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Nanotechnology's Entry into the Defense Arena

Madhuri Sharon

Walchand Centre for Research in Nanotechnology & Bionanotechnology, WCAS, W.H. Marg, Ashok-Chowk, Solapur, Maharashtra, India

Science is based solely on doubt-based, disinterested examination of the natural and physical world. It is entirely independent of personal belief. There is a very important, fundamental concomitant - that is to accept absolutely nothing whatsoever, for which there is no evidence, as having any fundamental validity.
Nobel Laureate Sir Harold W. Kroto

1.1 Introduction

When nanotechnology emerged as a new science, it had attracted the attention of scientists from all branches of science the world over. Similarly, people from different domains of life and governance started realizing the impact of nanotechnology. Authorities from the military, security and defense arena also started thinking about the use of this technology. It was realized that nanotechnology would make a big difference in areas such as troop functionality, high-speed conveyance and

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capacity, safety of soldiers, betterment of aircraft, systems for command, control, communication and surveillance, automation and robotics, innovative sensors, advanced war fighter and battle systems capability, electrochemical power, such as batteries or fuel cells, and many more. Nanotechnology is seen as being a technology of national importance to the economy and security by many developed countries especially in the defense sectors. This chapter is about the area of defense that is being impacted by nanotechnology. Almost all countries across the globe are experimenting to understand how this Small Science will help protect their country.

1.2 What Is Nanotechnology

Let us very briefly look at this topic. One may write volumes on what nanotechnology is. But that would be beyond the scope of this book, because this book is about the specific application of nanotechnology in defense. However, in a nut shell, the emergence of nanotechnology, which is a science that deals with the properties of materials with dimensions of 1–100 nm (Figure 1.1), is a result of the fruitful thinking of the visionary

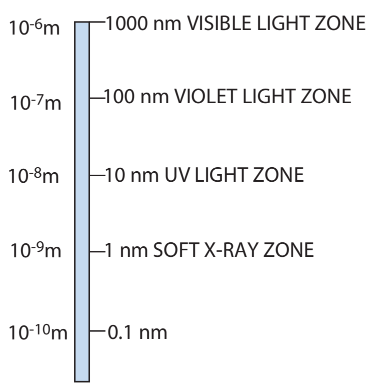

Figure 1.1 Nanometer scale.

Nobel laureate Professor Richard Feynman. Nanotechnology has revolutionized almost every field such as medicine, electronics, information technology, geology, space technology, material science, etc. Enough evidence on this subject has been provided to be able to state that *at macroscale and microscale objects behave differently than that at nanoscale*. The behavioral as well as the structural properties of a nano-object change. When one starts reducing the size of a solid from micro-level to nano-level, its appearance completely changes, especially where metals are concerned. Gold appears lustrous yellow at macroscale, but when brought to nano-level its color turns to red or blue depending on the size.

Such alterations in properties of nanomaterials have created vast applications in Physics, Chemistry, Materials Science, Computers, Engineering, Medical and Biosciences, etc. No wonder venturing into the tiny domain of atoms and molecules is catching on. The main aim and objectives of Nanotechnology and Nanoscience is to unravel as well as comprehend the appearance of strange but useful traits in nanoparticles when they venture into the realm of nanoscale (1–100 nm). The emergence of the physicochemical and optoelectronic properties of nanoparticles is primarily due to confinement of electrons within particles of dimensions smaller than the bulk electron delocalization length. This ability to tune the optical absorption or emission properties (quantum dots) by simple variation in nanoparticle size is particularly attractive in the facile bandgap engineering of material and the growth of quantum dots.

In a nutshell, nanotechnology is the branch of technology that deals with dimensions and tolerances of less than 100 nanometers, especially the manipulation of individual atoms and molecules, or is the manipulation of matter on an atomic, molecular, and supramolecular scale. Such small engineered materials exhibit unique properties that are not found in their bulk counterparts.

The unique properties of nanomaterials that are being utilized for various applications are their chemical reactivity, mechanical strength, electrical properties, optical properties, thermal properties, and durability and quantum effects.

It is difficult to say which country's defense department was first to start working out the possibility of using nanotechnology. However, strong participation of the United States Department of Defense in areas such as sensitive spectrum analyzer 3Hz – 50 GHz, quantum dots for nanoelectronics and sensors, highest Q mechanical resonator (cantilever, nanowire) for chemical sensing, nanomagnetic materials for DNA detection, nanoscale aluminium particles for energetic materials, smallest individual organic light emitting diodes (OLED) device, long shelf life packaging for food (nanoclay PE composite), high strength fibers from twisted nanotube yarns and maskless lithographic process for semiconductors are evidence that they have been investing in working out the applications of nanotechnology.

Out of the Asian countries, Japan is the leading up-and-coming nation investing in nanotechnology, followed by China and Taiwan.

In European countries, Germany, Russia, the United Kingdom, the Netherlands, etc., are running programs in nanotechnology.

1.3 Nanotechnology Offers Innovative Opportunities for Defense

Initially, many thought that nanotechnology applications offered more hype than hope. But as many fantasies started becoming realities, the considerations and joint as well as separate efforts of scientists have reached a consensus that nanotechnology can provide strength and enhanced efficacy to many requirements of the defense arena. The area in which nanotechnology inputs are being envisaged as a must are its applications for (i) soldiers, (ii) security, (iii) weapons, (iv) aeronautics, (v) naval vessels, (vi) vehicles, (vii) satellites and (viii) logistics.

1.4 Nanotechnology for Soldiers

At the moment the maximum focus for the safety of soldiers is on developing a nano combat suit, which should be as thin as spandex and contain health monitors and communications equipment, acts as a shield from bullets, and can protect from biological and chemical attacks. This is for the well-being and security of soldiers. Nanotechnology is crucial for such development because without miniaturization such functionalities cannot be adapted to lightweight, wearable systems.

