Defence Applications

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ABSTRACT (DEFENCE APPLICATIONS)

The potential opportunities promised by nanotechnology for enabling advances in defence technologies are staggering. Although these opportunities are likely to be realised over a few decades, many advantages are currently being secured, particularly for defence applications. This lecture will provide an insight into the capabilities offered by nanotechnology which will enable new defence capabilities, including; smart materials, harder/lighter platforms, new fuel sources and storage as well as novel medical applications.

More specifically, the lecture will address the following topics:

The vision and the challenges (overview)

Novel material characteristics, properties and functionalities for enhanced capabilities (mass storage, nano-magnetics, quantum computing etc)

Novel platforms (smart dust, self-assembly etc)

Medical and biomedical advances (biomimetics etc)

1.0 INTRODUCTION

Nanotechnologies promise revolutionary technological changes for a wide range of military applications and platforms. Technologies to be incorporated within the platforms which are directly relevant to the defence arena, including; aerodynamics, mobility, stealth, sensing, power generation and management, smart structures and materials, resilience and robustness etc. In addition, nanotechnologies will impact battlespace systems concerned with information and signal processing, autonomy and intelligence. With regards to information technology, in particular, substantial advantages are expected to be gained from this new enabling capability which include threat detection, novel electronic displays and interface systems, as well as a pivotal

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role for the development of miniaturized unmanned combat vehicles and robotics.

Finally, nanotechnology will enable the development of novel materials providing the basis for the design and development of new properties and structures which will result in increased performance (for example through nano-energetics and new types of catalysts), reduced cost of maintenance (for example through wear reduction, self-healing and self-repair), enhanced functionality (for example through adaptive materials), and new types of electronic / opto-electronic /magnetic material properties.

1 The evolving capability and the vision

Novel and emerging sciences such as micro and nanotechnologies offer the potential to significantly affect material properties by introducing new and enhanced characteristics to existing and future platforms. This capability of achieving macro-effects from nano-changes will have a critical impact on all future military personnel, hardware and the nature of warfare on the whole. More specifically these technologies will enable the development of materials for enhanced sensor performance and novel sensing capabilities, including bio/chemical sensors, biometrics, multi-analyte sensing systems and analytical microsystems. The list is, indeed, limitless but the following provides a few of the applications likely to benefit in the medium to short term;

- (Micro) μ radar for personnel use and for unmanned miniaturized vehicles
- Thermal IR sensors with enhanced sensitivity
- Portable and /or wearable inertial and position, motion and acceleration sensors
- Miniaturised and highly sensitive vision camera system
- Biochemical sensors (remote operation or hand-held)
- Health monitoring sensors (embedded, continuous or intelligent)
- Condition monitoring of equipment and munitions
- Drug and nutraceutical (nutrition) delivery sensors and systems
- Wireless secured RF-links between sensor and equipment

In the longer term, the technology promises developments with capabilities in terms of the following applications:

- Enhanced surfaces treated with anti-corrosion, hard wear, and frictionless coatings
- Soldier worn protective clothing
- Stealth coatings
- De-icing composites and materials
- Self-healing (self-repair) material
- Smart skin materials
- Adaptive camouflage
- Adaptive structures

- Impact resistant rheo fluidic system
- Reactive nano-armour composites
- Bio-active textiles
- Electronic textiles
- Adaptive textiles (incl. actuators)
- Structural materials
- High-performance coatings
- Catalysts
- Electronics
- Photonics
- Magnetic materials
- Biomedical materials

2 Practical examples and developments

In general, nanotechnology enables the above listed functionalities due to the properties offered which include as major features:

- Light weight
- RF tailored properties including, stealth and camouflage
- Highly adaptive structures
- Hardness and all-impacts resistance

Of late, a variety of companies have been announcing the development of a whole range of nano-based materials which include, as an example, the Nylon-6 / montmorillonite nanocomposite with reported properties:

- tensile strength up 40%
- tensile modulus (elasticity) up 68%
- flexural strength up 60%
- flexural modulus (bending) up 126%
- distortion temperature up from 65oC to 152oC
- Improved flame retardant properties

With regards to coatings and camouflage, BASF polymer researchers are looking into nanoparticles with highly branched polyisocyanates - The colour is produced exclusively by the textured surface of the wings and is within the wavelength range of visible light – the nanometre range. The aim is to produce a material which could be switched to reflect specific colours only. These coatings will it is claimed offer:

Superior abrasion resistance

- Anti-reflection
- Tailored refractive indices
- Protection from chemical agents (anti-corrosion)
- Self-cleaning surfaces (Pilkington's "Activ")

All properties of immense interest to the defence arena.

