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Nanotechnology

The Emerging Field for Future Military Applications

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INSTITUTE FOR DEFENCE
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Sanjiv Tomar

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Abbreviations

AHSS	Advanced High Strength Steel
CAS	Chinese Academy of Science
CDRI	Central Drug Research Institute
CNT	Carbon NanoTube
CoE	Centre of Excellence
CSIR	Council of Scientific and Industrial Research
DAE	Department of Atomic Energy
DARPA	Defence Advance Research Project Agency
DBT	Department of Biotechnology
DIT	Department of Information Technology
DoE	Department of Energy
DRDO	Defence Research and Development Organization
DST	Department of Science and Technology
EM	Electromagnetic
FTP	Federal Targeted Program
GITA	Global Initiative and Technological Alliance
ICAR	Indian Council of Agricultural Research
ICT	Information and Communications Technology
MR	Magnet-Rheological
IITR	Indian Institute of Toxicology Research
IOS	International Organization for Standards

IR	Infrared
ISN	Institute for Soldier Nanotechnologies
ITCT	Indian Institute of Chemical Technology
LED	Light Emitting Diode
MAV	Miniature Aerial Vehicle
METI	Ministry of Economic Trade and Industries
MIT	Massachusetts Institute of Technology
MEXT	Ministry of Education, Culture, Sports Science and Technology
MEMS	Microelectromechanical System
MNRE	Ministry of New and Renewable Energy
MNT	Molecular Nanotechnology
MoEF	Ministry of Environment and Forest
MoHFW	Ministry of Health and Family Welfare
MWNT	Multi Walled Nanotube
NASA	National Aeronautics and Space Administration
NATAG	Nano Applications and Technical Advisory Group
NBC	Nuclear, Biological and Chemical
NCNST	National Commission on Nanoscience and Technology
NDRC	National Research Development Corporation
NIPER	National Institute of Pharmaceutical Education and Research
NMCC	National Manufacturing Competitive Council

NNI	National Nanotechnology Initiative
NSAG	Nano Science Advisor Group
NSTC	National Science and Technology Council
NSTI	Nanoscience and Technology Initiative
NT	Nanotechnology
OLED	Organic Light Emitting Diode
OECD	Organization for Economic Cooperation and Development
QD	Quantum Dot
RFID	Radio Frequency Identification
SPASER	Surface Plasma Amplification by Simulated Emission of Radiations
STBP	Science and Technology Basic Plan
STF	Shear Thickening Fluid
STM	Scanning Tunnelling Microscope
SWNT	Single Walled Nanotube
UAV	Unmanned Aerial Vehicle
UCAV	Unmanned Combat Air Vehicle
WASN	Wide Area Sensor Network
WHO	World Health Organization
WNSN	Wireless Nanosensor Network
2D	Two Dimensional
3D	Three Dimensional

Introduction

"History is replete with examples of militaries that failed due to their inability to transform organizations and culture, adopt new operational concepts, or leverage breakthrough technologies…victory comes to those who foresee, recognize and act on changes in the strategic environment."

General T. Michael Moseley, CSAF 2007

Nanotechnology (NT) is a collective term given to a family of science and technology disciplines which deals with the materials and structures at nanoscale dimensions. Often termed as a 'technological revolution', nanotechnologies (NT) are set to bring immense benefits to society at large. In this domain, NT manipulates matter at the atomic, molecular or macromolecular level to create and control objects with the aim of fabricating materials, devices, and systems having novel properties and functionalities because of their small size.[1] However, the actual opportunity goes beyond the materials and consists of tiny yet powerful nanosystems that can be made from nanomaterials and nanoscale structures.[2] The small nanosystems so developed can be used as arrays which can be embedded in small assemblies and devices to construct bigger systems having advanced features and capabilities which are far more superior to existing ones. Considering the wide range of applications, NT has become a key area of research and development all over the world in the last two decades.[3]

Governments all over the world, having realized its potential as dual-use enabling technology, started investing heavily in its R&D starting

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1 Luisa Filippone and Duncan Sutherland, 'Nanotechnology: A Brief Introduction', at www.nanocap.eu/Flex/Site/Download07ab.pdf?10=2256 (accessed on January 17, 2014).

2 Neil Gordon, 'Interview with Neil Gordon on Military Nanotech', at www.nanotech-now.com/products/nanonewsnow/issues/o37/037.htm (accessed on April 14, 2015)

3 For comprehensive account of NT research and development and investment by various countries, see Sanjiv Tomar, 'Current Global Trends and Future Military Applications for Soldier as a System', *Journal of Defence Studies*, Vol. 8, No. 4, October-December 2014, pp. 55-82.

sometime in the beginning of the last decade. Although it is not yet a mature technology, the impact of NT enabled applications is already showing its impact in all walks of life. As per one estimation, over 1600 NT enabled applications encompassing the areas of food production, industrial manufacturing, social and human engineering, healthcare, electronics, power generation and modern warfare, have been put to use.[4] While NT is fast evolving, leading to new innovations and product development across various disciplines of science and technology, its profound effect on defence related applications has long been realized by countries all over the world.[5] The efforts in R&D in defence by leading countries are focused on increasing the capability of command and control, sustainability, survivability, lethality and mobility.[6] In addition to this, NT can directly influence the military applications concerning: stealth, signal processing, power generation, and smart and robust structures.[7] Development of novel materials will also increase the life and performance of vehicles, equipment, small arms and guns while at the same time providing enhanced safety to troops. Reduced cost of maintenance, increased functionalities and onsite 3D printing through nanomaterials will also help in decreasing the length and breadth of military supply chains.

The efforts made by Government of India in establishing 18 centres of excellence (CsOE) in various parts of the country together with the efforts being made by DRDO led R&D has created an ecosystem for fruitful applications. Notable progress has been made in the fields of nanostructures, MEMS and NEMS, advance sensors, energy

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4 Anne Clunan and Kirsten Rodine-Hardy, 'Nanotechnology in Globalized World: Strategic assessments of an emerging technology', PASCC Report No. 2014-006, at www.nps.edu/Academics/Centers/CCC/PASCC/Publications/2014/2014%20006%20Nanotechnology%20Strategic%20Assessments.pdf (accessed March 23, 2015).

5 Sanjiv Tomar, n. 3, pp. 65.

6 Neil Gordon, n. 2, pp. 3.

7 RV Kurahatti., AO Surendranathan, SA Kori, Nirbhay Singh, AV Ramesh Kumar and Saurabh Srivastava, 'Defence Applications of Polymer Nanocomposites', *Defence Science Journal*, Vol. 60, No. 5, pp. 551–63.

applications, stealth and camouflage, NBC devices, and characterization. A number of patents have been registered by Indian scientists to consolidate their R&D efforts. It is desired that private industries working in this field also collaborate with government agencies and integrate their efforts to develop applications best suited for Indian defence scenario. Not only soldier centric applications, Indian defence space is largely going to be benefitted in almost all its dimensions. Ubiquitous sensor network deploying autonomous and unattended sensors along the border will help in real time surveillance. Light weight nanocomposites with improved armour protection will provide better fuel economy, long endurance, more weapon carrying capability and lethality. Unmanned aerial vehicles (UAVs) and unmanned combat aerial vehicles (UCAVs) can be further miniaturized and employed at platoon or section level to have 'hover and stare' capability for close combat operations, operations in built-up areas and in difficult terrain.

Countries across the globe are bracing to tackle various forms of warfare, e.g., asymmetric warfare, cyber warfare, etc., beside extreme terrorism, however, the focus for preparedness remains in the domain of conventional warfare while these new forms are becoming an adjunct to it.[8] Considering the developments in the field of science and technology related to military oriented applications, the future of warfare will be characterized by short duration and high intensity, information centric warfare, with greater emphasis on light or medium size tactical force capable of rapidly escalating capabilities in its region of influence.[9] This is where the NT is likely to play a crucial role in providing wide ranging solutions and leveraging war fighting capabilities.

This monograph is divided into five chapters. Chapter I begins by tracing the history of nanotechnology and the properties of nanomaterials which provide the basis of developing innovative applications. Chapter II provides a detailed account of funding trends

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8 *Indian Army Doctrine*, Shimla: ARTRAC, 2004, p. 8.

9 Neil Gordon, n. 2, p. 3.

and nanotechnology initiatives taken up by some of the major countries across the globe. This chapter also provides a brief insight into the specific areas of R&D where the countries are currently focusing.

Chapter III is devoted to nanotechnology enabled military applications. This chapter provides a detailed discussion on military applications in the field of land vehicles, armoured vehicles, sensors, stealth and camouflage, electronics and communication, power generation, bio-technology, unmanned surveillance, military logistics and 3D printing. Chapter IV deals with a new concept of integrating nanoenabled applications into a single platform termed as 'Soldier as a System.' This new concept explains as to how a soldier can get benefitted in terms of enhanced protection, survivability and sustainment through NT enabled applications.

Chapter V also gives a brief outline of impact of NT on future warfare and how molecular manufacturing will play an important role in reducing the casualty rate and enhance the offensive and defensive capabilities of a nation having advanced molecular manufacturing facilities, followed by the conclusion in Chapter VI.

Chapter - 1

Advent Of Nanotechnology

1.1 A Brief Historical Account

Nanoscience and nanotechnology are fast growing areas of science and technology that span the entire spectrum of science and technology.[10] It is the study of phenomenon at the nanometer scale.[11] As on date, there is no strict definition of nanotechnology, possibly due to the large spectrum of scientific disciplines it covers. Besides, nanotechnologies at the current stage of development are being constantly updated and improved, which explains why many concepts about principles of their implementation are not completely clear.[12]According to the US National Nanotechnology Initiative, 'Nanotechnology is the understanding and control of matter at the nanoscale, at dimensions between approximately 1 and 100 nm, where unique phenomena enable novel applications. Encompassing nanoscale science, engineering, and technology, nanotechnology involves imaging, measuring, modelling, and manipulating matter at this length scale.'[13]In general terms, nanotechnology manipulates matter at the atomic, molecular or macromolecular level to create and control objects at the nanometer scale, with the goal of fabricating novel materials, devices and systems that have new properties and functions, because of their small size.[14]

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10 'Compendium on Indian Capability on Nano Science and Technology', Macmillan, New Delhi, 2012, p.1.

11 One nanometer (nm) is one billionth (10^{-9}) of a meter.

12 NK Tolochko, 'Nanoscience and Nanotechnologies—History of Nanotechnology', at www.eolss.net/sample-chapters/c05/e6-152-01.pdf (accessed January 23, 2014).

13 'The National Nanotechnology Initiative: Overview, reauthorization, and Appropriation Issues', Congressional Research Service Report at https://www.fas.org/sgp/crs/misc/RL34401.pdf (accessed January 30, 2014).

14 Luisa Filippone and Duncan Sutherland, n.1.

At the nanoscale, the properties of matter undergo a sea change due to diminished gravitational forces and dominant electromagnetic forces. At the nanoscale, the laws of quantum mechanics apply.[15] Increased surface to volume ratio as compared to bulk material, results in unique properties. At this level, properties like colour, strength, surface to volume ratio, chemical reactivity, etc., start changing, leading to new scientific opportunities in developing novel products and applications.

Historically speaking, the famous lecture by Richard Feynman delivered in 1959 at the session of American Physical Society, '*There is plenty of room at the bottom*,' laid down the foundation of possible creation of nanosize products by the use of atoms as their building blocks. The term Nanotechnology was coined by Norio Taniguchi in Tokyo in 1974 during the international conference on industrial production in which he described the super thin processing of materials with the accuracy of nanometer range. In 1986, K Eric Drexler propounded the feasibility of creating nano machines in his famous book, *Engines of Creation: The Coming Era of Nanotechnology*,[16] which was published in 1986.

In addition to the criticism of Drexler's vision of molecular manufacturing, three important developments that were independent of Drexler's paper helped turn nanotechnology into this broad field that it is today. First, the Scanning Tunnelling Microscope (STM) was invented by Binnig and Rohrer, in 1981. With this technology, individual atoms could be clearly identified for the first time. Despite its limitations (it works only with conducting materials), this breakthrough was essential for the development of the field of nanotechnology because what had been previously concepts were now within view and testable. Some of these limitations in microscopy were eliminated through the 1986 invention of the Atomic Force Microscope. Using contact to create an image, this microscope could image non-conducting materials such as organic molecules. This invention was integral for the study of carbon

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15 Quantum mechanics is the branch of physics that explains the nature and behaviour of matter and energy on the atomic and sub-atomic level.

16 NK Tolochko, n. 12, p. 2.

buckyballs, discovered at Rice in 1985–86.[17] Ultimately, with these two achievements, nanotechnology could develop through the scientific method rather than through the conceptual and thus un-testable visions of Drexler.

Nanotechnology is not a recent phenomenon as perceived commonly. Even long before the beginning of nanotechnology era, people in ancient times were using nano sized materials. Historical evidences suggest that nano materials were in use in various forms without any scientific theory attached to it. People were engaged in nanotechnology subconsciously, without realizing that they were dealing with phenomenon related to the world of nanotechnology. The nano production techniques were passed from one generation to the other for specific applications.

Since ancient times, people had developed the technique of cultivating and processing natural fabrics, e.g., cotton, silk and wool. The size of the pores of these fabrics was of the order of 1–20 nm. These fabrics demonstrated the properties of absorbing sweat and quickly swell and dry.[18] Making of beer, bread, cheese and other foodstuff also involved special fermentation process at the nanolevels, which the ancient man had mastered. People in ancient Egypt used black hair dye made up of lime, lead oxide and small portion of water. In the course of the dyeing process, nanoparticles of galenite (lead sulfide) were formed which gave even and steady dyeing. The British Museum showcases Lycurgus Cup, a glass bowl made by glass makers of ancient Rome having the unusual property of scattering different colours with change of location of light source. It was discovered by the scientists that the glass used in the bowl contains particles of gold and silver in the range of 50-100 nm size. Multi-coloured Church stained glass windows in Europe are other examples of use of gold and other nanoparticles of metals as additives leading to unusual properties.

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17 The early history of nanotechnology is available at http://cnx.org/contents/025b69ff-13ae-421b-8ae1-25734ef7de73@1/The_Early_History_of_Nanotechnology (accessed March 16, 2014).

18 NK Tolochko, n. 12, p. 1.

Over the centuries, and more recently, nanotechnology has come a long way. Nanotech is not merely about size, it is about the unique physical, chemical, biological and optical properties that emerge naturally at the nanoscale and the ability to manipulate and engineer such effects. It is a broad new area of science, involving physics, chemistry, biology, cognitive science, materials science, and engineering at the nanoscale. 'Notable recent developments include organically growing nanoenabled solar cells in the form of wallpaper or as paint; silicon nanoparticles covered with a layer of gold and used in combination with infrared light to destroy cancerous tumours; silicon coated nanowires that form a highly efficient paper-like 'sponge' to separate oil from water after, for instance, an oil spill; and nanoproducts that help to purify, desalinate and disinfect water, or store energy more efficiently.'[19]

1.2 What Makes Nanoparticle Properties so Alluring?

The properties exhibited by materials in bulk often start changing dramatically when reduced to nano scales. Nano composites made up of particle size smaller than 100 nm show exceptional strength. Metals with so called grain size of around 10 nm are as much as seven times harder and tougher than their ordinary counter parts with grain sizes in the hundreds of nanometers.[20] The exceptional properties of nano materials are a direct consequence of the quantum effect.[21] Due to this effect, the characteristics defining optical, magnetic and electrical properties also undergo a sea change. Once nano scales are achieved, a conducting material in bulk form may start showing semi-conductor or insulator properties. Change in colour or appearance at nano scales is another example of quantum effect. The gold as we see is notably

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19 Robert Falkner and Nico Jaspers, 'Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap', *Global Environmental Politics*, Vol. 12, No. 1, February 2012, pp. 30-55, at www.mitpressjournals.org/doi/abs/10.1162/GLEP_a_00096#.VWWTstKqpHw (accessed June 12, 2014).