1.4.1 Smart Clothing Using Nanotechnology for Various Applications

Using the process of manipulating materials on an atomic or molecular scale, clothes are manufactured that have the following characteristics:

- Because it has *greater tolerance to temperature* change, nanotechnology-based fabric can warm or cool the body.
- It is possible to *charge a phone* using a fabric that is solar-powered and to recharge a cell phone or iPod. The change in temperature can open or tighten the weaving pattern of the fabric because the fibers of the fabrics can be modified so their physical properties change with temperature.
- *Anti-microbial nanofabrics* coated with antimicrobial nanoparticles can be used to protect soldier's bodies from microbial infection.

- Another possibility that is being envisaged is to use fabrics coated with *encapsulated insecticides to eliminate mosquitoes.*
- In case a soldier faces smog or toxic gas, scientists are working on fabrics loaded with encapsulated gases that can be released to combat the condition.
- *High-strength fiber* made up of a composite of carbon nanotube impregnated in polymer can be used in nonwoven mats.
- *Multi-Functional Textiles* is another fantasy for the protection of soldiers that is being considered by modifying and functionalizing the surface properties by mixing yarn with nanomaterial and then weaving fabric from it. The new properties that can be exploited will be for the purposes of *sensing,* energy harvesting and energy storage.

1.4.2 Invisibility and Adaptive Camouflage

One of the ongoing dreams of scientists that has been dramatized and presented in many works of fiction and movies is a disappearing or invisible man. For this, one approach that is being considered is to make a cloak or fabric by *manipulating light* so that the soldiers wearing it cannot be seen or disappear. An "ultrathin invisibility skin cloak for visible light" is an outcome of this idea [1]. It is also known as *metamaterial cloaking* as it uses metamaterials, along with manipulating the paths traversed by light through a novel optical material. Metamaterials direct and control the propagation and transmission of specified parts of the light spectrum and render the object invisible.

This result is based on the fact that how we see any object depends on the role of light that bounces off the object and becomes distorted. This distortion is due to the angles and curves of the object. However, if the object is smaller than the wavelength of visible light (300–700 nm), it passes straight through and cannot be seen. That is why even after adding a very high magnification a nanoparticle cannot be seen under the light microscope. The development of a cloak that makes the object invisible is based on this principle. To make a cloak material look invisible it should be fully covered with tiny gold blocks of different nanosizes. Though it seems beyond reach today, soon it will become a reality; especially with the recent report of a dielectric "surface wave cloak" from Hao's group [2], this fantasy seems to be a possibility in the near future. They have made a cloak from engineered gradient index materials (seven ultrathin layers that each had different electric properties) using nanocomposites to control surface wave propagation through advanced additive manufacturing and coated a curved metal plate surface, about the size of a tennis ball, with their cloak. The seven ultrathin layers can hide whatever object they cloak from interacting with electromagnetic waves. Otherwise, the electromagnetic waves would bump into the object and scatter in different directions.

This device is designed analytically and validated through numerical simulations and measurements, showing good agreement and performance as an effective surface wave cloak. The unique aspect of this "surface wave cloak" is that it can make curved surfaces appear flat when they come in contact with electromagnetic waves. The cloak was made out of a gradient-index material with seven ultrathin layers that each had different electric properties. This technology can also be applied to escape detection by radiated probing.

Adaptive camouflage is another approach which is focusing on *electrochromic camouflage,* i.e., using nanoparticle coated fabric which changes colors instantly to blend in with the surroundings. The change in color of the fabric is based on reflective electrochromic device. Adaptive camouflage changes color in response to the environment. This chameleon sheet can be used for draping tanks, vehicles or even as soldier's suit.

In their patented work, Gorodetsky and Xu explain that this device consists of primary color tone plaque that is the main color of the entire fabric and secondary color tone plaque which is patched on this fabric. The fabric is a flexible conductive textile with ion storage layer, an electrolyte layer, the main color camouflage patched of conductive fabric, electrochromic polymer layer and a transparent protective film layer and a conductive flexible conductive fabric camouflage fabric respectively. It is connected to a positive and negative power supply through a wire. Since it uses two fabric electrodes, it makes fabric wearable. Moreover, the electrochromic polymer and a reflective structure having low voltage can be artificially controlled between two or more camouflage patterns that change color fast.

Luminex using integrated glass fibers + LED source is making luminescent fibers by weaving fiber optics into fabric. Super bright LEDs are attached to these colorless fibers that are controlled by a microchip (powered with a battery), which instructs them to emit different colors. An optical sensor is added; hence, the clothes glow by constantly changing colors to match the surroundings.

1.4.3 Armor Fabric

Especially for defense personnel, soldier's antiballistic and shatterproof armor will be of great benefit. It will not only benefit the military, but also fire fighters, police officers, and other emergency responders. Present-day armor, i.e., *Smart Armour,* is not only for protection but is also being researched using nanotechnology so that it can sense the impact of a bullet or shrapnel and automatically stiffen, which should make it even more resistant to penetration and less cumbersome than the ceramic-plate armor troops now wear. Researchers are working on the following materials for use as armor.

1.4.3.1 Artificial Muscles

A concept of weaving artificial muscles into armor that could enable soldiers to leap tall walls is being considered. This material uses nanotechnology and electricity and flexes when jolted by electricity and then relaxes when the electricity is turned off.

1.4.3.2 Strong, Lightweight and Self-Repairing Material

Nature has always been the guiding force for scientist for many discoveries. The use of abalone sea snails is one such guiding idea for scientists in their search for strong and lightweight armor. The shells of abalone are strong, lightweight and can self-repair. For this purpose, improved body armor using SiO or TiO_2 nanoparticles embedded in epoxy matrix is being explored. SiO nanoparticles in a liquid polymer harden on ballistic impact (*shear thickening fluid*). Similarly, iron nanoparticles dispersed in inert oil harden on stimulation with an electrical pulse (*magnetorheological fluid*).

