR (synthetic aperture radar) that brings radar sensing capabilities to small platforms, suitable for tanks, UAV's and small ships. The NanoSAR weighs only two pounds which includes the navigation system, antennas, cabling, real-time processor and RF front end. It therefore meets the size, weight, power, and cost requirements of small vehicles and UAVs.

SiGe technology

A new development is silicon-based microchips capable of operating in ultra-sophisticated phased array radar systems based on integration with silicon-germanium (SiGe) technology. It provides cost savings, compact size and improved efficiency in the same way that advances in silicon technology have made consumer electronics smaller and less expensive. In addition, silicon-germanium is a less expensive material than the compound semiconductors - such as gallium arsenide or indium phosphide - that have long been used in radar systems. In SiGe conventional silicon integrated circuit technology is the basis and nanotechnology techniques are used to introduce germanium inside the silicon on an atomic scale.

GaN technology

Transistors made with gallium nitride can operate at 10 times the voltage of silicon or gallium arsenide transistors because of the breakdown voltage of the wide bandgap semiconductor. This feature allows systems to operate at five to 10 times the power of conventional circuits, or it can be exploited to realize broader bandwidth circuits or higher efficiency circuits, depending on how designers chose to optimize transistor and circuit. The high-power amplifier circuits can be inserted into radar and electronic warfare systems. Its a "third-generation" RF technology, like SiGe, with the first generation being silicon and the second being gallium arsenide and indium phosphide. It will have a huge impact on defense systems and potentially commercial systems as well. Wide bandgap electronics for radars have the potential to significantly increase system performance, reduce size and weight, and reduce logistics requirements.

Liquid crystal polymers for antena's

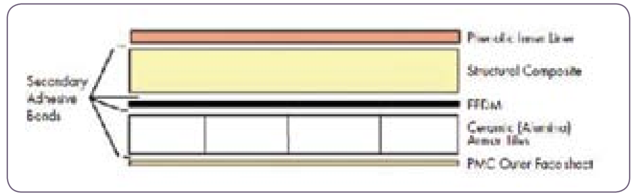
A new antenna technology is the use of liquid crystal polymers (LCP) in the shape of an ultra-thin, paper-like plastic which can incorporate a variety of electronic circuits. Yet it molds to any shape and appears to perform well in the extreme temperatures and under intense radiation. LCP outperforms conventional materials for antennas and circuit boards in high-frequency radio applications aboard vehicles. Flexible LCP antennas would be lighter than today's structured antennas, and LCP-based circuits molded to available vehicle areas could eliminate heavy metal boxes that currently house rigid circuit boards.

Plasma stealth technology

Radar and radio antennas are inherently radar-reflecting. At least two design solutions to this dilemma have become widely available. One is to have moveable radar-absorbent covers over radar antennas that move aside only when the radar must be used. A better solution, currently being developed, is the plasma stealth antenna. A plasma stealth antenna is composed of parallel tubes made of glass, plastic, or ceramic that is filled with gas, much like fluorescent light bulbs. When each tube is energized, the gas in it then becomes ionized, and it then can conduct current just like a standard metal wire. A number of these energized tubes in a flat, parallel array, wired for individual control (a "phased array"), are able to be used to send and receive radar signals from a wide range of angles without being physically rotated. When the tubes are not energized, they are invisible to radar, which can be absorbed by an appropriate backing.

nanocomposite armoured tank


CAV, composite armoured vehicle



armour plate structure

Nano armour for vehicles

In general, candidate materials for armor should possess high hardness, high elastic modulus, low Poisson's ratio and low porosity. Low specific gravity is needed in applications where achieving the lowest possible mass is important, such as body armor, vehicle armor and aircraft armor.

Armoured plates for military vehicles and tanks can benefit from nanomaterials such as nanofibers, nanotubes, nanocrystalline metals and ceramics, and combinations thereof in nanocomposites because of their prospects for:

- high hardness, appoaching diamond
- better flexibility and toughness
- high impact strength
- reduction in weight

Increase in strength and flexibility of ceramic plates incorporating nanocermic structures and new forms of metal alloys, such as amorphous metals and nanocystalline metals grains have been engineered to be as extremely hard, in some cases hard as diamond. The incorporation of carbon nanotubes or spherical nanoparticles of silica or titanium dioxide in a polymer offers improved ballistic resistance with significantly better flexibility.

Nanocrystalline Boron Carbide

Use of nanocrystallinity increases strength and ductility in ceramics. Conventional ceramics are brittle, while nanophase ceramics (such as nanophase titania) are ductile and are more sustainable than conventional metals. An example is a nanocrystalline ceramic of doped boron carbide based made by hot pressing of nanopowder at a temperature of 1900°C and a pressure of 30 MPa. The introduction of a front layer of the nanostructural ceramics into a test armor structure significantly increases its bullet resistance as compared to that of an analogous structure with a ceramics manufactured using the traditional technology.

Superthread nanocomposites

Its is expected that nanoparticle/nanofiber reinforced polymers can make the armour of helmets and tanks 40% to 60% lighter. Nanocompositematerials, such as nanoclay reinforced polyurethane for linings for vehicle armour, and ultra-high strength fiber fabrics with nanocomposite binders for light weight body armour, have great potential to improve the combat survivability of both vehicle and body armours, whilst reducing cost and weight. A drastic improvement can be expected from future composites made from super high strength carbon nanotube fibers such as Superthread in combination with a nanoreinforced binder (shear thickening fluid type). It is expected that these materials could provide a 3-4 times higher damage/bullet resistance allied with the lightweight and flexibility.

Inorganic fullerenes

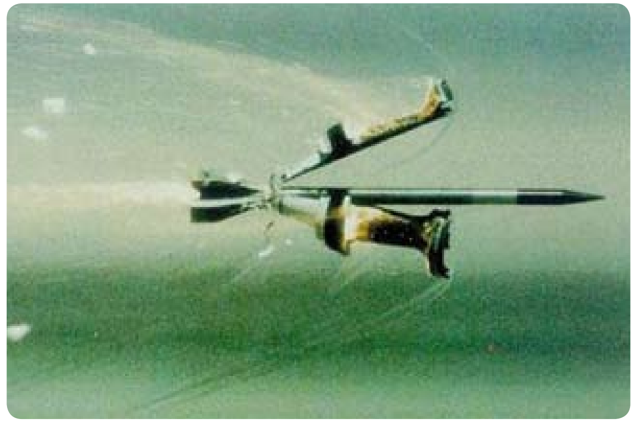
Inorganic fullerene-like nanostructures (ApNano, Isr) have a similar structure as carbon nanotubes but are made tungsten disulfide (WS2) or titanium disulfide (TS2). Inorganic fullerens show an extremely high degree of shock absorbing ability and could be used in impact resistant applications such as ballistic protection personal body armor, bullet proof vests, vehicle armor, shields, helmets, and protective enclosures. The new IF materials have shown up to twice the strength of the best impact resistant materials currently used in protective armor applications such as boron carbide and silicon carbide, and are over 5 times stronger than steel.

Transparant steel

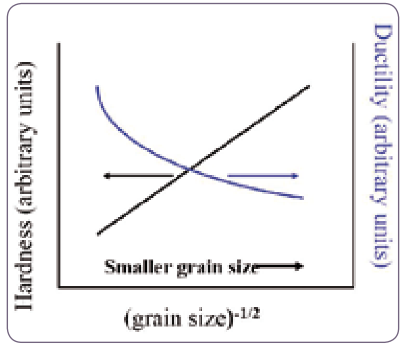
By mimicking a brick-and-mortar molecular structure found in seashells a composite plastic has been made (Univ Michigan) that is as strong as steel but lighter and transparent. It's made of layers of clay nanosheets and a water-soluble polymer that shares chemistry with white glue. Further development could lead to lighter, stronger armour for soldiers or police and their vehicles.

Liquid nano-armour

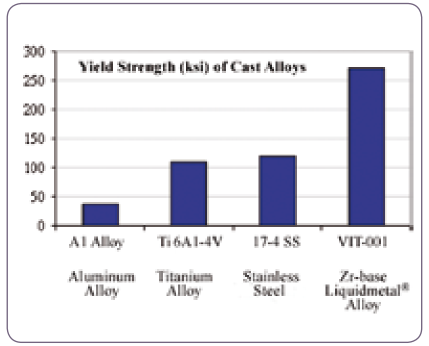
So-called liquid armour is based on shear thickening fluids, which is like gel with a high load of (silica) nanoparticles and is applied on the metal or clothe. The surface becomes bullet-proof in a sharp impact. When a bullet hits the surface or it is subjected to an attack by knife the nano-particles are being pressed and collected in a cluster and liquid becomes a hard composite. A bullet-proof jacket filled with gel weighs 2 or 3 kg. Another important factor is that liquid armour is flexible.



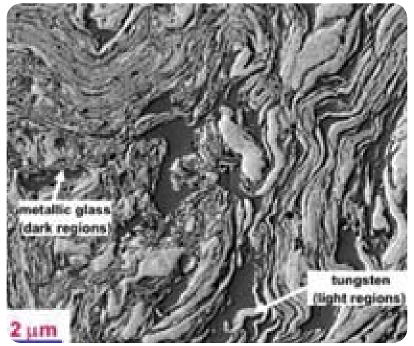
Kinetic Energy Penetrator



increased hardness with nanocrystallinity



properties of Liquidmetal alloy



nanocrystalline tungsten in a metallic glass matrix

Nanomaterials for ammonition

Nanomaterials have a high potential for creation of improved ammunition and projectiles, due to the fact that key characteristics of ammunition and other projectiles, such as penetration capacity, weight, guidance, and explosive force can be enlarged substantially. Nanotechnology could also enable built-in sensor such as ammunition condition sensors, embedded antennas for RF and GPS guidance sensors and power supply for sensors. The use of high energetic materials facilitates very effective propellants and highly explosive load of the ammunition and projectiles.