20 'The significance of the Nanoscale' at www.nanowerk.com/nanotechnology/introduction/introduction_to_nanotechnology_1a.php (accessed April 7, 2014).

21 Luisa Filippone and Duncan Sutherland, n. 1, p. 5.

yellow, but once shrunk to nano scales (10 nm to 100 nm) it becomes red if it is spherical or colourless if it is shaped in a ring.[22]

Increased surface-to-volume ratio at the nano scale compared to bulk material give rise to an entirely new set of physical properties having impact on melting point, boiling point, chemical reactivity and strength. Reactions that occur at the material surface are particularly affected, such as catalysis reactions, detection reactions, and reactions that require the physical absorption of certain species at the material's surface to initiate.[23] Small dimensions thus give rise to unique applications where high speed and high functional density are required. Devices can be made portable and light weight with high strength to withstand wear and tear. Electronic circuitry can be made to function much faster and efficiently along with increased functional integration.

New materials with new properties can be created for high capacity absorption, improved catalytic effect, and exceptional mechanical strength, improved sensitive for sensors, high signal-to-noise ratio, super conductivity, and high density memory.[24] Although it appears that the products/applications based on nanotechnology are simple miniaturization of larger objects, however, products based on nano materials require a different production approach. The two most common approaches are 'bottom-up' and 'top-down.' In the bottom-up approach, the fabrication of nanomaterial is done by assembling the individual atoms and then moving up to create larger parts. This is often referred to as self-assembly. The concept of self-assembly already exists in natural biological processes in which molecules self-assemble to create complex structures with nano scale precision.[25] By the process of self-assembly, nano materials can be created having specific functions. The top-down approach entails downsizing and miniaturization. This

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22 Ibid.

23 Ibid, p. 9.

24 Frank Simonis and Steven Schilthuizen, 'Nanotechnology: Innovation Opportunities for Tomorrow's Defence', *TNO Science and Industry*, 2006, p. 11, at http://www.futuretechnologycenter.eu/downloads/nanobook.pdf (accessed September 30, 2012).

25 Luisa Filippone and Duncan Sutherland, n. 1, p. 7.

approach requires precision engineering at nano scales involving lithographic patterning, embossing or imprint techniques with subsequent etching and coating.[26]

It is perceived that manufacturing by moving individual atoms for the purpose of mass industrial production is not suitable due to complexities involved as also the timeframe required is quite long. Molecular nanotechnology (MNT) is one such process in which nanorobots will be used to create objects and will also be capable of assembling themselves, just like the cells in the organic world.[27] This kind of manufacturing will alter the way industrial processes are being run today. The manufacturing would become cost effective with negligible waste and high quality output. However, research in this field is still at nascent stage and actual product development through molecular manufacturing may be few decades away.

The NT can be broadly defined through three distinct categories in order of their increasing sophistication.[28] These three categories are: *incremental, evolutionary,* and *radical.* Incremental NT deals with the assembly of large number of tiny particles to produce substances with novel characteristics, e.g., controlling grain structure to produce stronger metals, magnetic material with high magnetization properties, etc. On the other hand, evolutionary NT deals with building nanoparticles that individually perform some functions which can be translated directly into an application. While each one of the particles retain their novel property, but a large number of them are used as arrays to produce a device.[29] The third category of NT is radical nanotechnology in which the functional machines are created with components of the size of molecules. The radical Nanotechnology is further divided into molecular manufacturing and nanobots.[30] Molecular manufacturing, as and when

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26 Frank Simonis and Steven Schilthuizen, n. 24, p. 9.

27 'The Security Implications of Nanotechnology', NATO Committee Report 2005 at http://www.nato-pa.int/default.asp?SHORTCUT=677 (accessed December 4, 2013).

28 Chris Binns, *Introduction to Nanoscience and Nanotechnology*, Wiley, May 2010, p. 2.

29 Ibid.

30 Nanobots are nanomachines whose components are of the order of a nanometer. They are still at the R&D stage.

practically feasible, will be the first general purpose manufacturing capable of producing goods which are many times more plentiful, advanced, and high performing than any other existing products.[31] Once such a capability is achieved that can make virtually unlimited high performance products, development of weapons and weapon systems with unfamiliar capabilities cannot be ruled out.

1.3 NANOMATERIALS

Nanomaterials are not only miniaturization of materials as perceived commonly, but a production approach to reach nanoscales to exploit the radically different properties of materials which are not exhibited at the bulk state. Nanomaterials are of interest because at this scale unique optical, magnetic, electrical and other properties emerge. These properties have the potential to lead to new applications in healthcare, electronics, manufacturing, industry, social and human engineering.

Nanomaterials can be classified based on their existence in one dimension, two dimensions or three dimensions at nanoscales. These materials can exist in spherical, tubular and also in irregular shapes.

1.3.1 Nanomaterials in One Dimension

Thin films and engineered surfaces are some of the examples of nanomaterials in one dimension. The large surface area of thin film offers unique properties for application in fuel cells, solar cells, electronic industry and pharmaceuticals. Graphene is an atomic scale honeycomb lattice made of carbon atoms.[32] It offers unique properties which can be utilized in optics, electronic devices, sensors and bio-devices.

1.3.2 Nanomaterials in Two Dimensional

Nanomaterials that are nanoscale in two dimensions are categorized as two dimensional nanomaterials. These nanomaterials exhibit a plate

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31 Chris Phoenix, 'Military Implications of Molecular Manufacturing', at www.nanotech-now.com/products/nanonewsnow/issues/o37/037.htm (accessed April 16, 2015).

32 'Nanomaterials and Nanoscience', at http://www.nanowerk.com/nanotechnology/introduction/introduction_to_nanotechnology_4.php (accessed August 3, 2014).

like structure and shape and include examples such as nanofilms, nanolayers and nanocrystals. These novel electrical and mechanical properties are being researched extensively for various applications.

1.3.2.1 Carbon Nanotubes

These are extended tubes of rolled graphene sheets and exist in single wall (one tube) or multi walled (several concentric tubes). These tubes are a few nm in diameter while their length can be in a few micrometers to a few centimetres in length. The CNTs are mechanically very strong, flexible and are able to conduct electrically very well. They are now being used extensively in sensors, display devices, nano electronics, etc.

1.3.2.2 Inorganic Nanotubes

These are 2D layered solids such as tungsten sulphide, molybdenum disulphides, etc., and they also occur in mineral deposits of natural origin. Inorganic nanotubes exhibit high crystallinity, good uniformity and dispersion, high impact resistance with enhanced thermal, mechanical and electrical properties.

1.3.2.3 Nanowires

These are self-assembled linear arrays of dots or fine wire like structures which can be made from a wide range of materials. Their optical, magnetic and electrical properties are remarkable which can be utilized in high density data storage, electronic nano devices, quantum devices, etc.

1.3.3 Nanomaterials in Three Dimensional

Nanomaterials that are nanoscale in three dimensions are categorized as three dimensional nanomaterials. Nanocrystalline materials made up of nano meter sized grains, also fall in to this category.

[33] Ibid.

1.3.3.1 Nanoparticles

Nanoparticles are of great interest since they exhibit new behaviour compared with larger particles of the same material. Nanoparticles can be arranged into layers on surfaces, providing a large surface area which can be used for applications as catalysts.[33] While Nanoparticles cannot provide standalone applications, however, they can be used as ingredients or as additions in existing products.

1.3.3.2 Fullerene

Also known as Carbon 60 (C60), is a three dimensional structure of carbon atoms which is a spherical molecule of about 1 nm in diameter comprising of 60 carbon atoms. The physical properties of fullerene include high hardness, which is harder than steel, and the ability to withstand great pressure. Fullerene finds its uses in lubricants, drug delivery and electronic circuits, solar cells, and sensors.

1.3.3.3 Dendrimers

These nanomaterials are nanosized polymers units.[34] There are numerous chain ends which are located on the surface of dendrimers which can be used for various functions such as enhanced chemical reactivity, catalysis, etc. The dendrimers can act as nanoscale carrier molecules for targeted drug delivery. Water filtration is another area where dendrimers can be used for their property of treating metal ions.

1.3.3.4 Quantum Dots (QDs)

QDs are nanocrystals made up of semiconductor materials. Nanomaterials do not follow the classical Newtonian principles of physics as does matter in bulk, rather they follow the quantum mechanics where the energy is quantized in packets, because of the confinement of the electronic wave function to the physical dimension of the particle.[35] This phenomenon is referred as quantum confinement. As a

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34 'Carbon Based Materials', available at www.azonano.com/article.aspx?ArticleID =1872#_Carbon_Based_Materials (accessed April 8, 2015).

35 Ibid.

result, the optical properties of the particles can be finely tuned depending upon its size. Particles thus can be made to emit or absorb specific wavelength of light by controlling their size. The properties of QDs can be applied in transistors, solar cells, LEDs, laser diodes, medical imaging and diagnostics, quantum computing, etc.

Chapter - 2

Nanotechnology R&D Initiatives And The Current Global Landscape

Nanotechnology is recognized as a very strong driver for innovation and is therefore seen as a strategic technology for the world's future economy.[36] It is a recognized fact that innovations in science and technology often lead to potential defence applications. Nanotechnology is one such field where basic research can lead to successful innovations thereby impacting the war fighting strategies. Having recognized its potential as emerging technology with far reaching implications and possible solution to challenges being faced by mankind today, a large number of countries have embarked upon R&D in nanotechnology.

In 2011, Lux Research, an emerging technologies consulting firm, has estimated that during the year 2010 the total global nanotechnology funding was approximately US$ 17.8 billion with corporate R&D of approximately US$ 9.6 billion.[37] In 2010, Cientifica[38] has estimated approximately US$ 10 billion global public investments in R&D per year growing at a rate of 20 percent with global investment touching US$ 100 billion by the end of 2014.

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36 Frank Simonis and Steven Schilthuizen, n. 24, p. 17.

37 'The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriation Issues', Congressional Research Service Report at https://www.fas.org/sgp/crs/misc/RL34401.pdf (accessed January 30, 2014).

38 'Global Funding of Nanotechnology and its Impact', July 2011 at http://cientifica.com/wp-content/uploads/downloads/2011/07/Global-Nanotechnology-Funding-Report-2011.pdf (accessed June 4, 2013).

2.1 United States

United Sates, the first country to start a nanotechnology program in the year 2000, allocated US$ 500 million for setting up the National Nanotechnology Initiative (NNI). From the FY 2001 through to FY 2013, the US has appropriated approximately US$ 17.9 billion for nanotechnology research and development.[39] There were originally eight participating government agencies which have now grown to 27 including the National Aeronautics and Space Administration (NASA), the Department of Defence (DoD), the Department of Energy (DoE), amongst others. The thrust of NNI has primarily been the development of fundamental scientific knowledge through basic research.[40] Some of the funding to these agencies is aimed at application development while others are aiming at infrastructural technologies.

In order to maintain technological superiority for strategic advantage, DoD has been the lead agency for investment in military specific nanotechnologies with a view to improve the performance of existing systems and also to develop new applications. In the FY 2012, DoD accounted for approximately 23 per cent of total NNI financial outlay.[41] The US Army Research Laboratory, the Air Force Research Laboratory, and the Naval Research Laboratory are playing the lead role in developing defence related applications alongside Defence Advance Research Project Agency (DARPA). The US Army has also collaborated with industry and Massachusetts Institute of Technology (MIT) to establish Institute for Soldier Nanotechnologies (ISN) to discover and field technologies that dramatically advance soldier protection and

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39 'The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriation Issues', n. 36.

40 Ibid.

41 US$ 426.1 million have been allocated to DoD in the FY 2012 out of total budget of US$ 1,857.3 million, at https://www.fas.org/sgp/crs/misc/RL34401.pdf (accessed January 30, 2014).

survivability capabilities. Five strategic research areas[42] have been identified by ISN to address the broad challenges faced by soldiers. The military R&D in the US is focused at miniature sensors, high speed processing, unmanned combat aerial vehicles (UCAVs), improved virtual reality training, and enhancement of human performance.[43]

2.2 China

Considering the far reaching implications in the entire arena of science and technology, China embarked upon the journey of R&D in nanotechnology as early as 1989 when the Atomic Force multiplier was created[44] followed by Scanning Tunnelling Microscope, which are key laboratory instruments for nanotechnology research. The R&D was somewhat disjointed without any state sponsor. Over a period of time patenting activity, publication of research papers and development of standards have emerged as some of the indicators of China's advancements in the field of nanotechnology.

As part of a broad effort to expand basic research capabilities, China identified five areas including nanotechnology research that have military applications as major strategic needs or science research plans requiring active government involvement and funding.[45] As a result, the 8th Five Year plan (1991–95) listed the research of nano materials as one of the government's key projects, prompting the beginning of major

[42] The five research areas are: (a) Light weight, multifunctional nanostructure materials, (b) soldier medicine, diagnostic and far-forward care, (c) blast and ballistic threats, injury mechanism and light weight protection, (d) hazardous substance sensing, (e) nanosystem integration.

[43] The Security Implications of Nanotechnology', NATO Committee Report 2005, at http://www.nato-pa.int/default.asp?SHORTCUT=677 (accessed June 17, 2013)

[44] Sujit Bhattacharaya and Madhulika Bhati, 'China's Emergence as a Global Nanotechnology Player: Lessons for Countries in Transition', athttp://chr.sagepub.com/content/47/4/243.full.pdf+html (accessed on September 16, 2013).

[45] Mick Ryan, 'India–China in 2030: A Net Assessment of the Competition between Two Rising Powers', at http://www.defence.gov.au/adc/docs/Publications2012/01_India%20-%20China%20NA%20-%20Full%20Paper%20v16%20-%2015%20Dec%2011%20-%20final.pdf (accessed May 8, 2014).

investment in nanotechnology.[46] The following years saw coordinated efforts by China for R&D in nanotechnology. Since its 10th five year plan (2001–05), which earmarked goals for short, medium and long term development, and 11th five year plan (2006–10), China has created an ecosystem in which innovation driven by academic research and private firms are playing a critical role. National Mid- and Long-Term Scientific and Technological Development Plan Guidelines (2006–20) were formulated and released which sets the road map and targets to be achieved.[47]

Considering the impetus from the government, China has become one of the fastest growing nanotechnology markets in the world with value estimated to reach US $ 145 billion by 2015.[48] Key applications and research areas revolve around nanomaterial for coatings, fabrics, nanofibres, catalysts, etc. Notable developments have been seen in the transportation industry, Information Technology (IT), construction and healthcare industry.[49] Other notable areas of research are communication, environmental protection, and agriculture.