1.4.3.3 Tungsten as Ultrastrong Material

An attempt is currently being made to use tungsten as a basic material since it is five times stronger than steel and twice as strong as currently used impact-resistant material. It is to be used as a new nanomaterial for body armor so as to give ballistic protection. It will be useful for vehicle armor, shields, helmets, and protective enclosures.

1.4.3.4 Carbon Nanomaterials

Carbon nanomaterials (CNMs), especially those having onion-like layering or are multiwalled, i.e., multiwall carbon nanotubes (MWCNTs) (Figure 1.2), have also shown strong and durable properties when embedded in polymers. Investigations are underway to make nanosized umbrellas that open to seal the cloth's

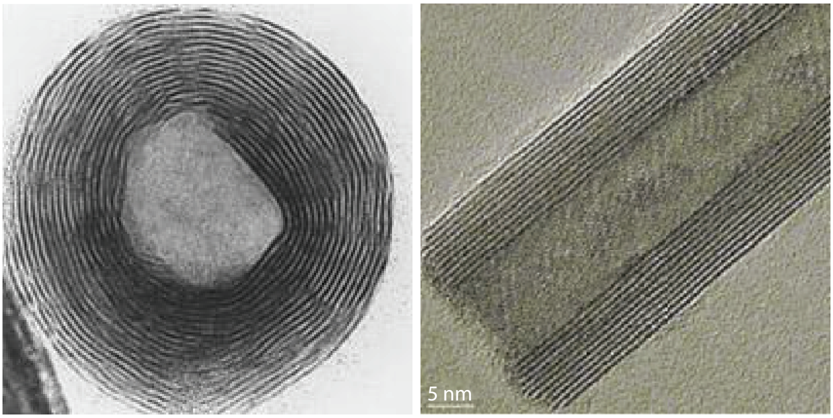

Figure 1.2 TEM images of a multiwall carbon nanotube from two different angles showing lumen in the center surrounded by many walls.

pores, making it impervious to airborne chemicals and pathogens. That would be much easier and lighter than the current equipment required for protecting against biochemical warfare.

1.4.3.5 Future Combat Suits

Future combat suits incorporating the above-mentioned developments in nanotechnology- and nanoelectronics-based textiles will protect against various threats (bullets, grenade fragments, bioagents, chemical agents), will be light, and will monitor vital signs with printed and embedded physiological sensors on textiles (i.e., ECG (electrocardiography) sensors to monitor heart rate, respiration, temperature, dehydration). These suits will have a power grid and energy generating system using ZnO nanowires on textile fibers which will act as piezoelectric nanogenerators. To face extreme temperature conditions, thermal management technologies for textiles use carbon nanofibers and CNTs for heat conductance, ventilation, insulation and local cooling. They will have external sensors for communication and identification. Adaptive camouflage has already been discussed above.

Giving smart armor properties to strong, lightweight backpacks and shoes is also being considered.

Protein nanospheres have been developed at Tel Aviv University. This material is transparent and can self-assemble. It has better properties than both stainless steel and Kevlar. This material could be used in body armor, medical implants, and to strengthen existing composites and ceramics.

1.4.4 Faster Intensive Medical Help

Medical help for a soldier needs a multidirectional approach. Improved medical and casualty care for soldiers is one of the main aims of military research into nanotechnology to produce lightweight, strong and multifunctional materials for use in clothing, both for protection and to provide enhanced connectivity.

1.4.4.1 Diagnostic Support Using Nanotechnology

For monitoring vital signs, such as heart rate or brain signals, of soldiers, sensors and antennas for communicating information from the sensors can be woven into the fabric of shirts or even pillows to use for a wounded soldier. These sensors would also provide the soldier's location to medics via radio. An adhesive chest patch fitted with sensors and a tiny radio can also be used if they are not embedded in the textiles. Another futuristic approach will be to develop medical nanobots and nano-enhanced reconnaissance and communication devices, such as micro-radar, for faster intensive medical help.

1.4.4.2 Nano-Tourniquet

To help a soldier with an injured arm or leg, scientists have developed nanofibers (that are woven into the fabric of the uniform). This fabric will constrict into a tourniquet and thus save blood loss till wounded soldiers can be treated.

1.4.4.3 Antitoxin Guard

Antitoxin guard is made of thin packaging films using nanotechnology that is capable of detecting pathogenic microorganisms, which can cause illness or disease.

1.4.4.4 Lab-on-Chip

For faster medical help and support, the concept of *lab-on-a-chip* is being worked out. In the near future, this may provide a portable diagnostic kit; so that the injury can be detected at the point of need. A lab-on-a-chip integrates many laboratory functions on a single chip of only a few mm to a few square cm in size and can handle multiparameter analysis using extremely small fluid volumes of less than pico liters. A lab-on-a-chip is made using silicon, glass, or plastic with tiny pumps and valves, along with sophisticated readout lasers and advanced charge-coupled device (CCD) cameras, etc. A *lab-in-a-phone* is a concept that can convert a standard cell phone into a portable blood diagnosis machine that can detect HIV, malaria, etc.

Nanotechnology supported theranostic agents and targeted drug delivery system are expected to be of great help in providing timely medical help to injured soldiers.

1.4.4.5 In-Situ Tissue Repair

In-situ tissue repair is a part of regenerative medicine in which nanotechnology is applied to stimulate the body to generate new cells *in situ* via bioactive DNA-carrying nanoparticles that induce specific cell growth. Some nanoparticle-based biomimetic scaffolds are developed for optimal uptake and growth of new cells on them. This is further supported by molecular nanomotors to synthesize drugs, repair damaged DNA, and release drugs in a cell.

1.4.4.6 Artificial Organs

Many nanotechnology-based approaches are being envisaged for this purpose. Nanomaterials are to be used for selective filtering and purification of the blood (for patients suffering from septic shock and acute poisoning, having renal or liver failure). Scientists have imagined developing a wearable, extracorporeal artificial kidney of nano-dialysis system in combination with a micro-pump and nano/micro-sensors, along with a wearable device for the purification of blood. Smart flexible phones and GPS system for navigation are already on the market to support immediate health care.