Superpenetrating materials

Depleted uranium (DU) based alloys is being used for armor-piercing projectiles, also known as kinetic energy penetrators, or KEPs. As a KEP projectile goes further into protective armor, pieces of the projectile are sheared away, helping to form a sharpened chisel point at the head of the penetrator. When DU penetrators hit a target at very high speeds, they deform in a “self-sharpening” behavior. But the use of depleted uranium is no longer without criticism: depleted uranium is slightly radioactive and has chemical toxicity properties that, in high doses, can cause adverse health effects. Nanomaterials are in development to replace DU.

Nanocrystalline tungsten

Unlike conventional iron showing a normal plasticity behavior of BCC-type crystals, nanocrystalline iron shows a KEP type behavior below the average grain sizes of 250 nm. This occurs not only in “soft’ iron but also in “hard” tungsten. A metallic glass matrix reinforced with nanocrystalline tungsten, with a grain size reduced to the nanometers scaleworks even better than depleted uranium (Ames Lab). The metallic glass and tungsten are environmentally benign and eliminate health worries related to toxicity and perceived radiation concerns regarding depleted uranium.

Nanocrystalline tantalum

Via the so callled high velocity deformation (HVD) process, micron-sized tantalum particles composed of entirely of nanocrystalline structures can be produced through a low-cost, high volume production process.. The high density and ductility of tantalum make it an attractive material for ballistic applications.. In the nanocrystalline state, the dynamic formability and processibility of tantalum greatly improves because the normal encountered strain hardening does not occur.

Liquid metal

Liquid, amorphous metal alloys show very high yield strengths, approaching the theoretical limit and far exceeds the strength currently available in crystalline metals and alloys. For example, a yield strength of over 250 ksi has been achieved in Zr-base and Ti-base liquid metal alloys. This is more than twice the strength of conventional titanium alloys. Liquid metals can ideally be combined with nanocrystalline particles in order to form high penetrating materials. Characteristic properties are:

- high hardness and yield strength
- superior strength/weight ratio
- superior elastic limit
- high corrosion and wear resistance
- unique acoustical properties

High energy laser gun

Laser weapons mounted on trucks could be ready to roll into battle within five years. Boeing is working on building the optics needed to track and focus lethal laser energy onto rockets, artillery shells and mortar rounds. The high energy laser technology demonstrator will use a new solid-state laser powered by electricity from a truck-mounted diesel generator, rather than bulky and dangerous chemicals. It can be regarded as a second generation laser weapon after the succesful trials with the (bulky) MTHEL mobile tactile high energy laser testbed.

Tests are underway with two rival designs for the 100-kilowatt solid-state laser. The winning laser will have to be ruggedised to survive field conditions and made small enough to fit inside the truck. The laser is scheduled to start shooting at real targets in 2013.

Quantum dot lasers

Upto now quantum dots are being researched and exploited as very high efficient light and laser sources and detectors for telecom applications. It will be a matter of time before this technology will appear in high energy laser applications as described here.

Quicc Diva

Aptera

BO solar powered all electric car

Tesla Motors

GM Volt (will be launched in 2010)

All electric vehicle

Green technology, zero emissions and rising oil prices all have become strong drivers. At present, almost every car manufacturer is working on electrical cars. Not only fuel economic hybrid versions for long endurance and range, but more and more 100% electric cars are coming into the picture for urban traffic. Some of them are already on the market such as Tesla Motors, Aptera, ZAP and the Zenn (zer emission no noise) car, others are very close to the market such as Nissan (Nuvu EV), Honda (Insight), GM (Volt), Smart and Joule. Also a new Dutch company Duracar is entering the scene with the Quicc DiVa.

Li-ion technology

Thanks to the progress in the Li-ion battery technology the weight issue of sufficient battery capacity in a vehicle is becoming less and less dominant. The electricity suppliers see big opportunities and are starting to invest in a network of electrical charging stations, just like the gas stations. It seems that it will be only a matter of time before most of our cars will run 100% on batteries, some people say 10-15 years from now.

Super capacitor technology

The secretive company EEStor's claims that its system, a kind of battery-ultracapacitor hybrid based on barium-titanate powders, will dramatically outperform the best lithium-ion batteries on the market in terms of energy density, price, charge time and safety. It could replace the electrochemical battery at half the cost and without the need for toxic materials or chemicals. The ZENN electrical car company is performing trials with ithis system.

Electric and plastic

Duracar, a new Dutch automobile manufacturer introduced in 2008 its first prototype of a 100 % Electric and Plastic car: the Quicc! Diva (Distribution Van). It offers the following interesting features:

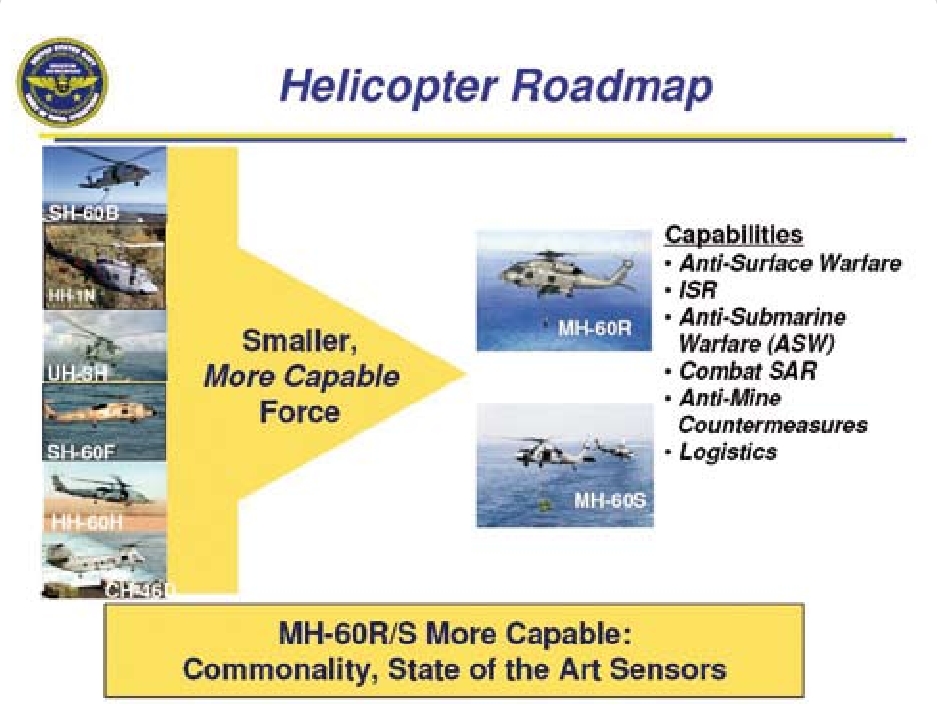
- fully -lithium ion iron phosphate- battery electrically powered
- body and chassis of the car are entirely made of plastic, cradle to cradle plastics
- green, economical and compact design, for urban traffic purposes
- topspeed 120 km/h, range 150 km
- 1-2 Euros per 100 km
- zero PM10 and CO2 emissions, practically silent
- completely new electric drive train

in 2009 the car will be launched on the market www.duracar.nl or www.quicc.eu

Impact

These developments will also effect military vehicles, especially the light and urban/short range vehicles. Next to the benefits as for consumer vehicles, all electric vehicles can be made much more stealthy in terms of acoustics, infrared and radar. This is especially true for the all-electric-all-plastic vehicles.
The role of nanotechnology is quite important:

- lightweight, high density batteries (nanowire batteries): with the development of silicon nanowire anodes, the capacity and energy density of current Li-ion batteries can be augmented by a factor 5-10. This is a giant step in obtaining small and lightweight batteries.
- new nanoporous electrical capacitors
- lightweight all plastic chassis: with nanocomposite polymers and CNT-fiber (Superthread) reinforced plastics, very lightweight structures will become available.
- both aspects will facilitate a low power consumption but also offer benefits for logistics and of course helps to achieve a very low signiture, both for radar as well as infrared.



Helicopter roadmap (Bruce Clinqan, 2006)

Smaller, more capable, less maintenance, unmanned

The extreme mobility gained by using helicopters in tactical operations is a key ingredient in supporting the manoeuver warfare and peace keeping tasks. The troop transport helicopter is a versatile weapons system and is also used for resupply, reconnaissance, medical evacuation and search and rescue missions. An assault force embarked in helicopters can bypass terrain obstacles and hostile areas rapidly moving deep behind enemy lines, giving a commander the ability to concentrate combat power at the decisive time and place.

The helicopter's use as an assault troop transporter evolved shortly after the Korean War. New technology allowed the helicopter to grow to a size that could carry a squad of Marines. The concept of vertical assault by helicopter was perfected in the Vietnam War.

The rotor system consists of the rotor blades and rotor head assemblies. The fiberglass rotor blades introduced in the early 1980's greatly reduced the number of maintenance man hours per flight hour as compared to the old metal rotor blades. The blade shape did not change, consequently aircraft performance stayed the same. These blades are reaching their service life as well as their rotor hubs. Rotor blade aerodynamic technology has made great progress. New rotor blade designs made of composite materials incorporated with a composite bearingless rotor hub will be lighter. They will provide more lift and airspeed with less chance to fail and demanding less man hours to maintain.

The transmission, gearbox and drive shafts will reach their service lift and are becoming more expensive to rebuild. Composite materials have been used in the Boeing 360's transmission and gearbox casings. Rotor shafts and interconnecting shafts are also made of mixed-modules composite construction. Composite parts are stronger and less likely to fail, lower in weight and require less maintenance

It is expected that nanotechnology will further improve the composite materials in terms of strength and selfhealing properties, providing better endurance and reduced maintenance. Even smart adaptive rotor blades can expected in the future for better maneuvrability and speed.

Osprey MV-22 hybrid helicopter-airplane

Wieland design for a coaxial rotor helicopter

High speed helicopters

How fast can a helicopter go? For several years, Sikorsky has been working on what it calls X2 technology, a suite of systems that it says could let a helicopter “cruise comfortably” at 250 knots. That would be a far zippier pace than most current rotary wing aircraft can handle.

The tilt-wing MV-22 Osprey, meanwhile, can hit speeds upward of 240 knots, but it’s a hybrid--half helicopter and half airplane. It can hover when its propellers are turned upward, but to go fast, it needs to fly like a plane. Due to the high costs, the MV-22 Osprey has not become a success sofar.