The People's Republic Army (PLA) has also been investing heavily in nanotechnology and appears to understand that this is a key transformational military technology.[50] Chinese Academy of Science (CAS) is also playing a major role in advancing nanotechnology based research for military modernization. According to Major General Sun Bailin of the Academy of Military Science, 'Nanotechnology weapons could bring about fundamental changes in many aspects of future military affairs and nanotechnology will certainly become a crucial

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46 'Market Report on China Biotechnology and Nanotechnology Industry', at http://www.ice.it/paesi/asia/cina/upload/174/Market%20Report%20on%20China%20Biotechnology%20and%20Nanotechnology%20Industries.pdf (accessed September 10, 2013).

47 Sujit Bhattacharaya and Madhulika Bhati, n. 44, p. 23.

48 'Market Report on China Biotechnology and Nanotechnology Industry', n. 45.

49 Ibid.

50 Richard D. Fisher, *China's Military Modernization: Building for Regional and Global Reach*, Greenwood Publishing Group, Westport (CT), 2008, pp.86-87.

military technology in 21st century.'[51] A 2006 Chinese article lists seven military related applications for nanotechnology, including potential nanodiscs with a 'million times' the storage of current computers, nano structures,'100 times stronger than steel,' the ability to make generic weapons, super thin stealth radar-absorbing coatings, microweapons, nanosattelites, and soldier equipment such as armour cloth laser-protected headgear.[52] These findings, correlated with research papers of Chinese origin available on nanotechnology in the public domain, indicate that a discourse does exist in China for development of nanotechnology enabled military applications.

2.3 Russia

The major initiative by the Russian government led by President Vladimir Putin for nanotechnology took off in April 2007. A comprehensive strategy to create world class nanotechnology industry resulted in allocation of considerable public resources and by 2009 Russia became the world's second largest public spender on nanotechnology.[53] At the face of it, the nanotechnology program is aimed at economic upheaval, however, government officials have identified defence and national security as priority targets of their nanotechnology projects.[54] In the last decade, the Russian political leadership and military leaders were discussing sixth-generation warfare,[55] referred to the new generation

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51 Sun Balin, 'Nanotechnology Weapons on Future Battlefields', quoted in Michael Pillsbury (ed), *Chinese Views of Future Warfare*, National Defence University Press, Washington DC, 1998, pp. 419-420.

52 Ibid.

53 Richard Connolly, 'State Industrial Policy in Russia: The Nanotechnology Industry', at http://www.tandfonline.com/doi/full/10.1080/1060586X.2013.778545#.VA06isKSywg (accessed April 21, 2014).

54 'Defense Nanotechnology Research and Development Program', DoD, 2009, p. 35, at http://www.nano.gov/sites/default/files/pub_resource/dod-report_to_congress_final_1mar10.pdf (accessed April 21, 2014).

55 In the aftermath of Desert Storm in 1991, the late Major-General Vladimir Slipchenko coined the phrase 'sixth generation warfare' to refer to the 'informatization' of conventional warfare and the development of precision strike systems, which could make the massing of forces in the conventional sense an invitation to disaster and demand the development of the means to mass effects through depth to fight systems versus systems warfare. See http://www.jamestown.org/programs/edm/single/?tx_ttnews%5Btt_news%5D=38926&cHash=2da97e307823618aa7c45191ac729ddf#.VA07LMKSywh (accessed on February 3, 2013).

of bio-, nano-, and information breakthrough technologies that will influence warfare by 2020.[56] President Vladimir Putin also underlined the role of nanotechnology that could lead to revolutionary changes in weapons and defence systems.[57]

Federal Targeted Program (FTP) for the development of a nanotechnology industry infrastructure was adopted in August 2007. The aim of this program was the creation of a modern national nanotechnology network infrastructure for the development and realization of the potential of Russian nanotechnology industry. Several federal agencies including Atomic Energy, Industry, Space, Education, etc., were made part of this program. The developmental program was allocated a budget of over 100 billion Roubles (US$ 3.3 billion), of which two-third was assigned to R&D. In July 2007, Rusnano, a state owned corporation, was created to act as a primary organization to implement the state policy in respect of nanotechnology. Rusnano is involved in multifarious activities such as future projection and road mapping, infrastructure development, R&D, educational projects and awareness, certification and standardization, international cooperation, etc. Russian involvement in developing nanotechnology enabled military applications is noteworthy in the field of rocket propellant fuel, military uniforms,[58] nanomaterial, and nano coatings for MiG and Sukhoy aircrafts.

2.4 Japan

Nanotechnology in Japan is considered to be a priority area and the financial support is provided by the Ministry of Economic Trade and

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56 Dimitry Adamsky, 'Defense Innovation in Russia: The Current State and Prospects for Revival', IGCC Defense Innovation Briefs January 2014, at http://www-igcc.ucsd.edu/assets/001/505260.pdf (accessed May 9, 2014).

57 Fredrik Westerlund, 'Russian Nanotechnology R&D: Thinking Big About Small Scale Science', at http://www.researchgate.net/publication/241280138_Russian_Nanotechnology_RD_Thinking_big_about_small_scale_science (accessed May 10, 2014).

58 'Innovation Day: New Russian Drones, Robots, Nano-armor Put on Display, *RT.com*, August 22, 2013 at http://rt.com/news/russian-defense-innovation-fair-803 (accessed January 13, 2014).

Industries (METI), and the Ministry of Education, Culture, Sports Science and Technology (MEXT). In 2001, the 2nd Science and Technology Basic Plan (STBP) laid down the initial goals for research in nanotechnology.[59] Later, Japan categorized nanotechnology as one of its four priority research areas in STBP (2006-2010).[60] The R&D in Japan is focused towards development of novel nano materials having applications in semiconductor industry, life sciences and safe energy generation. There is also considerable funding from the private sector, mostly aimed at developing applications related to nano electronics, nano coatings, nano fabrication, healthcare and biotechnology.

Although, there is no direct evidence to suggest development of military applications based on nanotechnology in Japan, however, National Defence Program Guideline for FY 2014 and Beyond, which has set up the new guidelines for Japan's national defence has highlighted the fact that military strategy and military balance will be significantly affected by the progress and proliferation of newer technologies[61] including nanotechnology.

2.5 European Union

The first reported endeavour of the European Union towards addressing the issue of nanotechnology can be found in 1996.[62] Later, in 2002, through the 6th Framework Program (FP6) for research and innovation, nanotechnology was recognized as one of the seven thematic priorities with an indicative budget of Euro 1300 million for nanotechnology alone. In 2005, the EU adopted an action plan called Nanoscience and Nanotechnology: An Action Plan for Europe (2005–

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59 'Nanotechnologies in Japan: Companies, Research, and University Labs', February 21, 2013 at http://www.nanowerk.com/news2/newsid=29193.php (accessed December 10, 2014).

60 Ibid.

61 'National Defense Program Guidelines for FY 2014 and Beyond', December 17, 2013, at www.mod.go.jp/e/d_act/d_policy/national.html (accessed December 10, 2014).

62 BW Budworth, 'Overview of Activities on Nanotechnology and Related Technologies', April 1996, at ftp://jrc.es/pub/EURdoc/eur16461en.pdf (accessed December 12, 2013).

09) with an objective to define a series of articulated and interconnected actions for the immediate implementation of a safe, integrated and responsible strategy for nanoscience and nanotechnology.[63] Followed by FP6, the 7th Framework Program (2007-2013) was unleashed with special emphasis of research in nanoscience, nanotechnology, materials and new production techniques with a financial outlay of Euro 3475 million. The FP7 was later superseded by Horizon 2020[64] which will run over a period of seven years. The new regime promises to address a widely perceived shortfall in technology transfer and put Europe in a strong position to grasp new opportunities in the commercialization of emerging nanotechnologies across a vast array of different sectors.[65] One of the important aspects of Horizon 2020 program is Euro 1 billion funding for graphene[66] related research which is considered to be the wonder material of 21st century with wide ranging applications in electronics, energy, automobile, transport, medicine, etc.

Defence related funding and research in EU involves a number of countries, e.g., UK, Sweden and France. The research areas include nano sensors, electronic devices, nano materials, protection against nuclear, chemical and biological hazards, electronic warfare, and nanotechnology solutions for soldiers.

2.6 India

The potential of nanotechnology was realized by government of India as early as in the year 2001 when Nanoscience and Technology Initiative (NSTI) was launched as a mission mode program in the 10th Five Year Plan (2002-2007) with a budget of approximately 60 million

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63 Alain De Neve, 'Military Uses of Nanotechnology and Converging Technologies: Trends and Future Impacts', p.7, at http://www.irsd.be/website/media/Files/Focus%20Paper/FP08.pdf (accessed May 11, 2012).

64 Horizon 2020 is the EU research and innovation program providing Euro 80 billion of funding over seven years (2014–2020).

65 'An overview of the European Union's Nanotechnology Projects', July 1, 2013, at http://www.nanowerk.com/spotlight/spotid=31109.php (accessed July 18, 2013).

66 Graphene is a two dimensional material consisting of a single layer of carbon atoms arranged in a honeycomb structure.

rupees.[67] Government of India appointed Department of Science and Technology (DST) as nodal agency to carry forward the plan. The NSTI was followed by Nano Mission in May 2007 under the 11th Plan (2007–12) with a budget allocation of 10 billion rupees.[68] Nano mission is an umbrella program for capacity building which envisages the overall development of the field of research in the country and to tap some of its applied potential for nation's development.[69] The Nano Mission program has various objectives.[70]

Nano Mission program is steered by Nano Mission Council at apex level whereas technical programmes are guided by two advisory groups – The Nano Science Advisor Group (NSAG) and the Nano Applications and Technical Advisory Group (NATAG). Significant contribution is being made by other government departments including Defence Research and Development organization (DRDO) to harness the potential of nanotechnology. DRDO is currently pursuing R&D in nanotechnology in 30 of its laboratories for defence applications.

Other than DST, various other government organizations and agencies such as Council of Scientific and Industrial research (CSIR), Department of Atomic Energy (DAE), Department of Biotechnology (DBT), Department of Information Technology (DIT), Indian Council of Agricultural Research (ICAR), Indian Council of Medical Research (ICMR), Ministry of Environment and Forest (MoEF), Ministry of Health and Family Welfare (MoHFW) and Ministry of New and Renewable Energy (MNRE) are also engaged in funding and policy formulation. Agencies such as National research Development

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67 Koen Beumer and Sujit Bhattacharya, 'Emerging Technologies in India: Developments, Debates and Silences about Nanotechnology', *Science and Public Policy*, 2013, p.5 at http://spp.oxfordjournals.org/content/early/2013/05/22/scipol.sct016.full.pdf+html (accessed January 7 2014).

68 'Mission on Nano Science and Technology (Nano Mission)', at http://www.dst.gov.in/scientific-programme/ser-nsti.htm (accessed January 8, 2014).

69 'Objectives of a Nano Mission', at http://nanomission.gov.in/ (accessed January 8, 2014).

70 The objectives are: (1) Basic Research Promotion, (2) Infrastructure Development for Nano Science & Technology Research, (3) Nano Applications and Technology Development Programmes, (4) Human Resource Development, and (5) International Collaborations.

Corporation (NDRC), Global Initiative and Technological Alliance (GITA) and National Manufacturing Competitive Council (NMCC) are also extending support to research agencies to translate the innovations into applications. The nanotechnology R&D in India has a strong ecosystem with its four pillars resting on policy makers, knowledge generation bodies, knowledge transfer bodies and knowledge application bodies as shown in Figure 1.[71]

DRDO is working on areas like sensors, high-energy applications, stealth and camouflage, Nuclear, Biological and Chemical (NBC) attack protection devices, structural applications, nanoelectronics, and characterization. DRDO is also setting up nano material research and production facility in Hyderabad, Delhi and Kanpur at a total cost of 10 billion rupees. India has also entered into bilateral nanotechnology programs with EU, Germany, Italy, Taiwan and US.[72] Other than government and public agencies, private industry has also started working on nanotechnology enabled commercial products. Two large Indian companies, Reliance Industries and Tata Chemicals have set up nanotechnology R&D centres in Pune.[73]

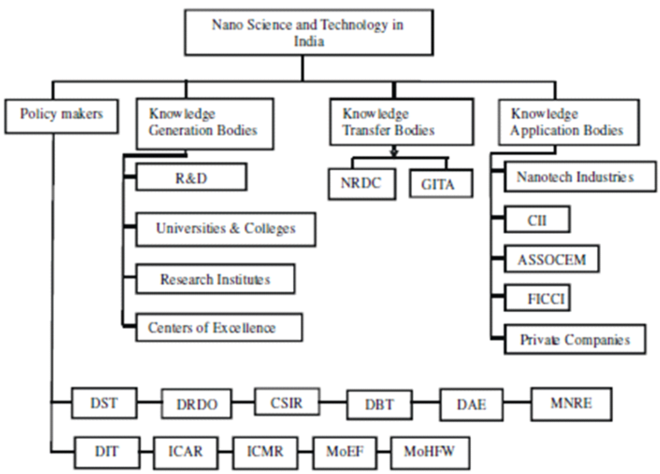

Figure 1. Nanotechnolgy R&D Ecosystem in India

[71] *Compendium on Indian Capability on Nano Science and Technology*, Macmillan, New Delhi, 2012, p. 2.

[72] Koen Beumer and Sujit Bhattacharya, 'Emerging Technologies in India: Developments, Debates and Silences about Nanotechnology', n. 67, p. 5.

[73] Ibid., p. 6.

2.7 Pakistan

Nanotechnology initiative in Pakistan started in 2003 by way of National Commission on Nanoscience and Technology (NCNST) established by the government for an initial period of three years with an investment of US$ 11 million. The mandate for the commission was to promote R&D activities, manpower training and development of infrastructure. After extension of another two years, the functioning of the commission was suspended in 2008 due to change of government policies.[74] Not to be left behind in the race of developing nanotechnology applications, an elaborate plan has again been set in motion by the government in December 2013 with a total funding of approximately US$ 25 million.[75] Interestingly, setting up of laboratories for defence applications has been categorized as one of the key objectives of this initiative with special emphasis on R&D in aerospace and protective personal clothing. In a latest move, Pakistan Foundation for Nanotechnology is proposed to be established that will formulate five and 10 year plan for nanotechnology.[76]

2.8 South Korea

Among the Asian Tigers, South Korea is the leading country in nanotechnology R&D. The Korean National nanotechnology Initiative started in Dec 2000 by the National Science and Technology Council (NSTC).[77] Phase I (2001–05) was preceded by Phase II (2006–15)

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74 RS Bajwa and K Yaldram, 'Research Output in Nanoscience and Nanotechnology: Pakistan Scenario', *Journal of Nano Res*, Springer, January 26, 2012, at http://link.springer.com/article/10.1007%2Fs11051-012-0721-z#page-1 (accessed December 18, 2013).

75 'Nanotechnology Driven Economic Development', Government of Pakistan, Planning Commission, at http://203.124.43.118/Files/Nanotechnology%20Driven%20Economic%20Development.pdf (accessed January 13, 2014).

76 'Hi-tech: Nanotechnology Foundation to be Established Soon', *The Express Tribune*, February 6, 2014, at http://tribune.com.pk/story/668107/hi-tech-nanotechnology-foundation-to-be-established-soon/ (accessed February 12, 2014).