1.4.5 Food and Safe Drinking Water

Nanotechnology offers tremendous benefits for improved food processing, packaging and safety and enhances flavor and preserves the nutritional value of foods produced. It is expected to be supported by precision agriculture using sensors (for monitoring soil, crop growth and pathogens), smart pesticides, and the automatic slow release of nanofertilizers as directed by a bio-activated trigger.

Nanofood and supplements, also known as nanoceuticals, containing added nanoparticles are becoming available. Storing degradable vitamins, improving the bioavailability of nutraceuticals and flavor enhancers can be achieved by nanoencapsulating them.

Smart packaging based on nanotechnology is another benefit of nanotechnology in food storage. Nanopackaging material works as a diffusion barrier via antimicrobial and UV-protecting additives that can identify and repel bacteria. In the future there is the possibility of developing a packaging material that can display (based on polymer light-emitting diodes) information on the source, history since production and nutritional status of products, such as self-signaling labels and displays on packaging, by using fluorescent nanoparticles to detect chemical or foodborne pathogens. Use of biodegradable nanosensors for temperature, moisture, time, etc., is also envisaged. Transparent UV-protective films based on TiO_2 nanoparticles along with antimicrobial, antifungal (e.g., silver or zinc nanoparticles) surface coatings are another possible use.

A nanotechnological approach for purifying water by photocatalytic decontamination of water as well as air has been successful through many routes, such as by nanofiltration membranes, attapulgite clay, zeolite, active carbon and polymer filters, using photocatalytic activity of TiO_2 nanosensor for the detection of contaminants. One of the great successes is a portable LifeSaver® water bottle that a soldier can easily carry. This bottle has a membrane having 15 nm pores that prevent bacteria and viruses from passing through.

1.5 Increased Surveillance for Better Protection and Security

Scientists in various defense laboratories are working on a revolutionary idea of manufacturing nano-sized fighter jets that will weigh no more than 10 g. These remote-controlled nano air jets will be as small as a seed and can go anywhere. They can collect military information from both indoors and outdoors and can carry a payload of up to 2 grams. These nanojets will be useful in protecting the lives of soldiers and enhancing operational effectiveness.

Used for its superior strength, CNT can theoretically have tensile strengths of as much as 120 GPa, though actually the highest tensile strength of SWCNT is recorded as 52 GPa and of MWCNT it is 62 GPa. However, the problem is in maintaining its strength. CNT is being envisaged as future weight material for body armor and helmets because it is a very lightweight material.

Protection and surveillance needs keep information in such a way so as to be readable only by those who know how to decode it. The existing cryptosystems use software solutions based on mathematics to distribute keys. The problem is that these mathematics can be copied and decoded and exposed.

Now, a new approach called *quantum cryptography* has been developed. It is an absolute security technology to protect voice, data or video communications using quantum physical phenomena, which makes unbreakable security possible for the first time. Using quantum cryptography the sender transmits a string of bits to the receiver whose values are carried by single photons. Even if an intruder intercepts it, their state gets irreparably changed. The sender and receiver both will detect that it has been intercepted, whereas in digital cryptography, an intruder's interference cannot be detected and messages can be copied.

A single-photon detection device is the ultimate in cryptography communications. These devices make very low-noise, high-speed operation and single-photon generation devices with a low incidence of simultaneous generation of multiple photons. A single-photon generation device contains within a resonator structure, self-organized InAs quantum dots selectively grown on gallium arsenide arsenic, which has confirmed the generation of single photons in the optical communications waveband by electrical drive.

1.6 Smaller, More Effective and Cheaper Nanotechnology-Based Weapons

Defense departments all over the world are trying to develop more lethal weapons than the existing ones. Such weapons focus on precision targeting, minimum weight and signature, optimal impact damage and onboard intelligence. Developing non-lethal weapons is also required, so as not to completely destroy the enemy but rather temporarily neutralize or disable them. Such weapons can be fabricated by using nanotechnology-enabled high strength and lightweight polymer nanocomposites. Stealth and smart skin materials with built-in condition and firing monitoring sensors will also be of great use. Scientists are also trying to develop

(i) *Nano-sized cone materials* that sharpen upon impact and can cause additional damage.
(ii) Q*uantum structures* for use as small and efficient directed energy weapons such as directed microwave and laser systems. Nano-dispersed alumina is being used as high energetic propellants. Nanotechnology is also being used to equip the weapon systems with sensors for μ-radar, μ-bolometer (infrared) and acoustic arrays for better targeting.
(iii) *Nanoparticles of aluminium* are used to create compact and powerful bombs. These bombs will create ultra-high burn rate chemical explosives much more powerful than conventional bombs.
(iv) *Mini-nukes* that are very small and light (less than a few kg) are on the agenda of many countries. These mini-nukes use super lasers to trigger comparatively small thermonuclear fusion explosions in a mixture of tritium and deuterium, which will be equivalent to less than a ton to hundreds of tons of high explosives. They are known as future weapons of mass destruction. Since these devices will use very little fissionable material, there will be "virtually no radioactive fallout."
(v) Just like *nano-flotillas* for targeted drug delivery, targeted delivery of highly toxic substances to vulnerable areas can be done using nanotechnology.

1.7 Nanotechnology in Aeronautics for Lighter and Faster Aircraft

Nanotechnology is being envisaged for developing lightweight, intelligence guided, low visual signature, high speed and manoeuvrable fighter jets and missiles; having specific detection and surveillance sensors and weapon systems.

There are many nanomaterials that exhibit ultrahigh strength or mechanical properties. This is especially true for CNTs, which have very high intrinsic strength. Whether used alone or in conjugation with other materials, such as polymers, CNTs offer not only stronger materials but also a substantial reduction in weight. In aircraft as well as land vehicles a lighter material will also be a big support for soldiers. It is expected that nanotechnology will offer an overall weight reduction by a factor of 2–3.