The most striking thing about the X2 design is that it makes use of coaxial main rotors, in contrast with the single main rotor that’s been characteristic of mainstream helicopters since-well, since Igor Sikorsky himself helped popularize that arrangement in the 1940s. The coaxial rotor system has largely been the lonely province of helicopter makers like Russia’s Kamov (Tandem-rotor designs like the Chinook, meanwhile, have two large rotors fore and aft.)

The other notable aspect of the X2 is the rear-facing tail rotor. Helicopters like the Blackhawk with a single main rotor invariably have a tail rotor that faces the side, a necessity to counter the torque from the main rotor that would otherwise spin the fuselage like a top. The X2’s coaxial setup would eliminate the torque, allowing the tail rotor to propel the helicopter forward much like the propeller on a ship.

Internally, an X2-based aircraft would have fly-by-wire (that is, electronic) flight controls, as opposed to traditional mechanical or hydraulic controls. Sikorsky says the eventual aircraft would serve as a “flying wind tunnel” to measure the performance of the rigid main rotors and their relationship to the rest of the aircraft’s aerodynamics.

Coaxial rotor designs allow for a more stable, more maneuverable, quieter and safer helicopter due to inclusion of a coaxial main rotor and exclusion of a tail rotor, which also means a smaller footprint. Coaxial rotor helicopters also provide a better power to weight ratio than traditional helicopters, produce greater lift and are also much more efficient.

The technology appears on the Sikorksy X2 demonstrator and now WHT is not only developing two and four seat models with combustion engines and 5 seat models with turbine engines, they are also working on Unmanned Aerial Vehicles and smaller 1 and 2 seat helicopters with electric motor configurations. On top of all this the coaxial rotor helicopters are much easier to fly and therefore much simpler and cheaper to learn to fly.

Vector-thrust ducted propellor

See the Piasecki video of the X-49A “Speedhawk” - a Sikorsky YSH-60F modified with wing and vectored-thrust ducted propeller for propulsion and control.

Role of nanotechnology

The role of nanotechnology is expected to enable the following developments:

- high strength rotor blades
- lightweight constructions
- morphing rotor blades for increased efficiency

futuristic artist impression

Aeroscraft concept

miniature helicopter (Norway)

Aeroscraft concept: combining buoyancy and dynamic lift in one

A new paradigm in air transport is born with the advent of the Aeroscraft -- an aircraft that utilizes a combination of buoyant and dynamic lift creating unique operational capabilities beyond what is available from any other air platform today.

The Aeroscraft is designed and built on the basis of a new concept in flight. The remarkable idea grew out of the belief that there is a more comfortable and safer way to fly than simply applying luxury to an existing airframe and re-naming it.

The capabilities of the Aeroscraft lead to its functionality -- and whether you choose to use the Aeroscraft as a private air yacht or a fully functional business center; the appointments of luxury are endless and left to the client's dreams to create.

Future concepts

The extreme mobility gained by using helicopters in tactical operations is a key ingredient in supporting the maneuver warfare and peace keeping tasks. The troop transport helicopter is a versatile weapons system and is also used for resupply, reconnaissance, medical evacuation and search and rescue missions. An assault force embarked in helicopters can bypass terrain obstacles and hostile areas rapidly moving deep behind enemy lines, giving a commander the ability to concentrate combat power at the decisive time and place.

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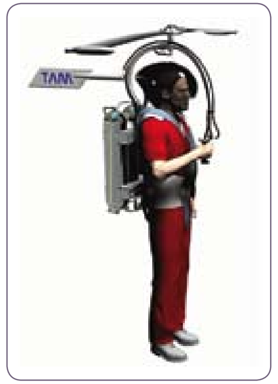
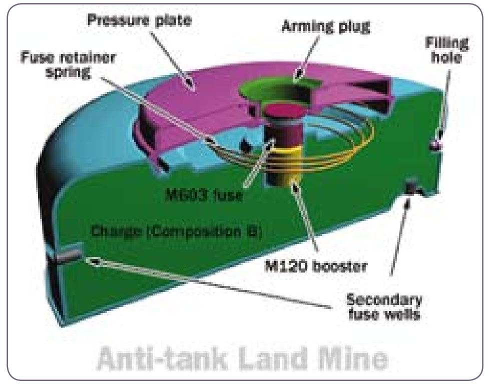


mine-detector ground penetrating radar Ho Missouri BAE



landmine-cutaway-m15

roadside bomb

Landmines and improvised explosive devices

Landmines and improvised explosive devices (IEDs) pose severe challenges to successful military operations. A related capability is needed for the disposal of unexploded ordnance. In general, the problem has three components: detection, exposure of the device (for example, by excavation), and neutralization of the device.

The detection and disposal of anti-personnel landmines is one of the most difficult and intractable problems faced in ground conflict.

Role of nanotechnology

One may find nanotechnology components in the future on the following levels:

- detection: both quantum structures as well as array technology on chip will lead to smaller, more powerful and capable micro-wave generators for detection purposes
- defeat: quantum structures may lead to smaller and more power lasers that can be used to defeat (land)mines from a remote distance
- land mine itself: nanomaterials offering increased energetic power might be used to create smaller, but more powerful mines with substantial better explosive power

Detection of landmines and IED's

Ground penetrating radar

The detection and disposal of anti-personnel landmines is one of the most difficult and intractable problems faced in ground conflict. Current detection methods use a microwave or ground penetrating radar sensor in combination with a neural-network type of identification system.

The ground-penetrating radar system developed by Non-Intrusive Inspection Technology (NIITEK) uses radar to detect and identify improvised explosive devices buried along roads; it then marks the buried device with spray paint for removal or detonation. NIITEK's system is mounted in front of the Husky, a vehicle used in mine detection, and scans a 180-degree arc fast enough to allow vehicles and ground troops to move at a walking pace. Currently, only one system has completed trials in the battlefield, in Afghanistan.

The current equipment on the Husky in simple terms is a metal detector. The current equipment cannot tell what the metal is that it identifies. So the army must stop, investigate and then act prior to moving on. The NIITEK system can positively identify both metallic and plastic mines. This system most likely will replace existing systems.

Nuclear quadrupole resonance

Nuclear quadrupole resonance (NQR) combines the spatial localization capability and convenience of metal detection or ground-penetrating radar (GPR) with the compound specific detection capability offered by chemical detection techniques. Starting in the mid-1990s, groups at Quantum Magnetics Inc. and the Naval Research Laboratory made considerable improvements in the basic scientific and instrumentation techniques for performing an NQR measurement over the ground. These advances have led to programs to build a vehicle-mounted NQR system to work in conjunction with a mine clearance system, and a man-portable system to meet requirements for a man-carried mine detector. Overall, NQR is the only new technology in the past 10 years to progress to the stage at which practical deployment has become a possibility. NQR is an electromagnetic technique–based operating system in the frequency range of 0.5–5.0 MHz.

Explosives Detection

At less than three pounds, the Fido Portable Explosives Detector is the world's most sensitive explosives detection system. Fido explosives detectors utilize proprietary amplifying fluorescence polymers (AFP) to detect trace levels of explosive materials in parts per quadrillion (ppq). This level of detection is comparable to that of highly trained explosives detection canines, the gold standard in explosives detection technology. Unlike the alternative, the exquisite sensitivity of the Fido supports detection of both explosive vapor and particulates without the need to modify the system in any way. This unique design enables previously unheard of functionality for explosives detection equipment.

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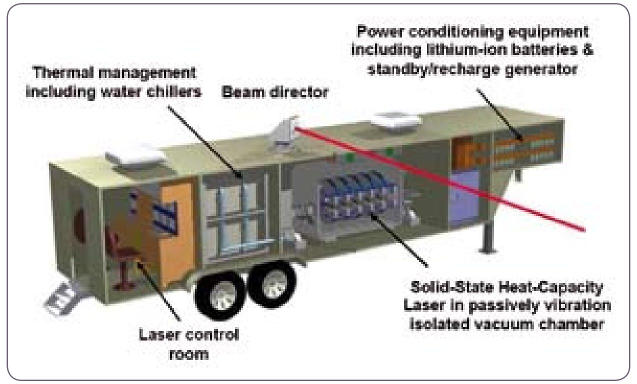
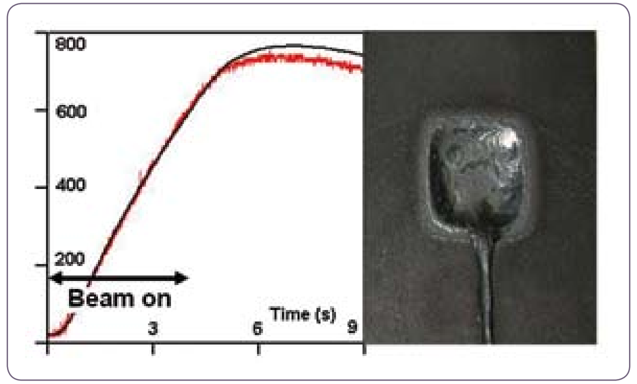
laser defeated landmine



setup for a movable 100 kW solid state laser system (LLNL)



heat effect (Celsius) of 20 kW solid state laser on steel (LLNL)

Role of nanotechnology

Nanotechnology is expected to play a role in future development of directtional, sweeping radar array systems, using quantum stuctures for generate and sense microwave radiatio more efficiently and hereby allowing smaller and lighter detection devices. Also in the field of fluorescence, nanotechnology will bring increased sensitivity thanks to the very high optical efficiency of quantum dots.

High energy laser system

Thor, a high-energy laser weapon system developed in Israel by Rafael, can defeat improvised explosive charges (IEDs), roadside bombs and unexploded ordnance (UXO) and other objects categorized "potentially explosive hazards". The vehicular system is mounted on a remotely controlled weapon station, carrying the laser beam director and high-energy laser and coaxial 12.7mm machine gun to neutralize improvised explosive devices from a safe, standoff distance. This dual capability enables Thor to be used for offensive and defensive purposes, as well as for safe stand-off removal of explosive obstacles by laser directed energy or projectile kinetic energy. Since the laser is used to burn the IED, rather than activate it, it can be used to avoid collateral damage which can result from other neutralization procedures. Thor uses powerful, air cooled laser, measuring up to 700 watt.