77 Hanjom Lim, 'Overview on Nanotechnology in Korea : Policy and Current Status', at www.andrew.cmu.edu/org/nanotechnology-forum/Forum_6/Presentation/Hanjo_Lim.pdf (accessed April 30 2014).

which envisages securing technological competitiveness to join firmly the global top three nanotechnology nations by 2015.[78] A total investment of approximately US$ 4.85 billion was planned for R&D for the period 2005-2015.[79]

Korea has three frontier research programmes[80] and five national nanotechnology fabrication facilities. These are large scale government R&D programs for developing nano enabled applications.

2.9 Elsewhere in the World

Nanotechnology R&D is not restricted to above named countries. As on now more than 60 countries are currently pursuing R&D in nanotechnology. Notable progress has been made in nanotechnology R&D by Australia, UK, France, Hong Kong, Singapore, Israel and Iran. Thailand leads the ASEAN countries in setting its National Nanotechnology Centre (NANOTECH) in August 2003 with an annual budget of US$ 11 million. The Thai government recently passed the National Nanotechnology Policy Framework (2012–21) which provides national guidelines for nanotechnology development, and it calls for science, technology and innovation in nanotechnology to be increased by ten-fold.[81]

Taiwan was ranked at number four in 2012 in nanotechnology patent holders in the world[82] with an approximate funding of US$ 634

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78 Ibid.

79 'ATIP08.018: National Nanotechnology R&D Plan in Korea', at http://atip.org/atip-publications/atip-reports/2008/5273-atip08-018-national-nanotechnology-rd-plan-in-korea.html (accessed January 15, 2014).

80 (1) Tera-level Nanodevice Development Program, (2) Nanostructured Materials Technology Development Program, (3) Nanoscale Mechatronics and Manufacturing Technology Development Program.

81 'Nanotechnology Development in Thailand: Meeting Society's Needs', at http://www.nanowerk.com/spotlight/spotid=33661.php (accessed November 8, 2014).

82 'Taiwan is World's No. 4 Nanotechnology Patent Holder', *Taipei Times*, October 13, 2013, at http://www.taipeitimes.com/News/biz/archives/2013/10/03/2003573538 (accessed April 24, 2014).

million[83] over 2003-2008. Although the current R&D efforts in most of the countries are directed towards basic research, it is anticipated that as the technology starts maturing, new horizons in civil and military applications will open up.

83 Chung-Yuan Mou, 'Nanotechnology Program in Taiwan', at http://www.facs-as.org/index.php?page=nanotechnology-program-in-taiwan (accessed November 12, 2013).

Chapter - 3

Nanotechnologies in Defence applications

While the nanotechnology is fast evolving leading to new innovations and product development across various disciplines of science and technology, its profound effect on defence related applications has long been realized by countries all over the world. Leading economies are investing substantial amount of funds in developing cutting edge research for exploring military related nanotechnology enabled applications. Nanotechnology has the potential to influence warfare technology in large number of ways. Lighter, stronger, heat resistant nanomaterial could be used in producing all kinds of weapons, making military transportation faster, strengthening armour and saving energy.[84] As far as the specific use for the soldier on the ground is concerned, the military use of nanotechnology will lead to higher protection, more lethality, longer endurance and better self-supporting capabilities.[85]

3.1 Nanotechnology Specific Functionalities

Due to cross-discipline nature of NT, its application in vehicle technology can play an important role. NT offers great promise of innovative products and sustainable solutions to entire discipline of automotive industry.[86] The aim of nanotechnology R&D for vehicle based applications is to reduce the overall weight of the vehicle, enhanced fuel efficiency, reliable and cost effective road worthiness, heightened comfort and protection. These attributes are equally applicable in military domain since a large fleet of vehicles would require a large defence budget in maintaining its operational readiness.

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84 'The Security Implications of Nanotechnology', n. 27, p. 10.

85 Frank Simonis and Steven Schilthuizen, n. 24, p. 67.

86 Sanjiv Tomar, 'Innovative Nanotechnology Applications in Automobiles', *International Journal of Engineering Research and Technology*, Vol. 1, No. 10, December 2012, at www.ijert.org (accessed December 12, 2014).

Militaries all over the world maintain a large fleet of different types of vehicles for different roles. The vehicle fleet mostly constitutes troop carriers, armoured fighting vehicles, infantry combat vehicles, reconnaissance vehicles, logistic carriers, etc. Fleet of such a diverse nature requires regular maintenance to keep it in warfighting readiness.

Other than the cost of procurement, requirement of fuel, oils and lubricants also forms a major portion of defence expenditure. Future military vehicles are required to be light weight, multipurpose, having low maintenance and fuel consumption, as also they should be able to provide heightened safety to the soldiers. In addition to the generic advantage, military vehicles are required to have additional armour protection, surveillance system, communication system, own weapon system and other associated systems.

3.1.1 Mechanical Properties

Nanostructured materials have demonstrated improved mechanical properties such as higher hardness, increased breaking strength at low temperature or super elasticity at higher temperatures.[87] The mechanical properties exhibited are due to decreased grain size as a result the size of the grain becomes small to withstand deformation mechanism.[88] These characteristics can lead to light weight material for various body parts, engine and chassis, increased life expectancy of components and efficient lubricating and cooling systems.

3.1.2 Nanosize Dependent Functionalities

At nanoscales, the surface properties are predominant than the properties exhibited while the matter is in bulk state, as a result, the reactions occurring at contact surface have special attributes. Interaction with such media makes special physical and chemical demands on the surface of particles, pores, fibres, semi-finished and finished products[89]. The

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87 Matthias Warner, Wolfram Kohly and Mirjana Simic, 'Nanotechnologies in Automobiles', at www.hessen-nanotech.de (accessed July 4, 2013).

88 Sanjiv Tomar, n. 86, p.1.

89 Matthias Warner, Wolfram Kohly and Mirjana Simic, n. 87, p. 8.

properties which have direct bearing are scratch resistance, resistance against corrosion and oxidation, mechanical abrasion and resistance against high temperature. Because of the extremely small size of the nanostructures, the high surface-to-volume ratio of those materials becomes more important. By increasing the surface area, the number of atoms at the surface increases dramatically, making surface phenomenon play a vital role in material performance influencing the chemical activity of the material.[90]

3.1.3 Optical Properties

At nanoscale, the size of the particles is much smaller than the wavelength of the visible light, as a result the property of reflection is not exhibited by them. The property of light absorption and emission undergoes a sea change at nanoscales. Nanoparticles can also cause dispersion effects where shorter wavelengths are deflected more than the longer wavelengths, which can cause colour effects.[91] By altering the size of the nanoparticles, desired wavelength region can be created for intended application.[92] This phenomenon finds its application in areas where optically functional surfaces are required.

3.1.4 Other Functional Properties

Chemical, electronic and magnetic functionalities are other such attributes which can lead to numerous applications. Electrical and electronic properties of matter at nanoscales are radically different compared to matter in bulk state. By altering the size of the nanoparticles, paramagnetic and ferromagnetic properties can be made to suite a particular application. The chemical functionality of nano objects is substantially based upon their surface structure.[93] Enhanced chemical

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90 Harini Kantamneni, Akihla Gollakota, Swetha Nimmagadda, 'Avant-grade Nanotechnology Applications in Automotive Industry', Vol. 3, Issue. 1, 2013, at www.ijammc-griet.com/publishedarticles.php?id=TWFyIC8gMjAxMw (accessed October 5, 2014).

91 Matthias Warner, Wolfram Kohly and Mirjana Simic, n. 87, p. 8.

92 Sanjiv Tomar, n. 86, p. 3.

93 Matthias Warner, Wolfram Kohly and Mirjana Simic,, n. 87 p.9.

reactivity and selectivity due to nanosized particles can lead to various automotive applications.

3.2 Nanotechnology Based Applications For Land Vehicles

Besides high standards of safety and comfort of occupants of a vehicle, the rising cost of maintenance, fuel consumption, and environmental impact of exhaust are some of the challenges which guide the automobile industry to look for new solutions to overcome these challenges. NT contributes significantly to necessary developments and to the production of innovative materials and processes in the automotive sector.[94] Use of NT can significantly enhance the efficiency of the sub systems and overall performance of a vehicle fleet.

3.2.1 Improved Vehicle Chassis

Keeping in mind the safety aspects of the occupants of the vehicle, it is important to have nanostructured materials which can offer high strength to take care of the high intensity impact during a crash.[95] Reduced weight of the nanostructured material also leads to fuel economy. Conventional steel used in the car body and other automotive parts can be replaced by a new class of nanomaterials called polymer Nano-composites.[96] Nano-composites offer excellent mechanical properties, flame resistance, resistance to scratch and impact, together with superior thermal properties. The nano-composites are also suitable for the automotive industry since their use can lead to reduced overall weight of the vehicle, increased engine efficiency, lesser harmful emissions and better safety and comfort.

94 Harini Kantamneni Akihla Gollakota and Swetha Nimmagadda, n. 90, p. 196.

95 SanjivTomar, n. 86, p. 2.

96 Nanocomposite is a multiphase solid material where one of the phases has one, two or three dimensions of less than 100 nanometers (nm), or structures having nano-scale repeat distances between the different phases that make up the material.

3.2.2 High Strength Steel

A high strength yet light weight material for car bodies can be produced by using NT.[97] The use of embedded Carbon Nitride can increase the strength of steel significantly. The recently developed nanostructure AHSS can significantly reduce the weight of the vehicle. This material can be used as thin sheet structural vehicle parts. The weight reduction due to the use of nanostructured AHSS leads both to greater crash safety and fuel economy.[98] A weight reduction in body weight of the order of 22 percent to 30 percent has been achieved as compared to a standard car by the use of nano-structured AHSS.[99] While high fuel economy can be achieved through light weight automotive structures, passenger safety has also been increased at the same time. It is estimated[100] that a mere 10 percent reduction in vehicle mass can result in 6–7 percent improvement in fuel economy.

3.2.3 Protection against Corrosion

One of the most common causes of deterioration of vehicle body and components is corrosion. The traditional Chrome III (Cr^{3+}) coating is not long lasting and so is the case with paints applied to the exposed body parts of a vehicle. By using SiO_2 nanoparticles in the electrolyte, it is possible to enhance the protection against corrosion. The layer of deposited SiO_2 nanoparticles of the order of 400 nm can also result in self-healing of corroded area by the process of nano-passivation. Other nano particles such as Nano-SiO_2, Nano-TiO_2, Nano clay, carbon nanotubes (CNTs)[101] can also improve anti-corrosion properties.

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97 Sanjiv Tomar, n. 86, p. 2.

98‘ ‘EDAG’ Analysis of Nanosteel AHSS Sheet’, available at www.nanosteelco.com/markets/automotive/edag-analysis-of-nanosteel-ahss-sheet (accessed April 11, 2015).

99 Ibid., p. 35.

100 Ibid.

101 Carbon nanotubes (CNTs) are tubular cylinders of carbon atoms that have extraordinary mechanical, electrical, thermal, optical and chemical properties. Nanotubes are categorized as single-walled nanotubes (SWNTs) and multi-walled nanotubes (MWNTs).

Other than the corrosion, the surface of the vehicle body is also affected by environmental conditions, e.g., extreme temperature variations, sunlight and humidity. Use of traditional automotive coatings degrade over a period of time and, hence, provide protection for a limited period of time. Nanoparticles of various metal oxides used along with conventional polymeric coatings can enhance the resistance against sunlight. The large surface-to-volume ratio of nanoparticles can capture large portion of ultra violet (UV) radiations of sun light and thus can prevent degradation for extended duration.

3.2.3 Tyres

Tyres are probably the earliest user of nanostructured materials amongst the entire automotive applications.[102] The life and other exhibited properties of tyres is mainly determined by the rubber mixture used in its manufacturing since it is the main ingredient which makes contact with the surface on which it is rolling. While a tyre is required to exhibit a good grip of the surface, at the same time the rolling resistance is required to be low. This, however, presents a contradictory requirement. The properties of natural rubber are greatly enhanced by adding soot, silica and organosilane.The nano sized soot and silica particles play an important role for tyre properties. By the use of nanostructured soot as a filler in tyres, prolonged durability and higher fuel efficiency can be achieved.[103] These nanostructured soot particles have enhanced interaction with natural rubber molecules leading to better rolling resistance which is helpful for driving on wet and snow clad surfaces.

3.2.4 Material suitable for Chassis

While a passenger automobile usually encounters better road surfaces, however, load carriers and other heavy vehicles have to negotiate surfaces which are not ideal. The damping system of a vehicle provides

[102] Rohit Goyal , Manish Sharma and Umesh Kumar Amberiya, 'Innovative Nano Composite Materials and Applications in Automobiles', *International Journal of Engineering Research & Technology*, Vol. 3, No. 1, January 2014, p. 3007, available at www.ijert.com (accessed February 1, 2015).

[103] Matthias Warner, Wolfram Kohly and Mirjana Simic,, n. 87, p. 23.

the driving comfort and passenger safety while the vehicle is in motion. But often the damping system has to strike a right balance between comfort and safety. While a soft chassis provides comfort, a hard chassis results in better safety. In a switchable damping system, the chassis hardness can be controlled by sensing the condition of the terrain and thus, the comfort level. In the core of this type of sensing system is magneto-rheologic (MR/ER) fluid which is classified as 'smart material.'[104] On application of magnetic or electric field, the viscosity of the fluid alters. On removal of the field, the fluid becomes thick again. The changing of viscosity of the fluid into the gel takes only few milliseconds and switching of fluid back into its original condition has a very short time cycle. The other advantage that accrues is that lesser mechanical parts are needed to build such a system and thus, overall weight reduction of the automobile can be achieved.

3.2.5 Engine and Transmission System

Overdependence on fossil fuels has led to overall depletion in fuel reserves. There is a need to conserve fossil fuel to sustain energy requirements for the future. In automobiles, about one-tenth of the fuel is consumed to overcome the friction amongst the moving parts of engine and associated sub systems, e.g., pistons, valve train, bearings, crank etc. These frictional forces not only increase the fuel consumption but also seriously affect the engine life. NT can play a major role in reducing the friction in moving parts. Nano-crystalline composite[105] coating material for cylinder surface and piston of engines not only makes the surface extremely hard but also provides low friction property. Nano size zirconium powder dispersed in mineral oil can cover the entire surface of moving piston and cylinder and can reduce heat generation, vibration, noise and pollution.

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[104] Ibid.

[105] Nanocrystalline composite is a system formed by small monocrystals sized in the range of 3–5 nm, which are embedded in a suitable amorphous matrix with thin inter-crystalline borders of about 0.3 nm.

3.2.6 Reduction in Exhaust Emission

Active catalyst material is used in modern automobiles for the reduction of exhaust emissions. The active catalyst is used for converting harmful emission into nitrogen, carbon dioxide and steam. The extent of conversion of harmful gases into the other products is directly dependent on the surface area of the active material used as catalyst. More the surface area, larger portion of emission will be reduced to harm less products. NT can dramatically increase the surface area of active material by reducing the size of the catalyst used in the nanometer range. The composition and structure is chosen in such a way that exhaust gases in contact interact optimally with the catalytically active coating resulting in accelerated transformation into harmless substances.[106]

3.2.6 Electrical and Electronics

Use of electrical and electronic devices to control various functions in automobiles has increased tremendously over the years. Whether it is fuel injection system, engine control, braking system, microelectronic devices are now present everywhere. NT based functional devices can be used to reduce the volume occupied as well as overall weight of the vehicle. Another area which is waiting to be researched is efficient storage of energy for the vehicle. Hybrid cars which have different combination of source of energy are now taking over the roads. Making use of mechanical energy generated during braking and converting it into electrical energy through a generator and its storage in a battery or super capacitor is now a reality. Using NT in a super capacitor for enhanced and quick storage of energy is path braking. Nanostructured super capacitors of the size of a match box can replace 100 million standard capacitors connected in parallel. The super capacitor gives the advantage of the quick current supply as compared to a battery. Nanostructured super capacitor have almost unlimited durability and a solid energy and eco-balance.[107]

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106 Matthias Warner, Wolfram Kohly and Mirjana Simic, n. 87, p. 30.