For making lighter and stronger vehicles or aircraft, composites of polymers blended with other nano inorganic chemicals, nanoplatelets or nanotubes in a particular ratio have been developed. The polymers that are usually used are epoxy, PE, PP, ABS, PET, etc., into which nanoparticles are blended to enhance mechanical, electrical or chemical properties. Nanoparticles of different shapes are being used, e.g., spherical, platelets, tubes, fibers, needles, etc. Moreover, the nanoparticles of sepiolite and attapulgite, CNT, layered double hydroxides and smectites, graphene or nanographite platelets, silica, zinc oxide, barium titanate, etc., are also being tried. One such composite that is already on the market is NanoXcel made by Yamaha, which is a nanocomposite of polyurethane matrix in which an exfoliated nanoclay is dispersed. This award-winning composite is lightweight, stiff, strong and durable. Yamaha has used it for hulls and hoods.

To suffice the need of having composites with better electronic and current-carrying properties, *intercalated nanocomposites* are fabricated that have polymer chains alternating with inorganic layers with fixed polymer to inorganic layer ratio.

1.7.1 Exfoliated Nanocomposites

Exfoliated nanocomposites have superior mechanical properties such as (i) high tensile and impact strength, (ii) improved fatigue behavior, (iii) improved flame retardancy, (iv) improved temperature stability, (v) enhanced thermal stability of additives, (vi) reduced linear thermal expansion, (vii) improved crystallinity, (viii) improved resistance to organic solvents, (ix) improved surface finish, (x) enhanced UV-light stability, (xi) reduced oxygen- and water-vapor permeability, and (xii) have new nanopigment basis (PlanoColors®).

Exfoliated nanocomposites have a continuously variable number of polymer chains between the layers that are > 10 nm apart.

1.7.2 Single-Wall Carbon Nanotubes (SWCNT), Double-Wall Carbon Nanotubes (DWCNT) and Multi-Wall Carbon Nanotubes (MWCNT)

These carbon nanomaterials having an inner lumen diameter of 1–2 nm and aspect ratio 103,104 have been found to be good additives for exfoliated nanocomposites. They exhibit up to 1–5 MPa elastic modulus; 30–180 GPa tensile strength; 6000 S/cm electrical conductivity; 2000 W/mK thermal conductivity and a surface area of as high as 1500 m^2/gram. NASA has developed a CNT polymer composite that bends when voltage is applied.

1.7.3 Nanoplatelets and Nanofibers of Graphite/Graphene

Nanoplatelets and graphite/graphene nanofibers are good additives for strengthening nanopolymers. Graphite plates having a thickness of 1–2 nm and an aspect ratio of 103 have induced increased chemical, UV and thermal stability, tensile strength, fracture toughness and diffusion barrier.

Nanofibers synthesized by different methods, such as from vapor-phase grown graphite, electrospun nanofibers or phase-separated liquid crystal fibers, have been found useful in nanofiltration systems. Similarly, nanoclay platelets dispersed in polymer have also been found to be UV-stable and flame retardant.

1.7.4 Electrospun Nanofibers

Electrospun nanofibers are produced by spraying a polymer solution through a fine nozzle by applying 25–50 kV; this reduces the polymer to fiber of 50–200 nm diameters and a few cm long. This process is suitable for producing fibers of ceramic, metal oxide and carbon. Areas in which application of such high throughput nanofibers are being extensively researched are nonwoven mats, nanofiltration units, absorption activity, as catalyst, as reinforcement material for anti-ballistics, and as insulators. Moreover, their selective gas permeability is used to fabricate breathing and protective fabric. Due to the large surface area sensitive to absorption and subsequent change in electrical resistance, they are being investigated for application in sensors.

Another suitable material being considered for lighter and faster aircraft is nanocrystalline metals (< 100 nm) and ceramics. It has been found that by putting the material such as aluminium and titanium under high pressure loads, the internal grain boundary surface area per unit volume increases, thus increasing the hardness and strength may increase by a factor of 2–3.

Helicopters are another consideration. To improve the performance of helicopter rotors, a change in morph per requirement so that it will last longer, as well as reduction in rotor vibration, etc., are being researched.

1.8 Nanotechnology for Stealth Warships and Submarines for Ocean Exploration

Nanotechnology is being used to make lightweight, high strength, smart sensor-guided, low energy consuming, safe, protective and high comfort submarines and naval vessels for ocean exploration. Nanomaterials with such functionalities are nanocomposites of plastics/polymers, metal nanoparticles and carbon nanomaterials, which are foreseen to become future material. One of the necessities for military use is the availability of remote and unmanned guidance, which is becoming possible due to advanced nanosensor and wireless communication.

The power requirement for naval vessels should be controlled by using lightweight ships, energy efficient powering, and reduction of thermal, radar and acoustic signature. For this purpose, the use of electric power systems enabling very low signature, hydrogen fuel cell, miniaturized unmanned vessels are being considered. For operations at sea there is a need to innovate underwater remote, electric and solar-powered ships.

1.8.1 Microwave Absorber for Stealth Technology

Microwave absorbers have the ability to eliminate electromagnetic wave pollution and reduce radar signatures; hence, they are used in civil as well as military applications. As reported by Emerson [3], the first electromagnetic wave absorber came into light in the mid-1930s to improve front-to-back ratio of a 4 GHz antenna. With the development of radar, there has been a growing and widespread interest in radar absorbing material (RAM) technology. RAM is coated on the target whose electrical and magnetic properties have to be altered to give absorption of microwave energy at broad band or discrete frequency [4]. The metallic surfaces of ships are coated with radar-absorbent materials so as to reduce the radar signatures of targets by the reduction of radar cross section, i.e., the actual area "seen" by a radar system when its transmitted wave is reflected from a given object [5]. Due to advancement in wireless and microwave communication technology, a lot of development has taken place in the telecommunication market and the demand for microwave absorbers in the frequency range of 1–20 GHz has increased because of their twofold use as EMI shielding and countermeasure to radar detection. Countermeasure involves the radiation of noise power in the operating band of the radar to confuse or deceive the radar as communication system. Because of these two uses, the suppression of EMI and meeting the electromagnetic compatibility (EMC) have become an essential requirement in industries dealing with high-speed wireless data communication systems operating at 1.9 GHz for handyphone system as well as 2.4 GHz wireless for local area networks (LANs). In addition to mobile communication systems, the satellite communication systems and automatic teller machines (ATM) also operate in the GHz range [6–8].