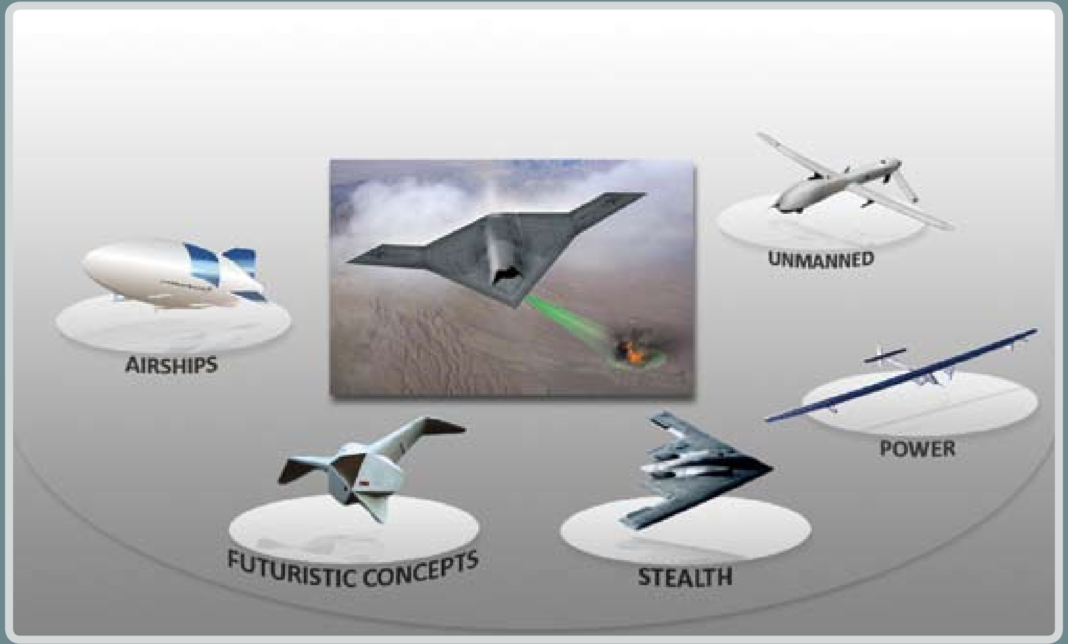
Solid State Heat Capacity Laser with 30-100 kW (LLNL)

Our system utilizes a high-power Solid State Heat Capacity Laser (SSHCL), as built at Lawrence Livermore National Lab and shown in Figure 1. The impetus for this laser was to counter projectile threats on the tactical battlefield. Currently, this most advanced laser operates at a time-averaged power of about 34 kW. This can be extended to the 100-kW regime by straightforward additions to the hardware. The laser system is compact. Destruction of a landmine or IED in a known approximate location is a two-step process. First, the laser exposes the device. The beam can excavate soil by creating micro-explosions in the groundwater, as we have demonstrated in laboratory experiments. The beam can burn through other types of covering, such as canvas or vegetation. Secondly, the beam is focused on the device. The beam can heat a metal container, or drill through a plastic container, leading to conditions for activation of a high explosive. For some IEDs, a simpler strategy might be merely to use the beam to cut electrical wires. Field operators would have detailed control over all such processes, by tuning the laser power and the spot size. In all cases, standoff would be limited only by the practical ability to sight the target.

Role of nanotechnology

Nanotechnology is expected to play a role in future laser systems, using optical quantum stuctures for more efficient and hereby smaller and lighter laser devices.

6.0 potential innovations for operations in the air



Aeronautics

Future manned airplanes, unmanned airvehicles (UAVs) and guided missiles are expected to be more lightweight, intelligence guided, low in radar, thermal and visual signature, have a high speed and highly manouverable. The onboard intelligence will continuously increase, facilitating automated control and maintenance. Special attention goes to specific detection and surveillance sensors and weapon systems.

Materials

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposite plastics and biomimic (human bone type) structures to reduce weight and radar signature
- smart components: components with built-in condition and load monitoring sensors, such as fiber bragg, on long term self repairing, healing materials
- adaptive and morphing structures: active structures that adapt to changing conditions such as adaptive aerodynamics, adaptive skin and adaptive shape
- stealth: radar absorption coatings, thermal camouflage high energetic propellants: e.g. nano dispersed aluminum as propellant agent

ICT

Aeronautic vehicles are expected to be equipped with the following ICT features:

- position sensing and signaling: GPS for navigation, with EAS for tracking and tracing
- identification: RFID tags for remote identification
- security and guidance: μ-radar, μ-bolometer (infrared) and μ-acoustic arrays

Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc satellite networks, enabling long range guidance. Advanced intelligence can be built-in thanks to the expanding μ-sensor capabilities, integration of sensor functions and information processing power. Especially for the military, continuous effort is put in the development of unmanned and autonomous flying platforms e.g. for surveillance. Nanotechnology is crucial here to minimize size, weight and power consumption, important for long range coverage.

Power

Focus is on lightweight and high energy powering. Reduction of thermal signature is for the military an additional aspect. Main developments are:

- nanocomposite energetic materials
- for miniaturised, unmanned vessels: μ-fuel cell, μ-thrusters

Future expectations

For future aeronautics the following platform developments can be distinguished which could benefit of the above described nanotechnologies:

- micro unmanned aerial vehicles (micro UAVs) for reconaissance, attack, sensing
- high precision guided weapons and missiles
- morphing airplanes
- lightweight airplanes


Russian Su-PAK FA 34 radar and laser stealth prototype plane


B2 stealth plane


F-117 stealth airplane


The Corax unmanned stealth plane


Boeing's "Bird of Prey" stealth aircraft


future Su-PAK FA stealth airplane


F-22 Raptor

Invisibility with left-handed metamaterials showing a negative refractive index.

The next generation of stealth planes could be virtually invisible to the human eye, roaming radars, and heat-seeking missiles, as well as disguising their sound vibrations and their impact on the Earth's magnetic field. If optical and radar metamaterials could be developed, they might provide a way to make a ship or a vehicle invisible to both human observers and radar systems, although the challenges of building a cloak big enough to hide an entire ship are huge.

Left-handed metamaterials

So-called metamaterials consist of stacked micro- or nanostructures with resonator capabilities for electromagnetic radiation such as radar, infrared en visible light radiation. At the resonator frequency these structures can show a negative refractive index. This occurs when both the permittivity ε and the permeability μ have negative values. Normal materials have positive values for both the permittivity and permeability and are called right-handed materials. Materials with negative ε and μ are called left-handed materials. The "EM-radiation resonator" metamaterials show negative values at the resonator frequencies.

Negative refractive index: radiation bends around objects

With a negative refractive index, incoming radiation is not being reflected or absorbed by the material, but it will be guided and transported along its surface just like in waveguides. The radiation is bended around the object. It means that you can not see through the object but your are able to see around the object. to see what is behind the object, without seeing the object itself. Several research groups such as Duke University, Purdue, Ames, UC Berkeley (USA), Louvain La Neuve (B), Imperial College (UK) and the Karlsruhe and Stuttgart University (Germany) have proven the concept and have built prototype materials. At first at microwave (radar) wavelengths, but since 2007 also for visible light: a refractive index of -0,6 was reported at a wavelength of 780 nm (joint effort Ames and Karlsruhe).

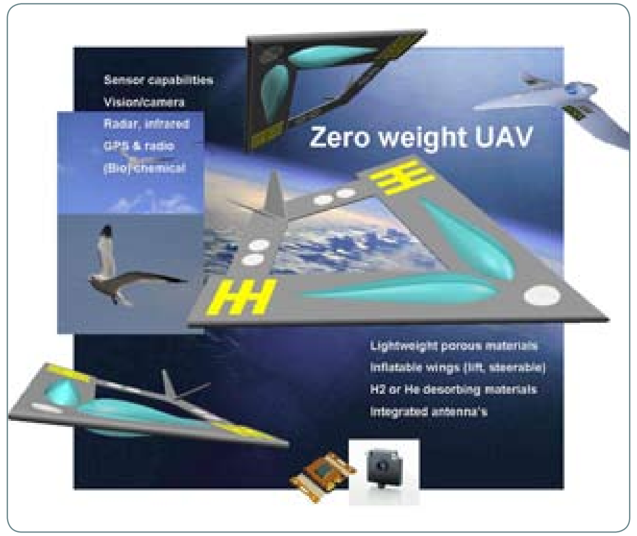
The application of an "invisible cloak" based on metamaterials can be foreseen in the area of radar stealth since it concerns a system that should work at a distinct radar (micro)wavelength. For visible- and infrared it should work for a broad wavelength spectrum, which will need considerable future development and time.

Alternative 1: radar absorption with carbon nanotubes

One of the most commonly known types of radar absorbing material (RAM) is iron ball paint. It contains tiny spheres coated with carbonyl iron or ferrite. Radar waves (100 MHz - 100 GHz, typically 8-12 GHz in military) induce molecular oscillations from the alternating magnetic field in this paint, which leads to conversion of the radar energy into heat. The heat is then transferred to the aircraft and dissipated. A related type of RAM consists of neoprene polymer sheets with ferrite grains, carbon black or carbon nanotube particles (30% load) embedded in the polymer matrix. Thin absorbing layers are capable of producing good absorption (≥25 dB) with restricted bandwidths by a combination of attenuation within the material and destructive interference at the interface. The electromagnetic properties and the thickness of the layer are such that the initial reflected wave and the sum of the emergent rays resulting from the multiple reflections within the material are equal in magnitude and opposite in phase. The thickness of the layer is close to a quarter-wavelength at the frequency of operation, giving a 180° phase difference between the interface reflection and the emergent waves.