107 Ibid., p. 25.

3.2.7 Fuel Cells for the Future Vehicles

Power requirement as mentioned earlier has risen drastically over the years in automobiles. Almost one third of engine power generated is now used up for meeting the demand of electronic gadgetry onboard. Increased cost of fossil fuels has forced scientists to look for alternate means. Fuel cell[108] is one such alternate which could relieve over stressed engine and can decrease the fuel consumption. Along with an accumulator, fuel cell could equally produce sufficient power for the vehicle's system and relieve the engine drive, which could then be made smaller in dimension.[109] There would then be no requirement of an engine for the combustion process. The fuel cells essentially require proton exchange membrane and platinum based electro catalyst to generate useful currents at high potential. However, platinum used as catalyst is very expensive which poses a problem for its commercial use in fuel cells. By using graphene[110] coated with carbon nanoparticles in fuel cells, use of platinum can be totally eliminated as demonstrated by researchers at Brown University.[111] The catalytic activity seen is 12 times more than the pure platinum. Similarly, use of silicon layer with pores of about 5 nm has been used in developing the proton exchange membrane at University of Illinois.

3.2.8 Antiglare and Dirt Repellent

Safety while driving is of paramount importance especially during night and bright sunshine. The light penetrating property through the windscreen or windows can be controlled through a coating of nanometer size nanostructuring on window surface which results in a

[108] Fuel cells are electrochemical devices which are able to convert fuel cell's chemical energy into electric energy with high efficiency.

[109] Matthias Warner, Wolfram Kohly and Mirjana Simic, n. 87, p. 26.

[110] Graphene is a thin layer of pure carbon having tightly packed layer of carbon atoms that are bonded together in a hexagonal honeycomb lattice. Layers of graphene stacked on top of each other form graphite, with an inter-planar spacing of 0.335 nanometres.

[111] 'Nanotechnology in fuel cells', at http://understandingnano.com/fuel-cells.html (accessed January 16, 2015).

refraction index gradient moving from outside to the inside, so that the light waves are practically not reflected. Also, by using hollow silica nanoparticles it has been demonstrated that the transparent screen can be made fog free having antiglare, anti-frost as well as anti-corrosive properties. This type of coating can also be used on vehicle dashboards, rear and front windscreen and viewing mirrors. Hydrophobic nanocoating for glass surface is one such invention which uses lotus leaf surfaces which is extremely difficult to get wet. This type of surface allows dust, dirt and water particles to slide down without leaving any trace.

3.2.9 Automotive Nanocoatings, Nanofluids and Nanolubricants for Engines

Continuous movement in automotive parts generate excessive heat and increases the wear resulting into excessive fuel consumption and higher maintenance cost. Removal of heat by means of coolants and use of lubricants are some of the conventional methods. However, these methods are not very efficient. Chrome and ceramic coatings are used to protect moving engine parts but they also have limitations in terms of longevity and are expensive to use. Use of nano-ceramic composites (alumina-titania ceramic coating) have shown excellent wear resistance.[112]

Adding nanosized material like nanofibers, nanotubes, nanowires, nanorods and nanosheets to fluids results in producing new generation of fluids having superior properties in comparison with conventional fluids as lubricants.[113] By using a nanoscale colloidal suspension, thermal conductivity, heat transfer and viscosity can be increased. By the use of these nanofluids in the cooling system, not only efficient cooling but also the size and weight of the cooling assembly can be reduced. Nanofluids could also reduce friction and wear in pumps and compressors, leading to saving of fuel up to 6 percent.

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[112] 'The Role of Nanotechnology in Automobile Industry', at www.intechopen.com/books/new-advances-in-vehicular-technology-and-automotive-engineering/the-role-of-nanotechnology-in-automotive-industries (accessed June 13, 2014).

[113] Ibid.

Heat transfer capability of water/ethylene glycol liquids used as coolant in vehicles can be increased by the use of nanoparticles, e.g., nanoCuO, and Al_2O_3. Thermal conductivity is found to be increased to about 175 percent by the use of one percent carbon nanotubes by volume in water/glycol mixture.[114]

The above applications of NT can be applied across the whole range of vehicle being used by defence forces. Other than the conventional vehicle fleet used as troops and logistics carriers, armed forces are also equipped with a wide range of fighting vehicles comprising of armoured vehicles, armoured personnel carriers, scout vehicles, infantry combat vehicles, mine clearing vehicles, etc. These vehicles are required to play an active and decisive role during active operations being in the frontline of military operation. These vehicles are designed to provide safety to its occupants by incorporating armour plates, underbelly shock absorbers and anti-mine protection. These vehicles are also designed to withstand the harsh terrains while participating in operations equipped with complete weapon systems and ancillary equipment.

The level of armour protection depends upon the role for which it is designed to play. Main battle tanks are required to withstand hits from weapons of various types, e.g., direct hits, anti-tank guided missiles, and airborne attacks. The material required for physical protection of armoured vehicles should therefore possess high hardness, high elastic modulus, low Poisson's ratio, and low porosity.[115] Nanofibres, CNTs, MWCNTs, nanoceramics and nanocomposites can offer solutions to provide the above mentioned advantages coupled with considerable reduction in weight. Nanofibre reinforced anti-ballistic structure and reactive nanoparticle armour are some of the latest materials being researched for use as armoured vehicle protection. Use of magneto rehofludic system in skirt and protection of the vital systems of tanks will prove to be very useful. Weight reduction, use of additives, sealants,

114 Ibid.

115 Frank Simonis and Steven Schilthuizen, n.24.

and nanocomposite bearings in moving parts will lead to increased fuel economy as well. It is expected that nanoparticles/nanofibre reinforced polymers can make the armoured tank 40 to 60 percent lighter.[116] A recent use of boron carbide nanopowder in developing armour material has shown 5 to 6 times improvement in protection of personnel and equipment with decrease in overall weight by 15–25 percent .[117] The future tank or military vehicle will be lighter having high fuel economy, better combat survivability, ease of maintenance and support, and be agile and flexible in its employment.

3.3 Stealth And Camouflage

The development of stealth capability using the principles of nanoscience and nanotechnology has wide applications in defence, as it helps to protect/hide strategic military power and equipment.[118] Stealth is a technique to make military equipment or weapons less visible to enemy's direct observation, radar, infrared, satellite or other methods of detection. The recent efforts in stealth and camouflage techniques is to make man and equipment literally invisible to available means of detection. The current stealth technique employs use of materials having optical, magnetic or dielectric properties. However, there are limitations to which these materials can be made applicable for camouflage and concealment for the entire range of electromagnetic spectrum (EM).

The later half of the 20th century has shown tremendous growth in the field of computers, electronics and communication, material sciences, etc., which has led to many advanced features in military weapons, especially in reconnaissance and surveillance, weapon control, target acquisition, intelligence and communication. On the other hand, developing counter measures to deny information has also gained momentum. Developments in the fields of sensors and signal

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116 Ibid.

117 'Russian Army will be Equipped with Nano-armr', available at www.technology.org/2013/08/22/russian-army-will-be-equipped-with-nano-armr (accessed September 26, 2014).

processing technologies have resulted in the use of sensors for gathering information over the entire electromagnetic (EM) spectrum. Battlefield commanders are now having real time battlefield intelligence with the help of a variety of sensors. To counter or deny the information to the adversary, camouflage paints, paint additives, traps, nets and foams have been developed for visual camouflage, and thermal and radar signature suppression.[119]Advanced materials having multispectral camouflage capabilities have also been developed for multispectral stealth/camouflage applications. Amongst these, specially developed nanomaterials as stealth materials are being increasingly used in the structure of the objects or surface coating of military equipment to ward off detection by altering their reflection, absorption and scattering characteristics of EM radiation in visible, microwave and infrared region.

Scientists at the University of California have created a new stealth coating that can change the way it reflects infrared light on command.[120] The film which is at the nanometer scale uses reflection and graphene. This coating can be used on surfaces of military equipment. On activation, the film changes its colour to match the surroundings. The activation of the coating can be carried out by the presence of humidity, acetic acid, vapour or vinegar. The Defence Laboratory at Jodhpur, India, has developed a paint using polymeric nanocomposites, nanometals and nanometal complexes for multispectral camouflaging. These paints have very wide ranging applications for military equipment. Nanocomposites are also being used in radar absorbing coatings and structures for military vehicles, aircrafts and naval vessels.

Metamaterials[121] with negative refractive index can be used for next generation stealth technology for military equipment. These

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118 *Compendium on Indian Capability on Nano Science and Technology*, Macmillan, New Delhi, 2012, p.29.

119 'Nanotechnology and Nanomaterials for Camouflage and Stealth Applications', available at www.nanowerk.com/spotlight/spotid=38899.php (accessed December 18, 2014).

120 Ibid.

121 Metamaterials are specially engineered materials having properties which have not yet been found in nature. Their precise shape, size, orientation and geometry help them in attaining those properties.

metamaterials consist of stacked micro or nanostructures with resonator capabilities for EM radiation such as radar, infra-red (IR) and visible light radiation.[122] By using negative refractive index, the radiations falling on the object are neither reflected nor absorbed but guided along the surface of the structure. The bending of radiation along the surface makes the object invisible. In a recent research output at the University of Florida, multilayer 3D metamaterial operation at visible range has been created. This research work can lead to creation of larger pieces of metamaterials which can be used for stealth in military applications.

3.4 Sensor Applications

Sensors are primarily devices which can sense change in any physical attribute and convert it into a measurable electrical output. Sensors find their utility in almost all gadgets of the modern world, e.g., cars, consumer electronics, medical devices, security devices, safety devices, etc. Need to miniaturize or downsizing of electronic gadgets has led to research in the field of microelectronics. The major application of microelectronics depends upon the development of future smart systems combining the area of electronic system integration, on-chip sensing and actuation, autonomous power scavenging and wireless communication.[123]

NT is playing a vital role in realization of nano sensors for a variety of purposes. Nano sensors can be classified based on the purpose for which they are designed.[124] Due to their extremely small size, large surface area, low power requirement and selectivity, nano sensors have a big advantage over conventional detection methods which are often time consuming and have low selectivity and sensitivity.[125] The most

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122 'The Promise of Nanotechnology for the Next Generation of Lithium-ion Batteries', available at www.nanowerk.com/spotlight/spotid=36096.php (accessed December 20, 2014).

123 'Compendium on Indian Capability on Nano Science and Technology', Macmillan, New Delhi, 2012, p.17.

124 Ibid. p. 18.

125 SanjivTomar, 'Nanotechnology Enabled Sensor Applications', *CBW Magazine*, July-December 2014, p. 4-6, available at http://www.idsa.in/cbwmagazine/Winter2014.html (accessed Feb 12, 2015).

important aspect is that these nano sensors can be used independently and can also be integrated with existing sensor applications for enhanced efficacy. The nano sensors are capable of detecting and measuring physical characteristics which are just few nanometers in size, chemical compounds in concentrations as low as one part per billion or the presence of biological agents such as a virus, bacteria or cancerous cells.[126]

Development of CNTs for the use of nanosensors has given rise to new opportunities in developing CNT based electro-chemical sensors. SWNTs and MWNTs offer excellent electrical properties resulting in highly agile and power efficient electronics which is highly desirable for nano sensors.[127] Due to their excellent mechanical properties, these nanosensors can be employed outdoors as well. Owing to the miniaturization, the features which can be realized by the use of nano sensors are as under:

(a) Single chip integration of sensing, data processing and storage.

(b) High sensitivity due to sensing surface of the order of single cell or molecular level.

(c) Efficient thermal properties and low power consumption.

(d) Self-sustained energy requirement by means of solar, heat or mechanical energy conversion.

(e) Portable, remotely operated.

(f) Low cost and disposable.

Military applications for nanosensors are immense. The use of nanosensors for health monitoring of soldiers in the battlefield, detection

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126 Sergi Abadal, Josep Miquel Jornet, Ignacio Llatser, Albert Cabellos-Aparicio, Eduard Alarcón and Ian F Akyildiz., 'Wireless Nanosensor Networks using Graphene-based Nanoantennas', April 11–14, 2011 available at www.imaginenano.com/2011/GENERAL/AbstractBooklet/Graphene_FULLPosters.pdf (accessed March 23, 2014).

127 Sanjiv Tomar, n. 125, p. 4–6.

of mines and explosives, detection of nuclear, biological and chemical agents, battlefield surveillance, monitoring of equipment health at crucial points, logistics and supply chain management. The most important military application of sensors can be realized through Wireless NanoSensor Network (WNSN). A WNSN comprises of large number of nanosensor nodes deployed densely over a large geographical area, viz., battlefield, border areas, vulnerable areas, etc. Each of the distributed node, equipped with a graphene based nanoantenna, typically has the capability to communicate with its neighbours, collect data, analyse them and route them to designated sink point.[128] A nanosensor device, as and when detects an environmental change, would communicate with other sensors in close vicinity and transmit the information in a multi-hop fashion to the command centre which will further communicate it to the end user.

3.4.1 Battlefield Surveillance

Nanosensors when deployed in battlefield or behind the enemy lines can be used to identify and differentiate between own troops, aircrafts, vehicles and other objects. These sensor networks in battlefield will also be helpful in target acquisition and fire guidance to the target. On body sensors of soldiers will pass on the information regarding health, location, and psychological condition of the troops in operational area which will help the commanders in decision-making. The nanosensor network can be autonomous and can get activated on an as-and-when required basis.

3.4.2 Nuclear, Biological and Chemical Sensing

With increasing global threat of use of chemical and biological weapons by non-state actors, it is imperative to look for highly sensitive, accurate and miniature scale sensors that can be deployed in sensitive areas for early warning.[129] Use of nanowires as sensors utilizing the principle of

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[128] Brian E. Usibe , Alexander I Menkiti, Michael U Onuu and C Ogbulezie,'Development and Analysis of a Potential Nanosensors Communication Network Using Carbon Nanotubes', *International Journal of Materials Engineering*, 2013, Vol. 3, No. 1, at www.sapub.org/ijme (accessed December 21, 2014).

[129] Sanjiv Tomar, n. 125, p. 4–6.

field effect transistors has given way in achieving specific sensing by linking a recognition group to the surface of the nanowire.[130] One highly important development in this field is state-of-the-art sensor array having a large number of addressable elements capable of detecting multiple viruses at a level of single distinguishable virus. In order to achieve selectivity, CNTs can also be selectively mixed or doped with different materials. With this development, disadvantage of conventional sensors which are designed to address single or few specific types of virus or chemical species has been overcome. Another attractive application of nanosensors is in the form of sensor arrays in which a large number of addressable elements are fabricated on a single chip which is able to provide multiplexed detection of diverse biological and chemical entities. Deployment of these kinds of nanosensors arrays can help in detecting bio or chemical agents simultaneously, thus eliminating the use of two different sets of detectors for both types.