Microwave absorbers are employed for effective countermeasures against radar surveillance in stealth technology for defense [9]. Application of microwave absorbing coatings on the exterior surfaces of military aircraft and vehicles also helps in avoiding the detection by radar [10].

Nanotechnology-based next generation warships of the United States are in the offing. These warships are all electric. It has been claimed that warships based on this new technology will be more effective, will have longer survivability and will be comparatively cheaper.

1.8.2 Invisible Stealth Ships, Planes and Vehicles

Nanotechnologists have developed invisible left-handed metamaterials that show negative refractive index, and therefore could be virtually invisible to the human eye, roaming radars, and heat-seeking missiles. Although this sounds like a fantasy, it may soon become a reality.

The *left-handed metamaterials* are stacked micro- or nanostructures with resonator capabilities for electromagnetic radiation such as radar, infrared and visible light radiation. At the resonator frequency the metamaterials may show a negative refractive index; when both the permittivity (ε_o) and the permeability (μ) will have negative values. Normal materials have positive values for both the permittivity and permeability and are called *right-handed materials.* In materials with a negative refractive index, incoming radiation does not get reflected or absorbed by the material, rather it is guided and transported along its surface just like in waveguides. Since the radiation is bent around the object, the object cannot be seen but one can see around the object.

Collaborative research by various universities in the USA, Louvain-la-Neuve University in Belgium, Imperial College London in the UK, and Karlsruhe Institute of Technology and University of Stuttgart in Germany have built prototype materials based on this concept.

1.8.3 Radar Absorbing Material: Carbon Nanotubes (CNT)

The first and most common RAM is composed of tiny spheres coated with ferrites. This is painted on the aircraft. Radar waves induce molecular oscillations from the alternating magnetic field in this paint, which converts radar energy into heat. The heat is then absorbed by the aircraft and then gets dissipated.

Another modified RAM that is now used consists of neoprene polymer sheets in which ferrite grains or carbon nanotubes are embedded.

The thickness of the absorbing layer is close to a quarter-wavelength at the frequency of operation, giving a 180° phase difference between the interface reflection and the emergent waves.

1.8.4 Radar Absorbing Material: Ionic Liquids

One more alternative method of microwave absorption being used is poly(ionic liquid)s and ionic liquids containing separated cations and anions which can absorb microwave. Ionic liquid polymers are synthesized by polymerizing monomers containing ionic liquid moieties. These polymers are extremely stable and have high microwave absorption properties. They can be fabricated as films, formulated into coating, painting or other applications.

A Piranha boat using carbon fiber nanocomposite is built by Zyvex Technologies. This boat is 40% stronger and 75% lighter than aluminium. It has shown very economical fuel consumption, hence can stay at sea for a longer time. It is being considered as an unmanned platform for a variety of applications. Moreover, in the future it can replace expensive aircraft carriers.

1.9 Nanotechnology for Vehicles

Vehicles to be used in defense are expected to be lightweight, multipurpose, intelligent guided, energy efficient, safe and protective for passengers. Armor protection and specific monitoring systems for weapons detection and surveillance also have to be taken into account.

A *transformer vehicle* is being developed by the Defense Advanced Research Projects Agency (DARPA) of the United States which can travel on roads, can take off vertically and land. The body of the vehicle could morph itself when airborne (grow wings) or pull them back when it is on land or aloft. It can go over rough terrain, avoid landmines or ambush, while retaining the capability to drive on roads.

1.9.1 Vehicles with Scratch Resistant Surfaces

The scratch resistance of coatings is done on the automotive body and windows (which are mostly made in poly carbonates in modern vehicles) to protect the surface and the underlying layers from mechanical damage, chemical and UV degradation; preferably by incorporating it in the automotive paint systems [11]. Moreover, to increase the fuel efficiency, lighter bodies are made using mold-in-color (MIC) plastics to replace painted interior and exterior components.

To improve the scratch resistance of automotive coats, Barna *et al.* [12] have worked on developing a scratch proof nanocomposite for clear coatings, through the introduction of nanoparticles; because certain nanoparticles can increase the surface hardness and resistance to indentation. The nanoparticles can be uniformly distributed throughout the coatings or they can be designed to preferentially segregate to the top surface.

Another attempt is to make abrasion resistant thin film nanocomposites composed of co-sputtered chrome zirconium (CrZrx) alloys on polymeric substrates. This is due to small grain sizes and complex grain boundaries of crystalline materials and a lower atomic packing density of an amorphous phase [13]. However, many concerns about using nanoparticles are currently being discussed [14] such as the long-term resistance to scratching of the coatings containing nanoparticles primarily at the surface not being known, as the morphological changes during weathering may reduce the effectiveness of this approach.

Another approach to combat scratching is developing it based on self-healing technology.

1.10 Nanotechnology for Satellites

Military satellites are needed for observation, inspection, communication, gathering information, etc. The advantages of swarms of nanosatellites for defense are that they can be used for destruction of other spy satellites; and can intercept communications or make observations.