Alternative 2: radar absorption with ionic liquids

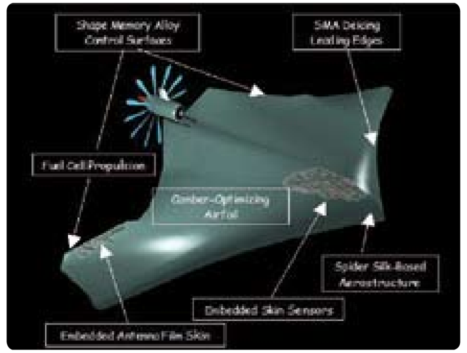
This alternative method of microwave absorption involves the use of poly(ionic liquid)s, which contain separated cations and anions, having very strong microwave absorption properties. Researchers have shown an ability to synthesize ionic liquid polymers by polymerizing monomers containing ionic liquid moieties using free radical polymerization or atom transfer radical polymerization, or other polymerization techniques. These polymers are extremely stable. These poly(ionic liquid)s or their copolymers have high microwave absorption properties due to the presence of high concentration of anions and cations. They can be fabricated into various shapes such as films, formulated into coating, painting or other applications. They have many potential applications, especially in military (University of Wyoming).



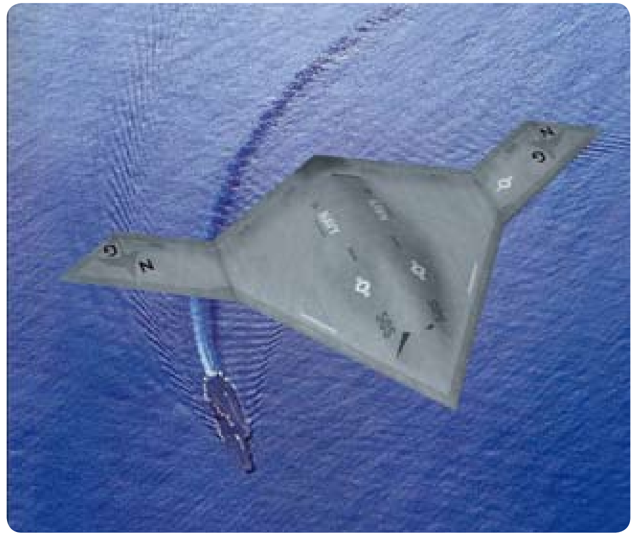

X-47 B robotic fighter


uav 2025


swarm of UAVs



future UAV Nasa concept


X-47B unmanned concept

Unmanned Aerial Vehicles (UAVs)

Unmanned aerial vehicles (UAVs) and manned aerial vehicles with larger dimensions seem to have more potential for the present operations and for the next 5 years. A number of robotic aeroplanes have been developed already in the past for reconnaissance tasks. Small unmanned aerial vehicles probably will be equipped with micro-thrusters for precise movements, an intelligent gasturbine with sensors and air-inlet and flow control, guidance, acceleration and gyros sensors, integrated fiber bragg optical sensors in the skin and structure for stress and crack sensing, stealth shape and radar absorbing materials.

For the period of 10-20 years from now vortex control with MEMS structures, biomimic bone-type structures, smart adaptive and self healing skins can be expected. On the opposite page one can find a concept for a UAV of the future as depicted by NASA, showing use of technologies such as shape memory alloys to control and adapt surfaces, embedded antennas and skin sensors, deicing surface on the front or the wings, use of spider silk for structural strength in composites.

Nanotechnology for high strength, lightweight and smart components

The use of reinforced plastics in structural strength proving parts and components of UAVs such as existing carbonfiber composites will be followed by the introduction of nanocomposites with carbon nanotubes and/or nanofibers as reinforcing fillers in composite plastics. Essential will be the use of high strength- to-weight materials, fire resistant composites, smart materials which can heal themselves, sense and actuate (adapting shape and structure for various purposes), multispectral index materials for refraction change, energy efficient fuels and propellants, active camouflage and protective coatings.

By material, sensor- and actuator integration new lightweight structures will arise that can adapt and morph into different shapes. Even adaptive “zero-weight” aerial vehicles with inflatable wings will be possible in the future, allowing long endurance surveillance operations.


solar Impuls


solarplane 460


solar Impuls


skysailor 15 600

Solar powered planes for continuous operation and surveillance

Thanks to the enabling role of nanotechnology, the technology for realizing planes that can fly continuously on solar power is coming very nearby. The progress in (thin film) solar cell efficiency, in light-weight high capacity (Li-ion) batteries and ligthweight construction materials already has led to succesful prototypes of unmanned solar powered planes. It will be a matter of years before these planes can carry significant payloads and can be commercialized for surveillance tasks. Even prototypes for manned solar powered planes are underway.

Solar Impuls SA (Swiss): around the world in a solar airplane

In a world depending on fossil energies, the Solar Impulse project is a paradox, almost a provocation: it aims to have an airplane take off and fly autonomously, day and night, propelled uniquely by solar energy, right round the world without fuel or pollution. An unachievable goal without pushing back the current technological limits in all fields... Solar Impulse is a window for the technologies of the future. Already under development, there are solar cells offering a better efficiency-weight ratio, intelligent systems of energy management, materials as lightweight as they are resistant and a storage system to rival the most efficient. Main partners are Solvay, Omega and Deutsche Bank but also many univesities are involved.

Zephyr (Qinetic): solar powered spy plane

A British-built solar-powered spy plane has set an unofficial world record for the longest continuous flight.The uncrewed Zephyr aircraft stayed aloft for 82 hours and 37 minutes by storing solar energy collected during the day in a rechargeable battery which powered the plane’s two propellers at night. But by operating over three day-night cycles, the aircraft’s designers at the UK defence firm Qinetic believe it could essentially operate indefinitely.

Sky Sailor (ETH Zurich)

Continuous flight was demonstrated in June 20087 during a solar powered flight of more than 27 hours over 874.4 km what represents a Zürich-London trip. This is a world record for this size and using no thermal winds or altitude gain before the night. This system, named Sky-Sailor, is fully autonomous in navigation and power generation. Equipped with solar cells covering its wing, it retrieves energy from the sun in order to supply power to the propulsion system and the control electronics, and charge the battery with the surplus of energy. During the night, the only energy available comes from the battery, which discharges slowly until the next morning when a new cycle starts.

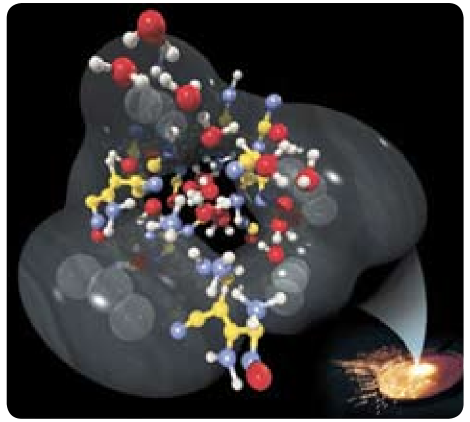
Solid propellants with high energy density

Combustion characteristics of conventional propellants are governed by characteristics of composite formulations. Because of their multi-scale amd multi-component character, the particulate size distributions are locally non-uniform and clustering of smaller components occur with significant agglomeration of aluminum (if present) prior to ignition. The rate of reaction is limited by mass and thermal transport.

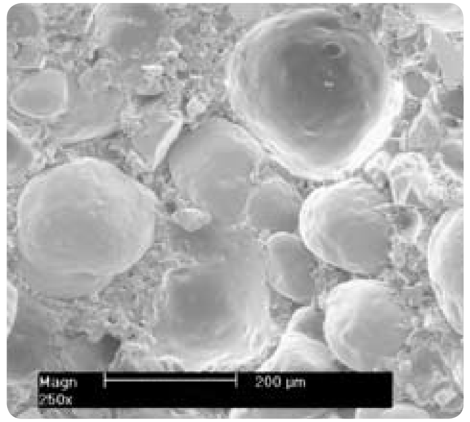
A novel approach to propellants utilizing nanoscale materials might mield a) higher reaction rates, b) reduced size dispersion, c) greater uniformity and d) reduced agglomeration of aluminum. A radical approach to propellants utilizing 3-dimensional nanostructures might yield controllable energy release and tailorable sensitivity.

Materials that are produced on the nanoscale have the promise for increased performance for energetics such as propellants & explosives. For energetics the focus is on solid propellants, where utilization of nanomaterials promises increased energy density, controlled energy release, reduced sensitivity, reduced environmental impact, and long-term stability.

- scale differences
  - very high specific surface area (4-6 magnitudes)
  - short diffusion path-length in burning
- performance enhancements
  - complete burning
  - accelerated burning rates
  - ideal detonation in fueled explosives
- coating benefits
  - intimate contact between fuel and energetic material
  - less coating defects ensuring long term stability

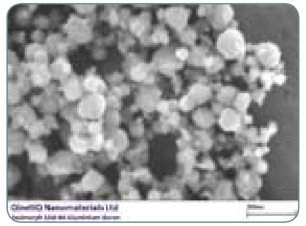


nano nitromethane

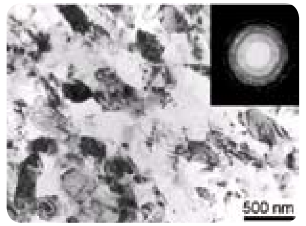


solid propellant

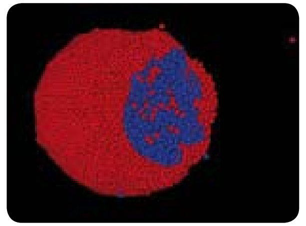
zirconium powder propellant



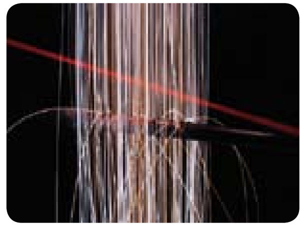
Qinetic nanoaluminumboron



UFG Aluminum



oxide coated aluminum



energetic materials

Ignition of nanothermite

Nano energetics

In the near-term novel propellants with nanoscale material will be used to reduce particle size dispersion(greater uniformity), reduce agglomeration of aluminum (increased combustion efficiency), and increase reaction rates (increased burning rates). In the long-term radical new propellant approaches will be explored to utilize 3-dimensional nanostructures that might yield controllable energy release and tailorable sensitivity. Recent experiments have shown that the ignition sensitivity and burning rate of nano-aluminum particles can be significantly higher than micron-aluminum particles. This resulted in increased burning rates and improved combustion efficiency for conventional composite propellants. It was observed that the nanometer-sized aluminum powder significantly reduced aluminum agglomeration. The low agglomeration rate may be the result of a thin aluminum oxide layer on the aluminum particles as observed on transmission electron microscope images.