The network of sensors can also be embedded in bridges, roads, vehicles, tanks, arms, guns, and uniform of soldiers. The embedded sensors will be designed to interact with micro and macro devices to detect and identify damage, fatigue, location and in some cases may lead to self-healing. Nanosensors can also be deployed in number of other ways. The use of 'smart dust'[131] in the form of tiny motes can be scattered over the entire geographical region to gather information. These motes appear as normal dust spread across operational area gathering information about enemy disposition, its movement, intentions, etc. Smart dust offers the advantage of ubiquity, flexibility, timeliness and persistence of intelligence to military leaders, planners and operators.[132] The motes can be tailored to provide information

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130 Ibid.

131 Smart dust refers to tiny, wireless networks of sensors. The smart dust detects data about light, temperatures or vibrations and transmits that data to larger computer systems.

132 Scot A Dickson, 'Enabling Battlespace Persistent Surveillance', Blue Horizon Paper, Center for Strategy and Technology, available at http://www.au.af.mil/au/awc/awcgate/cst/bh_dickson.pdf (accessed January 6, 2015).

on different parameters in the operational area. Researchers in Europe, the US and Japan have sought to develop 'artificial insects', implanted with sensors, electrodes and surveillance devices.[133] Brain machine interference in animals as research project is also underway to guide animals implanted with nanosensors in the desired direction for specific tasks. New surveillance tools, coupled with high density data storage, vastly increased computing power and a new generation of wireless communication tools are also expected to enable increasingly automated computer controlled battle management and logistics.[134]

3.5 Nano Based Communication

NT not only can enhance the performance of a specific application or enhance its capability in military hardware but can also have much profound effect in communication devices in operational areas. Nanomaterials and NT can have impact on basic communication hardware through advanced chip design and advanced electronic packaging methods.[135] The use on NT in information and communications technology (ICT) can lead to higher storage capacity, fast data processing, low power requirement and miniaturization of devices. At the same time, functional density will increase alongwith increased signal-to-noise ratio. With miniaturization of transistors reaching its limits due to limitation of manufacturing technology, further reduction in size of electronic devices needs a different approach. Newer materials with improved properties can be realized by the use of nanomaterials in traditional circuitry. Some circuitry can be replaced with application specific nanosystems, either digital or analogue, tailored to perform a specific signal processing task with vastly improved power efficiency and speed.[136] Transformable devices is one such area which

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[133] Georgia Miller and Mathew Kearnes, 'Nanotechnology, Ubiquitous Computing and the Internet of Things: Challenges to Rights to Privacy and Data Protection Draft Report to the Council of Europe, December 2012, p. 9.

[134] Ibid.

[135] Pallavi Ahale and DJ Pete, 'Nanotechnology Standalone System for War Fighter', International Technological Conference, January 3–4, 2014, p. 143.

has huge military potential. The device can be folded, slid and bent with added advantage of its wearability. CNT with its high toughness is suitable for weaving into the textile and coated with antimicrobial or super hydrophobic properties.[137] The soldier in the battlefield need not be over concerned of the physical safety of the communication device since the wearable and woven textile is washable and can withstand extreme climatic conditions.

Other than the traditional communication techniques, molecular communication is one such area using NT where the means of communication is through molecules. In the molecular communication process, during particle emission, the particle concentration rate in the environment is increased or decreased according to the modulating signal.[138] The particle concentration value is sensed by the receiver and decoded to obtain the information. The molecular communication is conceived to be of three types: walkaway based, flow based or diffusion based. Molecular manufacturing can also lead to single electron transistors, as compared to common transistor requiring millions of electrons to change its state. Using such single electron transistors, high functional density of electronic gadgets with very high processing can be achieved. Spintronics[139] is another field where spin of electrons is used to encode and transfer information within the device. With the help of spintronics, nanoscale memory device with high data storage capacity and low power consumption can be achieved.

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136 V Ermolov., 'Significance of Nanotechnology for Future Wireless Devices and Communications', The 18th Annual IEEE International Symposium on Personal, Indoor and Mobile Radio Communication, 2007, at http://ieeexplore.ieee.org/xpl/articleDetails.jsp?arnumber=4394126 (accessed June 17, 2014).

137 Ibid.

138 Sonali Aggarwal, Shanker Mahto and RC Aggarwal, 'Strengthening the Growth of Indian Defence by Harnessing Nanotechnology—A Perspective', *Defence Science Journal*, Vol. 63, No. 1, January 2013, pp. 46–52.

139 Spintronics is an emerging field of nanoscale electronics involving the detection and manipulation of electron spin.

3.6 POWERING OF NANODEVICES

Most profound applications of NT are in the area of energy generation and storage. On the one hand, NT can improve the storage capacity, offer high safety and durability and, on the other hand, it can be utilized in developing energy sources through solar cells, fuel cells, capacitors and hydrogen storage.

In order to achieve high power density as well as energy density, researchers are using NT to design electrodes with high surface area and short diffusion path for ionic transport.[140] Nanosized material for electrodes are being increasingly used for faster storage and delivery of energy.

The requirement of portable energy for present and future combat systems is ever increasing. With miniaturization of devices and enhanced applications, the requirement for additional energy has gone up tremendously. While NT is helping in miniaturization of military equipment, the source of power supply is also required to keep pace with the speed of miniaturization. NT is now being researched for hybrid system for rechargeable batteries and energy harvesting methods:

(a) Solar battery power pack: Combined with thin film battery with thin film solar cell.

(b) Energy scavenger: Electricity from vibration, radiation, temperature, etc.

(c) Remote charging with RF.

With increasing miniaturization,nanodevices will also be required to have a power source which is matching its own size, as mentioned earlier. Towards this, self-powered NT based piezoelectric nanogenerators aims at powering nanodevices and nanosystems, using the energy harvested from the environment in which these systems are

[140] Frank Simonis and Steven Schilthuizen, n. 24.

supposed to operate.[141] Nanogenerators can be powered by using mechanical energy by body movements, heartbeat, ultrasonic waves and other mechanical motion of machines. Prototypes of charge storage by super-capacitors, self-powered photon sensors and self-powered environmental sensor systems have already been demonstrated for use in nanodevices.

3.7 Nano Bio-Technology

The application in the field of medicines and healthcare holds the most promising future. From the realm of diagnosis to accurate drug delivery, nanomedicine has it all. In case of military applications, the most profound impact will be the on-site diagnosis and drug delivery for the wounded soldier. The targeted drug delivery involves continuous sensing and monitoring of vital body parameters through a network of on-body sensors. On sensing a change in parameters, the sensors activate a drug delivery mechanism which delivers a measured quantity of drug to the body.

Defence Advanced Research Project (DARPA) of the US is developing an implantable sensor microchip for use in troops. The proposed DARPA system would work by pumping unimaginably small nanosensors in the human body to monitor stress levels, inflammation, diseases, nutrition and many more vital signs.[142] These small implantable nanosensors are proposed to be monitored by the medics remotely in real time environment in order to maintain the health of troops at its peak during military operations. Nanobots is another such proposed area of research in which the nanobots would travel through the blood stream and diagnose the disease. They would search for the damaged tissues and deliver the required amount of drug dosage. Transdermal patches containing right amount of nanosized dosages can be injected into the body to maintain short- and long-term healthcare of troops.

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141 'Nanotechnology for Self-powered Systems', at http://www.nanowerk.com/spotlight/spotid=33308.php (accessed March 18, 2015).

142 Alex Newman, 'US Military Seeking Implantable Microchips in Soldiers', at www.thenewamerican.com/tech/computers/item/11286-us-military-seeking-implantable-microchips-in-soldiers (accessed May 12, 2014).

The other promising application of NT includes tissue reconstruction, organs grown artificially and long lasting implants and bionic body parts.

3.8 Unmanned Surveillance And Uavs

Unmanned aerial vehicles (UAV), also known as Drones have changed the face of the battle space since its employment in modern warfare by the US in 1991 during the Gulf War. UAVs are now being employed in multi-role capacity for reconnaissance, combat, target and decoy purposes. Unmanned combat aerial vehicles (UCAV) are the types which are now being extensively inducted by various countries for combat roles. The swelling number of UAVs being inducted by various countries points out the increased reliance on this technology for diverse roles. Not only for their combat role, they are now being extensively used for electronic warfare, jamming of enemy's electronic and communication systems, and other RF devices. Inspite of their success, contemporary UAVs are large in size and can be tracked and destroyed. The current UAVs lack quick manoeuvrability and its speed is not comparable to that of a fighter aircraft. Although, NT will not be able to offer a complete solution in miniaturizing the drones, however, specific applications of NT will make the UAVs more lethal, difficult to counter, agile and autonomous.

Use of carbon fibre reinforced plastic, nanocomposites, CNTs and nanofibres as reinforcing fillers will provide the required miniaturization and high strength to weight ratio, besides fire resistant properties. These UAVs will be equipped with NT enabled sensors and coated with protective coating to avoid detection enabled by NT. Nanosensors can be employed on micro UAVs to detect NBC attack in forward areas. The University of Pennsylvania GRASP laboratory demonstrated a network of 20 nano-quad rotors capable of agile flight which could swarm and navigate in an environment with obstacles.[143] This is a major

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143 'US Military Surveillance Future: Drones Now Come in Swarms?', at http://rt.com/news/us-drones-swarms-274 (accessed December 4, 2014).

shift away from the bulky UAVs. The future of hard-to-detect drone surveillance will mimic nature. Flapping wing bio-inspired micro drones are being developed by the US, France and Netherlands. Honeywell has developed a back-pack sized Miniature Air Vehicle (MAV) designed to gather and transmit battlefield information in support of small unit operations.[144] These hand launched MAVs can be carried in a soldier's backpack and deployed in a very short span of time. The MAV can operate at a height of 100-500 feet above the ground level and can operate under adverse weather conditions and provide imagery, video and can also carry synthetic aperture radar for tracking purpose.

Another area of NT application in drones/UAVs is adaptive structure that can change shape in real time as per operational need. NT enabled sensing and actuating devices on the surface and within the airframe of UAV will allow adaptive structure morphing. Artificial intelligence and biomimetics[145] combined with NT will help in developing materials, such as shape remembering alloys which can sense and change shape as and when required in certain conditions.

3.9 NT For Logistics

Use of technology in logistics is focused on two issues—how to enhance safety and security of transported goods and how to improve the speed and efficiency of the logistic chain.[146] It will be highly desirable in the next few decades that the supply chains are automated which can sense and respond to the requirement of troops and deliver critical payloads and other materials at desired places. This type of logistic supply will be integrated with real-time battlefield surveillance system, sensors, unmanned ground and aerial vehicles.

Use of NT in logistics will enable tracking of supplies using miniature sensors, radio frequency identification (RFID), and ultra-wide band tags. Sensors to monitor biological, thermal and chemical condition

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144 Frank Simonis and Steven Schilthuizen, n. 24, p. 105.

145 Biomemitics refers to human-made processes, substances, devices, or systems that imitate nature.

146 Frank Simonis and Steven Schilthuizen, n. 24, p. 81.

of stores will help in ensuring the optimum use of shelf life. Light weight containers embedded with nanosensors supported through ICT will accurately keep record of huge inventory of stores. Specific to certain stores, e.g., batteries will have improved performance in terms of life span, energy density and size. This will reduce the inventory of batteries substantially which form a major chunk of defence stores. NT enabled solar cells and renewable energy sources will reduce the burden on supply chains. Automotive parts, shields, tracks, arms with enhanced NT enabled safety and functions will require less maintenance stores. Precision guided and smart ammunition will also cut down requirement of reserves to be maintained in the rear.

Molecular assembly as and when it becomes a reality, will radically change the concept of supply chain or logistics management. A significant part of the molecular assembly is the assembler or machine that is able to position and connect individual molecules to create a component or machine. This assembler would be able to manufacture products with nanoscale precision. The creation of replicator would move the concept of an assembler to the next level by allowing copies of the assembler to be made.[147] Once a replicator has been constructed, it would create its own copy and the chain assembly would start which will result in unlimited number of similar products with atomic precision. The speed with which atomic products would be created by using available resources would make the supply chain concept redundant.

3.10 3D Printing and NT Based Manufacturing

Imagine a technician in a war zone sending an e-mail along with a digital scan of an unserviceable part of an armoured fighting vehicle which then gets printed at the nearest available 3D printer and delivered to him in no time. This can possibly minimize the need of carrying and maintaining large inventories in the battle zone. This revolution is taking

[147] Calvin Shipbaugh, 'Thinking Small: Technologies That Can Reduce Logistics Demand', at www.alu.army.mil/alog/issues/MarApr00/MS523.htm (accessed April 28, 2015).

place in a very silent manner and is likely to have far reaching implications for supply chain and logistics management of the armed forces. In a 3D printing technology, an object is created layer by layer through a specially designed printer using plastic or other materials.

Use of 3D printing concept together with NT could bring enormous benefits to nanofabrication. While 3D printing will facilitate converting digital blue print of and part or assembly through additive manufacturing, nanomaterials would provide a large range of materials to be used for incorporating desired physical or chemical properties. With combination of these two technologies, tiny parts, components etc. can be manufactured at nanometer scale,e.g., sensors, actuators, nano batteries, solar cells, etc.

The list of military application involving 3D printing and NT is unlimited. Printing electronic circuits for communication devices, radars, parts of bridges, small arms, artillery guns, parts of bridges, small arms, artillery guns, engine ports, etc., R&D in bio-printing of tissues, implants, replacement of broken teeth, and prosthetic limbs is now picking up very fast.

CHAPTER - 4

NANOTECHNOLOGY ENABLED MILITARY APPLICATIONS: SOLDIER IN FOCUS

In a human centric system of the future battlefield, there is a requirement of not only providing better protection to the soldier from bullet or splinter injury, but at the same time the system should be able to provide better survivability, mobility, execution of group tactics, communication and intelligence, NBC sensing and protection, sensing and reporting of vital body parameters, targeted drug delivery in case of injury, lightweight and smart weaponry, long endurance power source and yet the entire system should be lightweight and wearable. In this chapter, nanotechnology enabled innovations which can be applied to 'soldier as a system' have been discussed.

4.1 BATTLE SUIT

The requirement of lightweight, flexible anti-ballistic textile, chemical and biological protection, self-decontamination and switchable camouflage pattern together with thermal control is largely met by nanofibres and nanocomposite based textile. Nanocomposites consist of a matrix material, usually a polymer with a dispersion of nanoparticles/fibres.[148] These composites provide enhanced thermal, mechanical, and electrical properties.[149] Chinese and the US researchers have demonstrated a carbon nanotube (CNT) coated smart yarn which can conduct electricity and be woven into textile to detect blood or monitor health.[150] It can find its practical utility in the battlefield when a

148 G Thilagavathi, ASM Raja and T Kannaian, 'Nanotechnology and Protective Clothing for Defence Personnel', *Defence Science Journal*, Vol. 58, No. 4, July 2008, pp. 451–59.

149 Ibid.

150 'Nanotechnology Based Smart Yarn for Soldiers', at www.zdnet.com/blog/emergingtech/nanotechnology-based-smart-yarn-for-soldiers/1122 (accessed February 17, 2014).

wounded soldier is not able to send a message for medical assistance, the smart clothing will detect the presence of albumin and send a distress signal through a radio communication device.