As for weight and hardness, Toyota started using nanocomposites in their bumpers making them 60% lighter and twice as resistant to denting and scratching. This translates to approximately a 20% weight saving over conventional coatings (better fuel efficiency). Likewise, the Chevrolet Impala makes use of polypropylene side body mouldings reinforced with montmorillonite. These novel nanomaterials save on weight but enhance the hardness. Also, a plastic nanocomposite is being used for "step assists" in the GM Safari and Astro Vans. This nanocomposite is scratch-resistant, light-weight, and rust-proof, and generates improvements in strength and reductions in weight, which lead to fuel savings and increased longevity. Clearly, these materials offer many advantages to the military platforms ranging from conventional vehicles to more advanced miniaturized platforms (e.g unmanned autonomous micro-vehicles).

Resilient coatings are also beginning to emerge on the market, including BASF's "Lotus Spray" which has transforms the surface wood to an extremely water-repellent (superhydrophobic) surface. The treatment of surfaces to make them into Super-hydrophobic structures have implications on sensors and electronic materials and (sub)systems packaging which need to be operational and functional in highly humid environments.

Exploiting this property (barrier to moisture and oxygen) has led the ew Jersey-based InMat LLC to be selected by the U.S. Army Soldier Systems Centre in Natick, Mass. to develop improved chemical protective gloves. InMat LLC are also supplying the Wilson Double Core tennis balls which have a nanocomposite coating that keeps it bouncing twice as long as an old-style ball. This nanocomposite is a mix of butyl rubber, intermingled with nanoclay particles, giving the ball substantially longer shelf life. The long lifetimes of operation and storage in the military / defence world will greatly bebnfit from such a capability.

Improved energy utilization is also the premise of nanotechnology where, Oxonica, are commercializing cerium oxide to modify the combustion profile in order to deliver more useful work from each combustion cycle for a given quantity of fuel. Savings in fuel use, storage and combustion efficiency is a vital asset in military scenarios.

Equipment used for displays will also benefit from the nanotechnology developments. Kodak, for example, is producing organic light emitting diodes (OLED) color screens (made of nanostructured polymer films) for use in car stereos and cell phones. OLEDs will enable thinner, lighter, more flexible, less power consuming displays, and other consumer products such as cameras, PDAs, laptops, televisions, and other as yet undreamt of applications. The future soldier will greatly benefit from light-weight equipment.

In the medical field, nanotechnology offers a potentially impressive array of capabilities, including:

- Cochlear implants to restore, improve or enhance hearing
- Optoelectronic retinal implants for the blind
- Artificial skin
- Tissue reconstruction
- Tissues and organs artificially grown on nanopatterned scaffolds
- Body friendly longer lasting implants

To this end, the BIOKER project - a consortium of research institutes and industrial partners from three European Union countries - is investigating the use of zirconia-toughened alumina nanocomposites to form ceramic-ceramic implants with potential life-spans of more than 30 years. AngstroMedica has produced a nanoparticulate-based synthetic bone (Human bone is made of a calcium and phosphate composite called Hydroxyapatite). By manipulating calcium and phosphate at the molecular level, they have created a patented material that is identical in structure and composition to natural bone. This novel synthetic bone can be used in areas where natural bone is damaged or removed, such as in the in the treatment of fractures and soft tissue injuries. In addition, The combination of nanotechnology and genomics (which offers the possibility of manipulation of the DNA of humans and other species) will lead to the development of new vaccines, and treatments for genetically based illnesses. Smith & Nephew markets an antimicrobial dressing covered with nanocrystalline silver (A patented Technology of NUCRYST Pharmaceuticals). The nanocrystalline coating of silver rapidly kills a broad spectrum of bacteria in as little as 30 minutes.

In the future, when nano-assembly and nano-manipulation become common practices, single molecules consisting of carbon atoms in the form of a geodesic ball (a "buckyball") will be used to helium helium atoms through a nanotube ("buckytube"). This process could provide the basis of delivering a specific type of atom or a single molecule to a site at which it might be required. Smart drug delivery and self-healing follows on from such a capability.

Nanocubes made of organometallic network materials, currently being analyzed for their properties by BASF researchers, could prove a suitable storage medium for hydrogen. Their three-dimensional lattice structure has numerous pores and channels, making nanocubes an ideal storage medium. This capability offers enormous potential for the development of sustainable autonomous systems for surveillance and monitoring.

Finally, Carbon nanotubes which have a diameter as small as 0.7 nm will enable the production of atomically precise molecular machines much smaller than current microsystems-based devices by two to three orders of magnitude in each dimension, or six to nine orders of magnitude smaller in volume (and mass). Smaller more precise and lighter weight is also conducive to better performance more tolerance and less power consumption.

In essence, the current advancements in the field of nanotechnology will impact all aspects of defence applications and the vision is gradually being realised through real commercial success.

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