New efforts are directed towards coated nanometer-sized metal powder, which may yield controlled oxidation and improved storage lifetime. Encapsulation of aluminum particles in an oxidizer matrix has been successfully demonstrated as an example for the creation of a novel nanostructure using aerosol and sol-gel chemistry. The reactivity of the encapsulated aluminum increased by a factor of 10, when the structures were ordered through bipolar coagulation as compared to random structures with Brownian coagulation.

Future goals are 3-dimensional nano-energetics with a high degree of structure and order for controlled reactivity and improved manufacturability.

- 1st Generation (pre 2000)
  - Nanometer-sized Al powder/conventional propellants
  - Some performance gain
- 2nd Generation (current efforts)
  - Metal oxide / Al sol-gel quasi-structured nanocomposites (thermites)
  - Organic sol-gel quasi-structured nanocomposites (propellants)
- 3rd Generation (future)
  - 3-dimensional nanoenergetics
  - Structured/ordered
  - Controlled reactivity
  - Improved manufacturability/processing

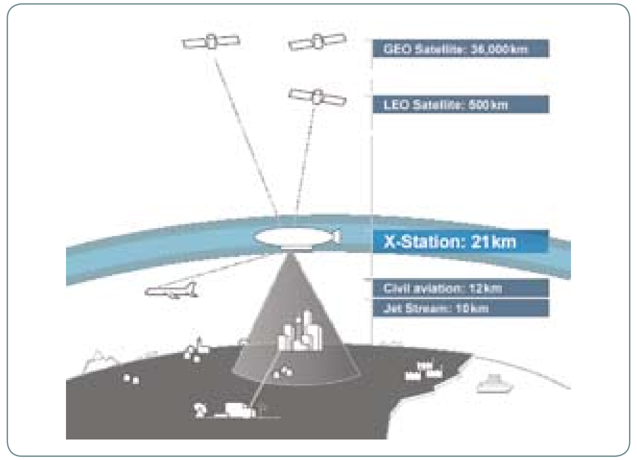
Nano-thermites

Nano-thermites, which are hightech energetic materials made by mixing ultra fine grain (UFG) aluminum and UFG metal oxides; usually iron oxide, molybdenum oxide or copper oxide, although other compounds can be used. The mixing is accomplished by adding these reactants to a liquid solution where they form what are called “sols”, and then adding a gelling agent that captures these tiny reactive combinations in their intimately mixed state. The resulting “sol-gel” is then dried to form a porous reactive material that can be ignited in a number of ways.

The high surface area of the reactants within energetic sol-gels allows for the far higher rate of energy release than is seen in “macro” thermite mixtures, making nano-thermites “high explosives” as well as pyrotechnic materials. Sol-gel nanothermites, are often called energetic nanocomposites, metastable intermolecular composites or superthermite, and silica is often used to create the porous, structural framework. Nano-thermites have also been made with RDX and with thermoplastic elastomers.

The most studied combinations are nano-Aluminum (oxidizer) combined with Fe_2O_3, CuO ,MoO_3, WO_3 and Bi_2O_3. But also $KMnO_4$ nanoparticles can be used as a source for oxygen. The observed pressurization rate for the Al/$KMnO_4$ (290 psi/μs) nanocomposite was about two orders of magnitude higher than that for Al/CuO and Al/MoO_3 (~8 psi/μs) and several orders of magnitude higher than Al/Fe_2O_3 (0.01 psi/μs).

CuO nanorods were synthesized using the surfactant-templating method, then mixed or self-assembled with Al nanoparticles. This nanoscale mixing resulted in a large interfacial contact area between fuel and oxidizer. As a result, the reaction of the low density nanothermite composite leads to a fast propagating combustion, generating shock waves with Mach numbers up to 3.



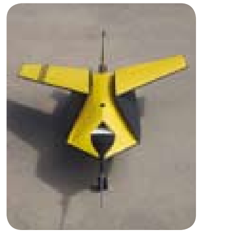

NASA's morphing wing airplane concept

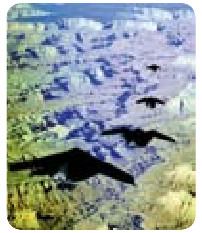


Lockheed's stratospheric platform system


active elastic wing concept NASA


Morphing aircraft concept NASA/DARPA


Lockheed Martin morphing wing concept




Aeroscraft cargo airship


Lockheed Martin morphing wing concept transformation

High altitude stratospheric surveillance airship

Lockheed Martin and Stratcom International are developing an unmanned lighter-than-air, high altitude airship , a so-called Stratospheric Platform System (SPS), that would operate above the jet stream and above severe weather in a geostationary position to serve as a telecommunications relay, a weather observer, or a peacekeeper from its over-the-horizon perch.

A limited number of these airships would provide overlapping radar coverage of all maritime and southern border approaches to the continental U.S., and may be a significant asset in homeland defense efforts.

The SPS can maintain a relatively geostationary position at 20.000 meter. Lift is provided by helium that is contained in its envelope. Differential thrust, electric-powered props control the pitch and roll and keep it in position. With the advent of thin-film photovoltaic solar cells (capable of producing voltage when exposed to radiant light), fuel cells, and lightweight/high-strength fabrics, a high-altitude airship could stay on station weeks or even months at a time by generating its own power and keeping helium loss to a minimal amount.

The onboard sensors' surveillance coverage extends over the horizon and monitors a diametric surface area of 1250 km. The airship would measure nearly 150 m long and 50 m in diameter.

An analysis by RAND indicates that these airships can also play a role in the telecom network featuring much lower costs than satellites. Nanotechnology is strong enabler providing lightweight materials and self powering solar and fuel cells

Aeroscraft: combining buoyancy and dynamic lift in one concept

The Aeroscraft is a concept for an aircraft that utilizes a combination of buoyant and dynamic lift creating unique operational capabilities beyond what is available from any other air platform today. The concept could be described as a high velocity airschip providing space, comfort and silence in flight, for use as a private air yacht or a fully functional business center.

Smart, adaptive and morphing structures

Smart, adaptive and morphing structures in MAVs and UAVs can de defined as structures which alter characteristics (shape, surface roughness, spectral index, sensing functions, de-icing of wing surfaces) due to changes in material characteristics, dimensions of components, shapes of structures. For unmanned and unmanned aerial vehicles of the future smart, adaptive and morphing structures can be developed based on microsystem (adapt shape via MEMS structures), material and nanomaterial developments. Unlike military aircraft today, future multi-role morphing aircraft will change their external shape features substantially to allow systems to adapt to changing mission environments, including unanticipated threats or challenges. These physical features include re-shaping inlets, re-sizing wings and tail surfaces and re-shaping fuselage dimensions. Most aircraft in the air today operate flaps using extensive hydraulic systems. The multiple hydraulic lines form a complex system of pumps and lines, is heavy and quite difficult and costly to maintain. Many alternatives to the hydraulic systems are being explored by the aerospace industry. Among the most promising alternatives are piezoelectric fibers, electrostrictive ceramics, and shape memory alloys, MEMS systems sometimes combined with inflatable balloons etc.

One of the examples is the macro fiber composite material (MFC, Smart Material) consisting of rectangular piezo ceramic rods sandwiched between layers of adhesive and electroded polyimide film. It is an innovative actuator that offers high performance and flexibility in a cost-competitive device. The MFC provides distributed solid-state deflection and vibration control or strain measurements.

7.0 potential innovations for operations at sea

Marine warfare

Future vessels are expected to be lightweight, intelligence guided, low in energy consumption, safe and protective for the passengers and high in comfort. Also onboard intelligence will continuously increase, facilitating automated control and maintenance. Naval vessels have additional requirements with respect to detection and surveillance sensors and weapon systems.

Materials

Nanotechnology enables the following material functionalities:

- lightweight: high strength nanocomposite plastics are foreseen to replace metal and by this reduce weight and signature
- smart components: components with built-in condition and load monitoring sensors, on long tern self repairing, self healing materials
- adaptive structures: active structures that adapt to changing conditions such as adaptive aqua dynamics, flexible/rigid etc

ICT

Vessels are expected to be equipped with the following ICT features:

- position sensing and signaling: GPS or underwater acoustics for navigation, with EAS for tracking and tracing
- identification: RFID - tags for remote identification
- security: μ-radar and μ-acoustic arrays for surveillance

Remote and unmanned guidance

With nanotechnology advanced sensor and wireless communication capabilities are becoming possible, e.g. via distributed ad-hoc sensor networks, enabling long range guidance of all kinds of vehicles. Advanced intelligence can be built-in thanks to the expanding μ-sensor capabilities, integration of sensor functions and information processing power. Especially for the military use, continuous effort is put in the development of unmanned and autonomous vessels e.g. for surveillance. Nanotechnology is crucial here to minimize size, weight and power consumption, important for long range coverage.

Power

Focus is on lightweight and energy efficient powering. Reduction of thermal, radar and acoustic signature is for the military an additional aspect. Main developments are:

- all electric vessel enabling very low signature
- hydrogen fuel cell
- for miniaturised, unmanned vessels: μ-fuel cell

Stealth ships

A nice example of a stealth boat is the prototype M80 Stiletto stealth boat. The Stiletto, a twin M hull vessel, is 80 ft in length with a 40 ft beam providing a rectangular deck area equivalent to a conventional displacement craft 160 ft in length. The vessel's draft fully loaded is 3 ft and is equipped with four Caterpillar engines, yielding a top speed in excess of 50 knots (nearly 60 miles per hour) when fully loaded and can be outfitted with jet drives for shallow water operations and beaching. M Ship Co. was responsible for the design and construction of the vessel made solely of carbon fiber for reduced weight and increased stiffness, the largest vessel ever built in the U.S. of this advanced material.

Role of nanotechnology

Nanotechnology will have a future impact on the stealth properties of these ships. It is expected that the following properties can be improved:

- high strength nanocomposite plastics with low radar signature, replacing metal
- radar absorbing coatings
- coatings with cloaking properties (metamaterials)

Autonomous underwater vehicle

Sentry is a state-of-the-art, free-swimming underwater robot that can operate independently, without tethers or other connections to a research ship.