Bullet or splinter injuries during active operations are a dominant factor resulting in military casualties. Extremities are most vulnerable to such injuries. Therefore, body armour which is able to provide complete protection against bullet or splinter injury, yet flexible, is desired. While currently used bullet proof jackets and vests do provide protection from medium and low energy small arms, however, there is a requirement of protection against more lethal ammunition and multiple strikes without compromising on manoeuvrability and operational effectiveness. The idea is to create a material having similar or superior ballistic properties, more flexibility and less thickness as compared to currently used Kevlar[151] fabric and its various forms.

Nanotechnology application in Shear Thickening Fluid (STF) has made it possible to create flexible armour. For some time now Kevlar is being used traditionally for its anti-ballistic properties with limited capabilities. However, Kevlar soaked with STF provides much enhanced anti-ballistic properties as compared to Kevlar alone.

STF consists of nanoparticles filled binders which remain flexible when low shear rate is applied and hardens under high shear rate impact in less than a millisecond. Once the stress is removed, it regains its flexible nature. This technology appears to allow conventional ballistic fabric to increase the level and quality of protection it provides without compromising on weight, comfort, and flexibility.[152]

It has also been researched and established that incorporating spherical nanoparticles of silicon or titanium dioxide or carbon nanotubes in a plastic epoxy matrix offers improved anti-ballistic resistance together

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151 Kevlar is a para-aramid synthetic fibre having a very high tensile strength-to-weight ratio.

152 Adam Wiœniewski, 'Nanotechnology for Body Protection', Military Institute of Armament Technology 2007, pp. 7-17 at http://yadda.icm.edu.pl/yadda/element/bwmeta1.element.baztech-article-PWAA-0019-0001 (accessed January 15, 2014).

with greatly improved flexibility.[153] The anti-ballistic performance in terms of absorbed energy is more than double so that four layers of Kevlar impregnated with STF[154] could absorb as much energy as absorbed by 10 layers without STF. Another application of nanotechnology which has caught the attention of researchers is the use of Magnet-Rheological (MR) or magnet-restrictive fluid. The flexible medium filled with nanoparticles become rigid when it gets activated electrically. MR fluids are made up of nanoparticles of iron in a thick or syrup suspension.[155] Once the magnetic field is applied, the fluid becomes thick providing necessary protection against sudden stress or shear caused by a bullet strike.

Due to its high yield strain and high elastic modulus, CNT is considered to be the material of choice for bulletproof vests. CNTs can be used in number of ways to enhance the performance of the armour. One approach is to increase the hardness by incorporating CNTs in the polymer matrix compound (PMC) based armour. Single wall CNT (SWCNT) or multi wall CNT (MWCNT) or both can be used for enhanced ballistic properties.[156] CNTs can also be used as reinforcing material for ceramics used for hard body armour, e.g., alumina and silicon carbide.[157]

Macroscopic CNT based fibre shows a unique combination of extraordinary mechanical, thermal and electrical properties with significant promise for futuristic applications such as next generation body armour.[158] CNT based neat or composite fibres are candidates

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153 Ibid.

154 G Thilagavathi, A S M Raja and T Kannaian , n. 148, p. 455.

155 Adam Wiœniewski, n. 152, p. 10.

156 'Carbon Nanotubes and the Pursuit of the Ultimate Body Armor', pp. 8–15, at http://www.nanowerk.com/spotlight/spotid=17548.php#ixzz31ZVXUHEQ (accessed February 17, 2014).

157 Ibid.

158 Ibid.

for the strongest, toughest and stiffest super fibres of the future and exhibit enormous energy absorption capacity at sonic velocity.[159]

4.2 Biological and Chemical Protection

Exposure of soldiers to hazardous conditions such as chemicals, gases or biological agents can lead to high battle casualties. Currently used conventional protection suits are heavy, bulky and uncomfortable to use. Electro spun nanofibres offer properties to act as membrane material for sensing, decomposition and filtration of harmful toxins owing to their lightweight, high surface area, and porous nature. The high sensitivity of nanofibres towards chemical or biological warfare agents make them excellent candidate as sensing surfaces.[160] Metal nanoparticles (Ag, MgO, Ni, Ti, etc.), which have proven capability in decomposing warfare agents, can also be embedded in nanofibres for enhanced decontamination providing operational advantage to soldier[161].

4.3 Health Monitoring and Sensing

For a commander in operations, it is essential to monitor the physical and mental condition of troops for better employability and mission accomplishment. On-body nano health sensors can provide vital body parameters through communication link to the medics assisting the commander. The nano-bio fusion can give rise to unprecedented applications in health treatment. Targeted drug delivery, regenerative medicine and smart implants are some of the most researched areas.[162] Bio-nanosensors[163] incorporated in clothing, helmet, boots, gloves, etc., can convey information on encountering any health hazard. DARPA

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159 Ibid.

160 M Boopthi , Beer Singh and R Vijayaraghvan.,‘ A Review on NBC Body Protection Clothing’, *The Open Textile Journal*, 2008, Vol. I, pp. 6–7.

161 Ibid.

162 Adam Wiœniewski, n. 144, p. 15.

163 *Compendium on Indian Capability on Nano Science and Technology*, n. 10, p. 39.

has proposed a system of pumping small nanosensors into the human body to monitor stress levels, disease, inflammation, requirement of nutrition, etc., to feed the medic real time information.[164] On sensing injury or failure of vital organs, targeted drug delivery can be actuated by bio-reaction or by external mechanism. Another application which can find its widespread use is a Transdermal patch (TDP). It is an adhesive tape which can penetrate skin to deliver nano formulated drugs to a patient.[165] Massachusetts institute of Technology (MIT) has developed a spray-on biological nano scale coating using Thrombin and Tannic acid to stop bleeding. The shelf life of spray is very long and can be carried by soldiers for stopping any kind of bleeding.[166] In-situ tissue repair is another promising area of nanotechnology application which can be extended to the battlefield. Electrospun nanofibrous scaffolds have been created to improve wound healing and skin restoration.[167] Other approaches involve bioactive (DNA carrying) particles that induce specific cell growth and molecular nano motors to synthesis drugs and releasing drug in a cell.[168]

4.4 Tagging and Tracking

Nano electronics enabled small ICT devices such as cell phones and smart phones will help in ensuring safe and secure communication in network centric warfare scenario. Radio frequencies Identification (RFID) can be used to identify enemy from own troops.

[164] Alex Newman, 'U.S. Military Seeking Implantable Microchips in Soldiers', at http://www.thenewamerican.com/tech/computers/item/11286-us-military-seeking-implantable-microchips-in-soldiers (accessed April 30, 2014).

[165] See http://nano—tech.blogspot.in/p/medicine.html (accessed December 18, 2014).

[166] 'MIT's Nano-Bio-Bandage Can Stop Your Bleeding Almost Immediately', at http://www.popsci.com/science/article/2012-01/mits-nano-treated-bio-bandage-can-stop-bleeding-almost-immediately (accessed December 27, 2013).

[167] Macarena Perán, Maria Angel Garcia, Elena Lopez-Ruiz, Gema Jimenez and Juan Antonio Marchal., 'How Can Nanotechnology Help to Repair the Body? Advances in Cardiac, Skin, Bone, Cartilage and Nerve Tissue Regeneration', *Materials 2013*, 6, 1333-1359, at http://www.mdpi.com/1996-1944/6/4/1333 (accessed May 12, 2014).

[168] Frank Simonis and Steven Schilthuizen, n. 24, p. 46.

Nanotechnology alloy based war tags with RFID and nanosensors can replace the conventional metallic plate identification. The RFID tag can store the complete information of the soldier. The RFID tags could be active or passive with incorporated sensor function for positioning and identification on long distances by using radar reflection characteristics. These RFID tags will also be helpful during rescue and search operation. Once the signal emitted by the sensor is picked up by a receiver, it would be possible to exactly locate the missing soldier. Garments and shoes can be designed around ultra-high frequency RFID tags for access control and positioning.

4.5 Communication

Nanotechnology can greatly enhance the communication capability of the soldier. Use of nanotechnology leads to enhanced functionality, improved stability, reduced weight and system miniaturization.[169] Advance chip design using nanomaterial can decrease the size of the device further. Recent advances in nanoelectromechanical systems (NEMS) have led to the development of nanoscale resonators which are used for GHz signal processing applications characterized by high data rate up to several Gbps.[170] The soldier thus using these devices is able to stream live videos of his area of operation for better situational awareness and decision making. A team of researchers at Monash University have modelled the world's first surface plasma amplification by simulated emission of radiations (SPASER) using graphene and nanotubes. This could mean that the communication device becomes small, efficient, and flexible and can be printed on textile/clothing.[171] Researchers from Nokia have collaborated with Cambridge University to produce Morph Phone. The morph phone utilizes nanotechnology to allow bending, rolling and folding.[172] The morph phone will allow

[169] Pallavi Ahale and DJ Pete, n. 135, p. 141.

[170] Ibid, p. 143.

[171] 'Your T-shirt's Ringing: Telecommunications in the Spaser Age', at http://phys.org/news/2014-04-t-shirt-telecommunications-spaser-age.html (accessed April 18, 2014).

[172] 'Nanotechnology and the Bracelet Phone', at http://www.smartcompany.com.au/growth/economy/1535-nanotechnology-and-the-bracelet-phone.html (accessed April 25, 2014).

the ease of portability and communication by soldier. Development of gold nanomesh electrodes by researchers at Harvard University has led to its application in fully foldable mobile phone or flat screen display unit which can be folded and carried in pockets.[173] Such designs not only reduce the weight of the device but at the same time have very low power consumption.

4.6 Nano Power

Energy requirement for nano enabled system used by future soldier will grow manifolds due to integrated nano sensors, communication device, smart weapon, bio medicine actuator, adaptive camouflage, ventilation and healing system and hosts of other devices. The sources of energy supply have to be low in weight, compact and portable. Therefore, miniaturization of power sources is of foremost importance.

Energy density of Li-ion battery is although good but its life is limited due to finite charge cycles. However, nano structured anode using lithium-vanadium oxide has demonstrated 10 fold increase in energy density with significant drop in weight.[174] Researchers at Rice University, Houston, have demonstrated energy storage device based on nanowire array.[175] In this device, all essential elements of the storage device have been integrated in a single nano wire. In another demonstration of flexible energy storage device, researchers at Stanford University have found a cheap and efficient method of manufacturing light weight paper based battery and super capacitor using fabric soaked in a special ink fused with nanoparticles.[176] This device leads to printed textile having

173 'Flexible, Transparent Conductor Created: Discovery Brings Bendable Cell Phone, Foldable Flat-screen TV Closer to Reality', at http://www.sciencedaily.com/releases/2014/01/140128094720.htm (accessed February 23, 2014).

174 Frank Simonis and Steven Schilthuizen, n. 24, p. 61.

175 Lisa Zyga, 'Energy Storage Device Fabricated on a Nanowire Array', at http://phys.org/news/2011-07-scientists-battery-nanowire.html (accessed March 11, 2014).

176 'Nanotechnology Sparks Energy Storage on Paper and Cloth', *Stanford Report*, February 20, 2010, at http://news.stanford.edu/news/2010/february15/cui-aaas-nanotechnology.html (accessed March 3, 2014).

energy storage property. Other advances in miniaturization of energy storage devices are Peizoelectric nanogenerator, a self-powered nanodevice, and triboelectric nanogenerator Other methods of generating energy for nanodevices are nanowire solar cells,[177] organ dye sensitized solar cell with nanowires.[178], quantum dot solar cells,[179] and Fullerene/CNT solar cells.[180] These devices reduced to nanoscale can be integrated with the uniform worn by the soldier, helmet, weapons or carried on the body.

4.7 Smart Helmet

One of the most essential parts of a soldier's combat gear is the helmet. Conventional helmet these days are made up of synthetic fibre, Kevlar and Aramid, which offer improved protection against small arm fire and blast shock waves. Some of the present day helmets also incorporate provision to integrate night vision device and camera. The efforts of researchers have been to reduce the weight of the helmet at the same time to improve ballistic performance. Owing to the high strength, lightweight, and good absorption capabilities of CNTs, polymatrix nanocomposites where a polymer matrix is reinforced by nano particles like CNTs, will be material of choice for headgear.[181] By using highly ordered CNT arrays, field emission visor display can be created to provide high resolution display along with wide angle (180 degree) display. The display will also have real time simulation awareness and night vision capabilities. Biometric facial recognition capability to recognize enemy or friend will also be incorporated using 3D scene

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177 Frank Simonis and Steven Schilthuizen, n. 24, p. 63.

178 Ibid.

179 Ibid.

180 Ibid.

181 SG Kulkarni, XL Gao, SE Horner, JQ Zheng, and NV David, 'Ballistic Helmets—Their Design, Materials, and Performance against Traumatic Brain Injury', *Composite Structure*, Vol. 101, 2013,,at http://digitalcommon.unl.edu/cgi/viewcontent.cgi?article=1200&content=usarmyresearch (accessed May 5, 2014).

segmentation technology and 2D database comparator.[182] By using STF, the helmet can be categorized as a platform system equipped with multi-sensor system to undertake various tasks of surveillance, positioning and identification, RF and audio communication, BC sensing, sniper detection, and life sign monitor using nanosensors and nanoelectronics.[183]

4.8 Adaptive Camouflage

Camouflage and concealment is a tactical manoeuvre to minimize the possibility of detection. Conventional methods of camouflage involve use of disruptive clothing, nets, paints, etc., to merge with the background terrain. However, conventional techniques are specific to a particular terrain and surroundings. Adaptive camouflage is a concept wherein material surface changes its external appearance in response to pre-programmed stimulus in the environment in which it operates.[184] Nanotechnology based techniques under development are categorized into Active and Passive systems. In an active system, nanotechnology based fibre coating, light emitting diodes (LED), optical sensors and power source is used. The colour of the fibre changes as per the surrounding on receiving signal from the optical sensor. Passive systems use tuneable photonic crystals. Researchers at the University of California have succeeded in changing the colour of nanosized particles of iron oxide by applying an external magnetic field.[185] These photonic crystals are fully tuneable in the visible range of spectrum.[186] Complete nanotube based photo-detector architecture can operate at very high speed in

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182 'Future Soldier 2030 Initiative', at http://www.wired.com/images_blogs/dangerroom/2009/05/dplus2009_11641-1.pdf (accessed on May 5, 2014).

183 Frank Simonis and Steven Schilthuizen, n. 24, p. 111.

184 'Potential Applications of Nanotechnology in Maritime Environment Engineering Essay', at http://www.ukessays.com/essays/engineering/potential-applications-of-nanotechnology-in-maritime-environment-engineering-essay.php#ixzz31bsiY6gz (accessed February 11, 2014).

185 Ibid.

186 Ibid.

real time to adapt to the surroundings. Nanotube interconnections, switches, sensors, and emitters can make the whole design compact with very low power consumption.[187]

4.9 Soldier as a System: System of Systems

The basic idea behind proposing a concept of nanotechnology enabled application for Soldier as a System is to enhance the combat capability of a soldier while at the same time equip him to protect and defend himself in adverse situations. It is an established fact that in future warfare, man-machine interface is likely to become more complicated with advances in technology. However, the individual soldier will remain central to the entire spectrum of warfare.