Nanotechnology is being applied to make lightweight, miniaturized components and hence very small satellites. This is expected to not only make them cheaper to manufacture, but also to launch them into orbit in space. Trials are ongoing for a distributed network of small satellites instead of one large one. Based on their weight these will be minisatellites (50–500 kg), microsatellites (10–50 kg), nanosatellites (1–10 kg) and even beyond nano, picosatellites (< 1 kg). Each micro-satellite will have its own solar panels as a power source. The ultimate goal is to develop a complete satellite-on-a-chip, the so-called picosatellites. One Delfi-C3 microsatellite was already launched in 2008 for a 3 kg CubeSat measuring 10×10×30 cm. It flies thin-film solar cells, two autonomous wireless sun sensors and a miniaturized UHF-VHF transponder.

1.11 Nanomaterials for Portable Energy/Power

Energy supply is needed for all the combat systems in defense, such as for wearable invisible or camouflage suits or garments, helmets or head protection and hand weapons, integrated sensors, communication, etc. The energy supply systems have to be low weight miniature power sources because there is a demand for lightweight batteries with a high energy density for wearable electronics, electric vehicles and robotics (Table 1.1).

The areas in which efforts are being made are described below.

1.11.1 Portable Fuel Cells (FC)

Fuel cells are composed of nanoporous membranes and nanostructured catalysts. Available portable fuel cells are solid oxide fuel cells running on 2.5 kg propane and hydrogen fuel cells.

Table 1.1 Different battery technologies used in vehicles and their energy density.

Battery technology	Energy density (Wh/kg)
Old: Lead-acid	30–40
Mature: Nickel Metal Hydride	30–80
State of the art: Li-ion	150–300
-Li carbon/iron-phosphate	
-Li vanadium oxide/cobalt oxide	
-Li polymer	
In development: Na-ion	400
Future: nano Li-ion	1000–2000
- Li-vanadium oxide aerogel	
- Silicon nanowire Li-ion	

1.11.2 Rechargeable Lithium (Li) Batteries

A Li-ion battery stores electrical energy in a chemical form. Nanoparticles are being developed for metal oxide nanocomposite cathodes because they offer higher density lithium intercalation, excellent electrical conductivity and improved diffusion. For the anode, graphite and metal alloys are used. It offers higher tensile strength to cope with the increase in volume changes during the charging cycle and provides 3x higher energy electrode material.

1.11.3 Supercapacitor

Supercapacitor stores electrical energy directly as charge on sets of electrodes that are separated by an insulator and covered with a thin coating of electrolyte. Since the electrode surface area determines the power density in a supercapacitor, CNTs, nanocrystalline materials, and aerogels are being developed because they have a large surface-to-volume ratio. So far, the developed systems offer capacitive energy storage of up to 200 F/gram.

1.11.4 Solar Cells

Nowadays, 90% of solar cells are made of silicon. Silicon wafers are costly to manufacture and have an efficiency of 14%. However, up to 50% efficiency has been achieved in a lab with multilayered III-V semiconductors (GaAs/InSe/GeTe). These are even more costly than the solar cells that are used in the space satellite systems. To reduce the cost and increase the efficiency, nanotechnology-based solar cells are being developed, such as

- ***Silicon Nanowire Solar Cell —*** This type of cell has not shown very high efficiency, with only a maximum efficiency of 18% so far.
- ***Nanowire Solar Cell*** — This is another nanowire solar cell which is based on indium phosphide (InP) nanowires on the metal electrode of indium tin oxide (ITO); and then the nanowire-electrode platform is covered in the organic polymer, poly(3-hexylthiophene). Once the electron and hole split, the electron travels down the nanowire – the electron superhighway – and merges with the electron-capturing electrode. This rapid shuttling of electrons from the p-n

junction to the electrode may be a more efficient future photovoltaic device.

- ***Organic Dye-Sensitized Solar Cell (DSSC)*** **—** This cell uses a dye molecule to absorb a photon and TiO_2 nanoparticles to capture the electrons. The cost of DSSC is 60% less than the silicon-based solar cells; however, its efficiency is hardly 10%.
- ***Quantum Dot Solar Cell (QDSC)*** — This type of cell is expected to give as high as 86.5% efficiency. In QDSC the absorption can be tuned to any wavelength of visible light by altering its size. Hence, there is a possibility of generating three electrons per photon, as compared to only one for existing silicon-based technologies.

1.12 Nanosensors

It can be noted that almost all developments and research work related to defense applications use sensors in one form or the other; for example, sensing light by photocells, sound by microphones, ground vibrations by seismometers and force using accelerometers. Moreover, there are sensors for sensing magnetic fields, electric fields, radiation, strain, acidity, etc. In our everyday life we also depend on sensors such as metal detectors at airports, malls, hotels, etc., and smoke detectors for building protection. Computers have greatly benefited from the advent of nanotechnology, which has revolutionized computers. Different types of ultrasensitive nano-sized sensors are now being developed for various applications. The use of nanotechnology for developing sensors is focused on (a) *Smaller and ultra-compact sensors* with the help of micro-electromechanical systems (MEMS); these nanosensors have an electronic nose and cantilever molecular sensor. (b) *Smarter devices* are another new mantra of nanotechnology. The nanosensors have built-in "intelligence" which can store and process data on the spot, selecting only the most relevant and critical items to report. (c) *Faster mobility* with the help of today's wireless networking technologies; such sensors can send back data from remote locations or even while they are in traveling mode. In one integrated chip these nanosensors have advantages of function integration by sensing, data processing, storage, wireless communication in a network, multi-parallel analysis for high throughput, matrix arrays for high zeptogram (a zeptogram is 10^{-21} g) sensitivity and directional information. Their production uses less chemical waste, is low cost and has low power consumption. They are capable of of energy scavenging (solar, temperature, mechanical) for continuous power supply. Being very small, they are portable, wearable, point of analysis and self-operating in remote locations and are disposable.

Many sensors have already been developed taking advantage of the unique properties of nanomaterials to become smaller and more sensitive compared to conventional technology. Portable, efficient and highly sensitive infrared thermal sensors will be a very valuable addition to the military such as small, lightweight accelerometers, GPS for motion and position sensing, health monitoring sensors and drug/nutrition delivery systems. Robotic drones are already operated by remote control.