The autonomous underwater vehicle, or AUV, is pre-programmed with guidance for deep-water surveying, but it can also make its own decisions about navigation on the terrain of the seafloor.

Sentry is designed to swim like a fish or fly like a helicopter through the water. The sleek hydrodynamic design allows the vehicle to descend quickly from the sea surface to the depths (about 3,500 meters per hour). The novel shape also gives the vehicle tremendous stability and balance while cruising through bottom currents.

The vehicle has thrusters built into its foils, or wings. Like an airplane, the foils allow the vehicle to gain lift or drag or directional momentum, as needed.

When necessary, the AUV also can hover over the bottom for close-up inspections, navigational decision-making, and for rising up and down over rugged seafloor terrain. The design allows the vehicle to start, stop, and change directions, whereas many AUVs tend to travel in one direction.

The AUV steers itself with a magnetic compass; long-baseline (LBL) navigation triangulated from underwater beacons; a sophisticated inertial guidance system (INS); and, when within 200 meters of the bottom, an acoustic sensor that can track the vehicles' direction and speed with incredible precision.

Powered by more than 1,000 Lithium-ion batteries-similar to those used in laptop computers, though adapted for extreme pressures, Sentry dove for as long as 18 hours and 58 kilometers, with the potential for longer trips in the future.

Sentry a newly developed robot capable of diving as deep as 5,000 meters into the ocean, has been successfully completed by scientists and engineers from the Woods Hole Oceanographic Institution (WHOI) and the University of Washington (UW).


concept solar powered ship


electric motors


concept solar powered ship


all electric ship


DSe hybrid diesel-solar-wind motor boat


electric driven ship

Solar powered ships

Future vessels are expected to be low in energy consumption. The use of solar power is getting more and more interest.

Solar submarine Goldfish

Project Goldfish is the code name for a solar-powered submarine - and the floating solar power platform that would charge it - on the drawing boards at Swiss company BKW FMB Energy. It envisions an all solar powered shuttle boat to carry tourists. BKW envisions a greenhouse-gas emission-free U-boat that could carry up to 24 passengers as deep as 300 meters (984 feet) on underwater tourist jaunts. The floating solar power platform could charge the submarine and also provide power to customers on shore, the company says.

Hybrid powered boat

DSe Hybrid combinings a diesel engine with solar and electric power (hence “DSe”) and with wind-power to be added to the production model, the 40ft vessel can take advantage of a sunny day by cruising at speeds of up to six knots indefinitely using only solar energy. Not only does this save fuel, it eliminates the rumble of diesel engines to bring one of pure sailing’s greatest attractions to the motoryacht format: silence. In diesel mode the yacht achieves 13 knots and in electric mode, the permanent-magnet motors provide the silent 6 knot cruising speed. The hybrid system also means that there’s no need to fire-up the diesel motor before casting off, it can get up to 4 hours out of solar, wind and stored battery power before requiring the diesels, which in keeping with the design philosophy, are housed in sound-deadening enclosures.

All electric ships

Potential benefits of electric-drive ships include improved fuel efficiency, greater flexibility of design, reduced internal volume, and reduced susceptibility to enemy radar.

All electric ships involve advanced electrical power systems (AEPS) including the conversion of virtually all shipboard systems to electric power – even the most demanding systems, such as propulsion and catapults aboard aircraft carriers and need systems for power conversion and distribution, combat system support and mission load interfaces to electric power systems.

This will lead to increased computerisation of the warships operations – which means the crew can be significantly downsized from thousands to only 100 members. It will also lead to a reduction in the size of electrical components that will lay the foundation for more advanced weapon systems. This is a trend in ship construction.

The new British/French CVF/PA2 carrier class will be all-electric ships, for instance. So will the USA’s new DDG-1000 destroyers. The US Navy hopes to have an operational ship kicking ass on the high seas by 2012.

Role of nanotechnology

Some of the technologies under consideration include high- temperature superconducting electric motors, advanced gas turbine engines, fuel cell auxiliary power supplies, and podded propulsor technologies. The role of nanotechnology will be primarily in the area of fuel cell technology (nanomembranes and catalytic surfaces) and possibly in the area of new conductive materials.

flexible radar antenna's made from LCP's

small phased array radar system

nanoSar synthetic aperture radar (Imsar USA)

Nanomaterials for small radar systems

Nanotechnology can contribute to development of more accurate, faster, lighter and more stealthy radar systems for defense vehicles by:

- denser memory, faster processors, rf-switches and electronic devices needing less power
- conductive materials capable of emitting RF-waves at high frequencies, embedded in the structure of vehicles to enhance recognition capacities
- reduction of radar and visual signature (stealth)

Nano synthetic aperture

A good example is the NanoSar system (Imsar USA). NanoSAR is a revolutionary SAR (synthetic aperture radar) that brings radar sensing capabilities to small platforms, suitable for tanks, UAV's and small ships. The NanoSAR weighs only two pounds which includes the navigation system, antennas, cabling, real-time processor and RF front end. It therefore meets the size, weight, power, and cost requirements of small vehicles and UAVs.

SiGe technology

A new development is silicon-based microchips capable of operating in ultra-sophisticated phased array radar systems based on integration with silicon-germanium (SiGe) technology. It provides cost savings, compact size and improved efficiency in the same way that advances in silicon technology have made consumer electronics smaller and less expensive. In addition, silicon-germanium is a less expensive material than the compound semiconductors - such as gallium arsenide or indium phosphide - that have long been used in radar systems. In SiGe conventional silicon integrated circuit technology is the basis and nanotechnology techniques are used to introduce germanium inside the silicon on an atomic scale.

GaN technology

Transistors made with gallium nitride can operate at 10 times the voltage of silicon or gallium arsenide transistors because of the breakdown voltage of the wide bandgap semiconductor. This feature allows systems to operate at five to 10 times the power of conventional circuits, or it can be exploited to realize broader bandwidth circuits or higher efficiency circuits, depending on how designers chose to optimize transistor and circuit. The high-power amplifier circuits can be inserted into radar and electronic warfare systems. Its a "third-generation" RF technology, like SiGe, with the first generation being silicon and the second being gallium arsenide and indium phosphide. It will have a huge impact on defense systems and potentially commercial systems as well. Wide bandgap electronics for radars have the potential to significantly increase system performance, reduce size and weight, and reduce logistics requirements.

Liquid crystal polymers for antena's

A new antenna technology is the use of liquid crystal polymers (LCP) in the shape of an ultra-thin, paper-like plastic which can incorporate a variety of electronic circuits. Yet it molds to any shape and appears to perform well in the extreme temperatures and under intense radiation. LCP outperforms conventional materials for antennas and circuit boards in high-frequency radio applications aboard vehicles. Flexible LCP antennas would be lighter than today's structured antennas, and LCP-based circuits molded to available vehicle areas could eliminate heavy metal boxes that currently house rigid circuit boards.

Plasma stealth technology

Radar and radio antennas are inherently radar-reflecting. At least two design solutions to this dilemma have become widely available. One is to have moveable radar-absorbent covers over radar antennas that move aside only when the radar must be used. A better solution, currently being developed, is the plasma stealth antenna. A plasma stealth antenna is composed of parallel tubes made of glass, plastic, or ceramic that is filled with gas, much like fluorescent light bulbs. When each tube is energized, the gas in it then becomes ionized, and it then can conduct current just like a standard metal wire. A number of these energized tubes in a flat, parallel array, wired for individual control (a "phased array"), are able to be used to send and receive radar signals from a wide range of angles without being physically rotated. When the tubes are not energized, they are invisible to radar, which can be absorbed by an appropriate backing.

Urban operations

Urban operations are very different from operations in the open due to the presence of civilians, buildings, limited fields of view and fire, enhanced concealment and cover for defenders, below ground infrastructure, and the ease of placement of booby traps and snipers. Tactics are complicated by a three-dimensional environment. Especially for future urban operations nanotechnology is expected to be a very valuable innovation driver. It will help to improve and develop many new concepts.

Smart weapons

For urban combat, precision is needed in terms of centimeters of dispersion at 100's of meters with weapons that are highly mobile, lightweight and small. Nanotechnology will facilitate the development of the following concepts.

- lightweight precision weapons using smart nanostructures for stabilization and compensation of shooting dispersion, breathing and human heartbeat. And to actively slew the rifle and automate the firing in order to guarantee shot placement.
- hands free weapons e.g. a weapon which consists of electronically fired caseless ammunition fired from the forearm would be a novel urban capability.
- weapons operating in a network so that a squad of soldiers can engage multiple targets in a synergistic fashion.
- non lethal weapons that incapacitate the adversary e.g. in the case of uncertain target identification. Small lightweight weapons that can deliver EM-energy or optical energy in a point or netlike fashion to subdue one or many potential threats.

Active sensing

Lightweight, wearable sensor systems that allow the soldier to discriminate and identificate adversaries from noncombatants in urban clutter and that can be used for precision aimpoints and covert target designation for friendly forces. Such as a squad scanning the area with head-mounted infrared sensors and rifle-mounted laser radars. In this way soldiers in 2025 might detect concealed threats.

Sniper detection

Tiny, lightweight acoustic array sensors can be mounted into the soldier's helmet. These sensors can analyse the sound direction of shots and hereby detect the location of snipers.

Smart suit

Nanotechnology can offer the soldier a lightweight, higly protective suit with improved stealth and anti-ballistic characteristics. This will become possible thanks to advances in high strength fiber fabrics (carbon nanotubes, Superthread), shear thickening binders to allow flexible armour, and adjustable colouring via tunable quantum dot pigments in textile for adaptive camouflage.

Packbots

Packbots are in use to help clear caves and bunkers, search buildings and cross live anti-personnel minefields. Nanotechnology will help to further miniaturize and to empower the packbots with new sensor functions.

Armband sensor for explosives

The soldiers within the building proceed to their objective over the enemy command and control room. Simultaneously, the soldiers on the ground attempt to enter. However, an armband sensor detects elevated levels of explosive particles, indicating a possible booby trap. The soldiers retreat and fire a door-breeching munition that rams open the door and activates the booby trap.