Soldier as a system is in fact a 'system of systems,' in which nanotechnology enabled applications are proposed to be integrated to provide a multidimensional capability to the soldier. There are five broad areas where these applications can be categorized as sub systems and integrated to form one major system. These sub systems are as under:

a. Combat Suit.

b. Smart Helmet

c. Bio sensor and drug delivery network

d. Communication

e. Weapon

The future combat suit will be capable of providing protection against small arms threat and splinter injuries by integrating bullet proof jacket as its integral part. The combat suit is nano-material enabled providing protection against biological and chemical agents. A network of nano sensors can also be interwoven to monitor physical and mental well-

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187 Ian YenYin Lee, 'Nanotubes for Noisy Signal Processing', May 2005, at http://sipi.usc.edu/reports//pdfs/Scanned/USC-SIPI-365.pdf (accessed May 5, 2014).

being of the soldier. Use of single or multi walled CNTs will help in thermal management by providing ventilation, cooling and insulation as per external environmental condition. RFID textile antennas embedded in the combat suit will help in identifying the foe or friend. In case of close combat operations or operations in urban areas, RFID (radio frequency identification) tagging will help the fellow soldiers to identify the fellow soldier in area of operation. The RFID tagging will also help in access control, accurate positioning of own troops and their movement. Use of nanofibres for adaptive camouflage for the combat suit will provide concealment from getting detected by the adversary. Adaptive camouflage will also be useful in employing the troops in all types of terrains without going into time consuming process of applying new scheme of camouflage pattern to weapons, uniform and equipment.

The smart helmet will not only provide protection from bullet or splinter injuries, but also act as a platform for information gathering, processing and sharing. Nanofibre and nanocomposite based helmet shell will be lightweight and higher impact resistance compared to conventionally used helmets. Use of shear thickening fluid in helmet fabrication will provide head size flexibility and comfort in wearing the helmet with ventilation and thermal management. Reduction in overall weight will lead to incorporation of other nano enabled devices which can be mounted on the helmet. The core value of nanotechnology lies in miniaturization of mounted camera, array antenna and sensors.

Owing to small overall weight of the shell of the helmet, nano devices and multi sensor array can be mounted on the helmet. The visor will act as organic light emitting diode (OLED) display unit acting in tandem with optical and IR camera. Use of acoustic array technology will help the soldier in identifying the location from where the gunshot is fired during combat. EEG and heart rate sensor will be embedded in the helmet due to nano size for monitoring these vital signals. The visor display and vital body signs can also be communicated to the commander in the rear for live situational awareness.

Bio sensors and targeted drug delivery will be the hallmark of innovations in the field of nanotechnology. The commanders in the rear will never lose touch of each soldier under their command during operations, be it their physical or mental state. Sub skin bio sensors will help the medics in the rear to monitor and provide onsite medical assistance in case of any bullet injury or emergency. Speedy recovery or evacuation will bring down the causality rate.

Communication is one such area where large opportunities exist for improving the communication capabilities of a soldier. Primarily, nanotechnology will help in building up extremely small size, rugged, flexible and low on power consumption communication devices. However, there may be a requirement of working out completely new protocols for voice and data transmission. Data rate will be enhanced multifold which will be the key ingredient of fast decision cycle. A platoon or company commander will be able to monitor and view the immediate battle space through digital eyes and ears of his troops.

One of the most potential innovations for nanotechnology will be in the field of weapons. Using nano materials for weapons will lead to light weight and rugged weapon and firing mechanisms. Nanotechnology enabled weapons will incorporate micro radar for target tracking and feedback by the projectile. Once the projectile leaves the barrel, sensor on the projectile gets activated and homes on to the target. These projectiles will carry camera, radar array, sensors and explosive onboard enabled through nanotechnology. In advance innovations, the path correction of the projectile while in flight will also be possible even for small arms ammunition. Remote operation of small arms via RF link is now close to reality.

CHAPTER - 5

FUTURE TRENDS AND IMPACT

The development and use of nanotechnology enabled weapons and systems will bring in changes in generic capabilities of defence forces. More specifically, land forces will find significant impact on engagement capability by way of lighter, precise and long endurance weapons and systems. Use of nanocomposites, nanofibres and CNTs will bring down the weight of the equipment carried by the soldier, which is the biggest impediment in close quarter battle. Miniaturization of sensors, power sources and communication equipment will help him in sustaining the long drawn operations at the same time health monitoring systems, remote bio-informatics, and situational awareness will leverage his fighting capabilities.

Use of lighter and stronger bulletproof jackets, helmets, body suits, adaptive camouflage, reduction in electromagnetic signature, and nano scale bio-sensors will greatly enhance the protection level of land forces. Navigational aids enabled through NEMS, quantum dots and CNTs will enhance manoeuvring and navigational capability of land forces. In the era of information dominant battle space, functional capability of land forces will be enhanced through collection of real time information and its presentation in a usable form for decision-making. Nanotechnology inspired encryption and compression of data will also have significant impact on decision-making cycle.

In near term (5–10 years) nanomaterials will have a profound effect on performance of existing military systems. Lightweight and strong materials will find their uses in military vehicles including armoured vehicles, armoured personnel carriers, self-powered artillery guns and a variety of other vehicles. While systems and sub-systems will be made lighter, the overall weight reduction and improved performance of engines will result in low maintenance cost and economy in fuel consumption.

Wear and tear resistance of structures will get enhanced by the use of NT enabled powders and coatings to give scratch resistance properties.

Similar rise in performance could be observed in hand held weapons, anti-ballistic helmets, bullet proof jackets and backpack of soldiers. Radio frequency identification tags will help in identifying between friend and foe, access control would be foolproof, logistic management will improve with accurate tagging and tracking.

Nanocoatings and nanomaterials for camouflage and stealth will help in deception and protection of men and material. Nano based bio applications will help in quick diagnosis, development of implants and prosthetics. Early applications in sensors will help in detection of biological and chemical agents in the environment. More powerful energetic materials will increase the lethality and range of projectiles.

Remarkable advances in mid-term (15–20 years) are expected in fields like battle system architecture, information technology, ubiquitous sensor network, and systems having situational awareness capabilities. The processing speed and memory of computer systems will grow dramatically allowing system integration and increased functional density. The commanders at every stage of operation will be assisted by powerful and highly capable computers to assess the data received from various sensor networks located in the battle space, viz., ground or aerial. While wide area sensor network (WASN) spread over large geographical area will provide data back to the command and control centres through interspersed wireless networks, on body sensor network will help soldiers in gathering information in immediate vicinity to identify looming threats. The on-body sensor network will also help in monitoring physical and psychological condition of soldiers and help medics in providing remote diagnosis and treatment.

Conventional weapons will benefit immensely from mid-term developments. On board computers and sensors will be much smaller which will reduce the missile signature at the same time capacity to carry payload will increase for increased destruction. Weaponized robots, remotely operated small arms, nanofood and supplements, smart implants, self-adaptive targeting, nano and micro robots, extended range of tele-weapons, brain-machine interface will be the hallmark of mid-term developments in nanotechnology enabled applications.

Long term (20–30 years) NT applications will be characterized by molecular manufacturing. New types of weapons which are still in the realm of fiction might be developed more rapidly with inexpensive fabrication methodology. For example, a new type of armoured tank or artillery gun or a UAV might be tested and fabricated at a very small cost as compared to the way it is being done at present. The cost of prototyping will come down drastically while at the same time it will allow rapid scheduling and accelerated experimentation. Currently available armour protection is not quite effective against a barrage of high precision impacts. Molecular manufacturing might lead to a smart armour configuration which would deflect incoming attacks and allow rapid shifting to interpose material at the point of impact.[188]

Molecular manufacturing as and when possible will provide a paradigm shift in balance of power in favour of the side having molecular manufacturing capabilities. Advanced robotics and artificial intelligence coupled with molecular manufacturing will eliminate the fielding of soldiers in the battlefield, thereby reducing the battle casualty rate to near zero. Since autonomous and remote use of weapons would not require fielding of soldiers, the chances of attacking the civilian population would increase. Cyber space would also become quite important for target as almost the entire weapon systems and command and control will be networked and computer driven.

Advent of nanofactory will be the most defining event which will lead to another nanofactory eventually giving rise to exponential manufacturing. In a very short span of time millions of nanofactories could produce thousands of tons of finished products per hour. These products would be high performing, more powerful, highly precise and many folds stronger than currently available weapon systems. A wide range of components and devices including computers, sensors, displays, etc., would be possible with much less cost of developing and manufacturing. Military capabilities would grow hundreds of folds through nanofactories. Weapon systems would become cheaper as well as more advanced and functional which would make a game changing difference.[189]

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188 Neil Gordan, n. 2.

189 Ibid.

Considering the fact that military applications of NT are still evolving, it is thus difficult to analyse exactly as to how attack and defence in tactical terms will span out. Use of NT at the tactical level will be characterized by a variety of offensive mechanisms: kinetic impact, toxic chemicals, electromagnetic beams, autonomous remotely operated weapons, precision guided small projectiles, electromagnetic jamming, etc. On the other hand, defensive mechanisms will involve stealth and improved camouflage, drones for aerial surveillance, wide area sensor network, NBC sensors, smart dust, etc.

Chapter - 6

Conclusion

In the rapidly changing post-cold war period, characterized by extreme terrorism and dominance of non-state actors, even the most advanced and technologically superior countries are finding it difficult to ensure security to its citizens. Revolution in information technology and rapid globalization has led to availability of new technologies accessible and inexpensive to many nations. NT is one such technology which is being vigorously pursued by a number of countries for its dual use capabilities. Nanotechnologies are enabling technologies which are likely to have far reaching impact on almost all facets of modern society, from industrial growth to medicine to warfare and finding solutions to some of the most critical issues being faced by the world as a whole.

Advances in nanotechnology over the last 10–15 years have resulted in discovery of new phenomenon, radical properties of material and their functions at the nano scale. Incorporation of these newly discovered properties in existing technologies has led to innovations not only in products existing in the commercial domain but also in defence related applications. History shows that today's scientific realities can readily become tomorrow's realities and today's scientific explorations can become sources of development for tomorrow's socially productive forces and military combat powers.[190] It is in this context that nanotechnology which is going through a phase of intense research and evolution is likely to deliver unprecedented applications like micro sensors, soldier's protective clothing, targeted drug delivery systems, communication and intelligence devices, nano power sources, navigational and surveillance aids, etc. These applications are not only going to ease the carried load of dismounted soldier, but at the same

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190 Sun Balin, 'Nanotechnology Weapons on Future Battlefields', n. 51.

time afford better engagement capability, survivability, endurance, protection , stealth and decision making. Notable progress has been made in the fields of nanostructures, micro-electro mechanical systems (MEMS) and nano-electro mechanical systems (NEMS), advanced sensors, energy applications, stealth and camouflage, NBC devices, and characterization. Not only soldier centric applications, the defence space is largely going to be benefitted in almost all its dimensions. Ubiquitous sensor network deploying autonomous and unattended sensors along the border will help in real time surveillance. Light weight nano-composites with improved armour protection will provide better fuel economy, long endurance, more weapon carrying capability and lethality. Unmanned aerial vehicles (UAVs) and unmanned combat aerial vehicles (UCAVs) can be further miniaturized and employed at platoon or section level to have 'hover and stare' capability for close combat operations, operations in built-up areas and in difficult terrain.

While it is encouraging to use and apply nanotechnology enabled applications for societal benefits through exploring the novel properties exhibited by nanomaterials, it is also a matter of concern as to how nanomaterials may interact with the human body and ecological system. An important aspect is that the techniques utilized to manipulate, measure and to predict the behaviour and control of nanoparticles, devices and systems is still not mature and, as a result, their long term effects are unknown and unpredictable.[191] It cannot be ruled out that some nanomaterials because of their miniscule size may enter the human body through skin, inhalation or digestive track and enter the blood stream or may cross the blood-brain barrier. They may enter the vital body organs and interact at the molecular level or tissue level, leading to cytotoxic or genotoxic effects.[192] This may result in a negative effect on the human body and unknown risks to life and the population at large. The effect on environment is also unpredictable and may cause irreversible damage.

191 'Nanotechnology Risk Governance', IRGC Policy Brief, at www.irgc.org/IMG/pdf/PB_nanoFINAL2_2_.pdf (accessed January 10, 2015).

192 Robert Falkner and Nico Jaspers, 'Regulating Nanotechnologies: Risk, Uncertainty and the Global Governance Gap', n. 19.

In spite of aforesaid uncertainties, over 1600 commercial products are existing in the market across the globe. Current efforts for regulation and control are largely focused at the regional and national levels with very few initiatives at international level for its regulation. For the governments and regulators, the challenges lying a head are serious. Intense R&D, rapid commercialization and globalization is opening up uncertain technological pathways and regulatory dilemmas. Scientists and experts are of the opinion that conventional risk management techniques are inadequate to deal and address the risks posed by nanomaterials.[193]

Regulatory system thus faces multi-dimensional challenges ranging from uncertain risks to intense commercialization of nanomaterials, lack of global information sharing platform to rapidly changing technological and scientific systems.

The current regulatory mechanism in the US, Europe and other countries are inadequate and there are wide gaps in terms of knowledge and scientific uncertainties. In India, the risk appraisal related to nanomaterials is funded by the DST led programmes through various agencies such as: Council of Scientific and Industrial Research (CSIR), Indian Institute of Toxicology Research (IITR), National Institute of Pharmaceutical Education and Research (NIPER), Central Drug Research Institute (CDRI), Indian Institute of Chemical Technology (ITCT), etc. The US and EU have, however, taken a lead role in initiating and coordinating efforts through Organization for Economic Cooperation and Development (OECD) and International Organization for Standards (IOS) as also through bilateral links. However, these coordinating actions are not enough considering the efforts required for complete global governance. The World Health Organization (WHO) and The United Nation Industrial Development Organization's International Centre for Science and High Technology (ICS UNIDO) have initiated dialogues for regional networking between nations, scientific community and industry to begin work on nanotechnology related safety and governance issues.

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193 Ibid., p. 11.

Countries which have started early in initiating nanotechnology related R&D are bound to get rich dividends provided the risk governance and regulatory mechanisms are foolproof and are in place. It is contemplated that sufficient advances made in molecular manufacturing will give a distinct edge to the country engaged in its development to disarm its adversary without any physical engagement reducing the battle casualties to near zero. Although convergence of bio-technology with nanotechnology is likely to provide greater safety and immunity, however, their hostile application in creating genetically engineered pathogens specific to particular genotype or ethnic background cannot be ruled out. These pathogens may remain dormant for a very long time and become active only on meeting certain conditions or remote actuation. Therefore, there also exists a requirement of balancing the whole act of R&D and development of applications due to this new vulnerability to which humans and the environment is likely to get exposed.

Nanotechnology is an area of science and technology that holds highly promising prospects for military applications, considering its wide applicability in defensive as well as offensive operations. Given the research and development (R&D) efforts being made in this field by a large number of countries, new products with much superior properties in terms of performance and durability are likely to be realized very soon. The most important aspect of nanotechnology-enabled products is the miniaturization of devices and the diverse functionalities that can be integrated within a singular system. Accordingly, the most profound applications in the future will be realized for the war fighter. Whether it is a battle suit integrated with sensors for nuclear, biological and chemical (NBC) weapons protection, bullet injuries and monitoring of vital body parameters, nanotechnology will find its application in camouflage and concealment, weapons, communication, and situational awareness in the battlefield. This monograph traces the R&D initiatives being undertaken in this field, followed by specific applications which are relevant for the Indian defence forces. It also attempts to foresee how nanotechnology-enabled applications are likely to impact the future battlefield.

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