Exoskeletons

Dominant pieces of terrain in an urban environment frequently are the"high ground". One way to defend against threats above the ground is to use exoskeletal technology. Exoskeletal technology seeks to enhance the physical ability of the soldier to carry more, further and a higher combat pace.

Smart rope: science fiction or .....

A special rope is shot over the building.The end of the rope has a material that adheres to the wall of the building much like a Gecko. The rope contracts when the soldier applies an electrical current and he is lifted to the top of the building. After scanning the area, he climbs over the top, assisted by Gecko kneepads, and signal for his wingman. They deploy into the building and become visible on the network, marked as friendlies with a blue dot overlay.

packbot

mule

packbot scout

PackBot

Packbots have been developed (IRobot) to help clear caves and bunkers, search buildings, cross live anti-personnel minefields and to dispose explosives. It has a unique propulsion system developing a road speed of up to 14 km/h. The system is characterized by distinctive "flippers" which offer continuous 360 degrees rotation and negotiation of rough terrain and obstacles such as stairs, rocks, logs, rubble and debris. The platform can climb grades up to 60% and survive submersion in water up to two meter deep. It is built to survive drop from two meter height, on a concrete surface, or being thrown through a window or tumbling downstairs. The 18 kg robot can be carried in a backpack, and deployed in a few minutes. The Packbot chassis is integrated with a GPS receiver, electronic compass, orientation and temperature sensors. The robot is controlled by an integral Pentium based computer. It uses a modular payload system offering standard (USB, Ethernet) communications and networking. The control station uses laptop PC or eyepiece displays and hand-held controller. Wide angle (fisheye) or close-up images are displayed for orientation with all operating parameters.

The Pacbot 500 robots will be equipped with the Fido explosive-detection technology developed by ICx Technologies. These sensors detect explosives' vapors emanating from improvised explosive devices (IEDs).

Dragon Runner

These robots represent a modular ground robot system capable of performing a wide range of missions in urban, mountainous or rural environments, from underground and in-house to the handling of improvised explosive device (IEDs). The Dragon Runner as developed by Qinetiq is a modular base unit, weighs less than 20 pounds and can be carried by one person in a standard-issue pack. The wheeled base unit is field-transformable, with quick snap on or bolt on tools, morphing the robot for different missions, including reconnaissance inside buildings, sewers, drainpipes, caves and courtyards; perimeter security using on-board motion and sound detectors; checkpoint security; in-vehicle and under-vehicle inspections; and hostage barricade reconnaissance and negotiation. In addition, day and night pan/tilt/zoom cameras, motion detectors and a listening capability allow Dragon Runner to further extend the combat team's situational awareness.

MULE

The Multifunction Utility/Logistics and Equipment (MULE) autonomous vehicle is developed by Lockheed Martin for the US Army Future Combat Systems program. The vehicle is designed to carry the load of two infantry squads, totaling about 2,000 pounds (907 kg), and support troops with water and power sources for extended operations. The Mule will be a "follower" to the human team. Each of the team members will be able to order the Mule to come forward, to support the operation. Otherwise, the vehicle will maintain a safe distance behind the team, waiting for orders. Like its human combatants, the Mule will have day and night thermal sights, while additional sensors, such as forward-looking imaging systems and chemical biological sensors will be installed in a forward payload to support team operations. The mule can communicate with and sometime, deploy unmanned aerial and ground vehicles (UAV/UGV) to give the squad members a true 360-degree image of the battlefield.

Role of nanotechnology

Nanotechnology will help to further improve, miniaturize and to empower the packbots with:

- lightweight structures
- small and lightweight battery packs
- better sensor functions, e.g. quamtum dot fluorescence techniques

Packbot (IRobot)

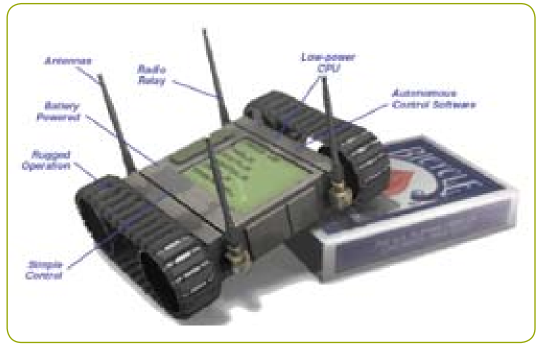

mobile sensor and communication network


situational awareness sensors


situational awareness sensors


scout ball


handheld sensor



Landroid mobile network node

Situational awareness sensors

A situational awareness sensor (SAS) network may consists of scatterable networked sensor units that are designed to detect, report, record, and interpret movements and activities of people and vehicles within the area of sensor deployment. It can scout and monitor urban and complex terrain without human intervention.

Such a system can provide persistent surveillance over areas of interest, it can distinguish threats from friends, monitor the cleared area after operation, can function as a remote sentry, monitor crowds or militia movements and can characterize population. In maneuvers, both under pressure and unconstrained, the network can serve as route-side monitors wirelessly linked to vehicles, tracking both friendly and threat vehicles.

The SAS system as developed by BAE systems, consists of the graphical user interface and the multi-sensor nodes:

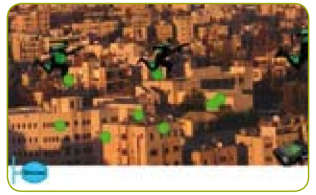
- GUI will allow easy communication among team members, as well as provide responses to basic questions such as “Where am I?” “Where are my buddies?” and “Where is the enemy?”
- multi-Node Sensors: the sensor nodes process detections and identifications locally. They use node-to-node collaboration to assess and identify threats.
  - variety of sensing modes: acoustic, seismic, passive infrared, microradar, chemical warfare agents
  - target signature detection: human motion (footsteps, speech) vehicular sound (vibration, motion0, geospatial tracking
  - low power consumption: battery and/or solar-cell power
  - GPS for self-locating functionality
  - low cost/disposable

Mobile Scout Ball

A nice example of a multi-sensoring unattended mobile sensor is the scout ball developed by MobileFusion. It is a baseball size sphere made of LEXAN, weighing less than one kilogram. Scout ball is equipped with visual and IR cameras, microphones, position sensors, signal processing and data recording. This ball can see, hear and store information as it monitors its surroundings. The scout ball is designed for military, law enforcement and firefighting applications. The scout ball system includes two spheres and a monitor based on a toughbook 30 laptop and a battery charger. The scout ball can also be used as an unattended mobile sensor, attached to an aerial or ground robot.

Explosives Detection

At less than three pounds, the Fido Portable Explosives Detector is the world’s most sensitive explosives detection system. Fido explosives detectors utilize proprietary amplifying fluorescence polymers (AFP) to detect trace levels of explosive materials in parts per quadrillion (ppq). This level of detection is comparable to that of highly trained explosives detection canines, the gold standard in explosives detection technology. Unlike the alternative, the exquisite sensitivity of the Fido supports detection of both explosive vapor and particulates without the need to modify the system in any way. This unique design enables previously unheard of functionality for explosives detection equipment.



9.0 conclusions

Civil driven:
- wireless μ -sensors and RFID
- nanomedicine, lab-on-chip
- lightweight structures & nanocomposites
- personal health condition monitoring
- flexible displays

Civil and Defence driven:
- quantum cryptography
- small and micro (portable) power
- water treatment

Defence driven:
- anti-ballistic materials
- high energetic materials
- bio-chemical sensing and protection
- array sensors (directed, high performance)
- actuators (body support, ventilation)
- camouflage (via CNTs, aerogels, nanodots)

Conclusions
The presented nanotechnology survey gives a momentary overview of civil and defence oriented technology developments. Nano- and microsystemtechnologies are subject of many R&D programs for civil application (materials, life sciences, electronics, sensors) as well as for military uses (weapons, structural material, sensor, protective materials, electronics). Some subjects are covered by both civil oriented and defence oriented programs. The progress in nanotechnology is present in many domains, but it is very much present and dominant in the following categories:
- biology and medicine
- energy and power generation
- information and communication technology
- materials

The exploitation of nanotechnology is already part of society, with high investments worldwide. Many nano products already exist on the commercial market such as:
- additives in cosmetics, paints, polymers
- catalysts and filters
- tyre pressure sensor, wireless sensor networks
- lab-on-chip systems
- accelerometers, condition sensors
- nanocomposites (nanoclay and carbon nanotube composites)

Some products are expected to come soon (within 5 years), especially wireless tags and nanosensor systems others are expected to come later at a timeframe of 5-15 years (high strength nanomaterials, smart/adaptive materials). More and more nanotechnology is being converged with other technologies, especially biotechnology, information technology and cognitive science.

The defence organization can gain a lot of benefit from these new technologies and should actively participate in these developments. The following dominating or main technologies impacting the military operations can be identified:

Opportunities for soldier system
Nanotechnology can offer the soldier better equipment that enables a higher security and safety level, better operational capacities and effectiveness. Next to commercial developments such as nanosensors (lab-on-chip, electronic noses etc), tags (RFID, sensortags), wireless communication systems and nanomaterials (nanocomposites, nanomedicine), the following technologies and products are considered to be essential for the future soldier:
- nanocomposites for flexible, wearable antiballistics
- nanofibers for smart textiles (sensoric, BC decontaminating, high strength)
- smart suit (sensor integration, BC protection, switchable fabrics)
- smart helmet (integrated)

We expect that these products can become available within a time frame of 5-10 years, provided that sufficient R&D investments are allocated by the ministry of defence and industrial parties with complementary knowledge. Elements of these developments could be fitted in the soldier modernisation program and could be also subject of international cooperation.

Some NATO countries are executing and/or developing R&D programs which contain elements of the key technologies described above (USA, UK, Germany, France, Sweden, Canada). International collaboration with one or more of these countries might be interesting if they if they can supply or bring essential technology or know-how.

Although the ministry of defence and TNO are aware that nanotechnology could introduce ethical concerns and/or environmental, health and safety risks, these concerns and risks are not covered in this study because they are subject of study by other ministries and organizations.

This book is also accessible as a website including video streams:
see **www.isoconnectors.com/defensie**

The authors of this book are not employed by TNO anymore.
Steven Schilthuizen is now active for SCINT BV and Frank Simonis for ICInnovation BV.