1.12.1 Chemical Nanosensors

Chemical nanosensors are built by using CNT for sensing properties of gaseous molecules and ionization of gaseous molecules, while titanium nanotubes are used to detect atmospheric concentrations of hydrogen at the molecular level.

1.12.2 Mechanical Nanosensors

Mechanical nanosensors work by displacing a nanocantilever, beam or nanowire under the influence of an inertial force, vibration or pressure difference. A change in a system can be measured by capacitive displacement sensors or electronically by using field effect transistors, optically by laser deflection or via surface charge on piezoelectric potential of zinc oxide (ZnO). Forces as small as 10–18 N (N is Newton symbol) 1 $kg \cdot m \cdot s^{-2}$ can be detected. The mechanical sensors currently in use are 3D acceleration sensors, pressure sensors and vibration sensors.

1.12.3 Magnetic Nanosensors

Magnetic nanosensors are fabricated using unique magnetic properties of very small nanoparticles that exhibit quantum properties. These ultrasensitive sensors have a sensitivity of 10^{-9} Tesla.

1.12.4 Radiation Nanosensors

Such sensors are used for sensing electromagnetic radiation. For this purpose, a nano-sized dipole antenna with optical dimensions (50 nm – 100 μm length) connected to a microbolometer matrix array is used. A more sensitive radiation sensor is made by using a quantum well structure. In quantum wells, electrons tunnel through a barrier when activated by external radiation. This has a high signal-to-noise ratio and the presence of many quantum wells on a chip yields a large signal output. It has found applications in infrared and THz radiation.

1.12.5 Portable Miniature X-Ray Nanosensors

These portable nanosensors are fabricated using carbon nanotubes (CNTs). Because CNTs are very effective electron emitters, they are used as electron source to generate X-rays used in portable X-ray detection devices.

1.12.6 Surface-Enhanced Raman Spectroscopy (SERS) Nanosensors

The SERS nanosensors are used for detection of up to parts-per-trillion range of explosives and contraband molecules such as TNT, DNT, RDX, TATP, PETN, DMDNB and cocaine.

1.12.7 Smart Dust Sensors

Smart dust sensors are a very tiny network of sensors that detects data about light, temperatures or vibrations and then transmits it to larger computer systems. However, this technology has not yet reached reality.

1.13 Nanotechnology for Logistics

Technologies for logistics are concerned with how to perfect the security and safety of transported goods and how to improve the speed and efficiency of the logistics chain. This needs automated, unmanned operations for tracking, tracing and identification of security mishaps. Nanotechnology and advanced robotics operations deliver critical payloads and materials to designated sites that may be miles across control system. There will be a need for unmanned ground and aerial vehicles linked to high-precision, multi-platform, and strike capabilities for protecting supplies in transit.

Needless to say, nanotechnology can offer logistics lightweight containers made of nanocomposite polymers that will also be able to absorb shock, reducing the impact of G-forces.

Self-signaling containers made up of smart materials and sensors (chemical, vibrations, heat) to alarm for any deficiencies in display functions are being developed. It is believed that the nano-assemblers will reduce logistics.

1.13.1 Smaller, Faster Nano-Cameras

In 2013, a group of scientists from MIT media Lab (Ramesh Raskar, Kadambi, Refael Whyte, Ayush Bhandari, and Christopher Barsi) and the University of Waikato in New Zealand (Adrian Dorrington and Lee Streeter) were in the news for producing an inexpensive "nano-camera" that can operate at the speed of light. Apart from the use of this device in medical imaging, collision-avoidance detectors for cars, and interactive gaming, its very critical role in defense has also been envisaged. This three-dimensional camera has found use in improving the accuracy of motion tracking and gesture-recognition devices. The camera is based on "time-of - flight" technology, in which the location of objects is calculated by how long it takes a light signal to reflect off a surface and return to the sensor. It can operate in rain, fog and even through a translucent object, so it cannot capture translucent objects in 3D. That is because the light that bounces off the transparent object and the background smear into one pixel on the camera. But according to the inventors, translucent or near-transparent objects can be generated using these 3D models. The "nano-camera" can probe the scene with a continuous-wave signal that oscillates at nanosecond periods; and using light-emitting diodes (LEDs) can strobe at nanosecond periods, i.e., the camera can reach a time resolution within one order of magnitude of femto-photography. Just by changing the code, light paths are unmixed and therefore light moving across the scene is visualized. One of the accomplishments of NASA was to develop a new class of camera using nanotechnology where a photon-plasmon-electron conversion approach demonstrated a new detector imaging that converted photons from an incoming optical signal into surface plasmon waves. The plasmon waves are formed in a 100 nm thick metal film that is bonded to a semiconductor substrate. A slit in the metal film helps to collect plasmon waves, where their energy is focused to produce electron/hole pairs in the semiconductor substrate. The electron/hole pairs generate a measurable electrical signal. Slit orientation is very important here because it helps in producing different polarization signals from the same imaging chip. The imaging chip has different slit sizes and orientation can produce multi-spectral signals.

1.14 Conclusions

For application in military and defense, Nanoscience, Nanoengineering and Nanotechnology will play a significant role. Fundamental knowledge of nanoscale science and engineering is a must for optimization of any process. This chapter presented a brief overview of defense-oriented nanotechnology-based developments. There are many concepts and theoretical possibilities that are still in R&D stages. However, many weapons, structural material, sensors, protective materials, electronics, etc., are already in military use. The progress in nanotechnology in biology and medicine, energy and power generation, information and communication technology has been tremendous. Significant investments are being made worldwide on nanotechnology-based research for military uses. Many nanoproducts already exist and are commercially produced, such as:

- Accelerometers
- Additives in food and cosmetics
- Condition sensors
- Filters
- Lab-on-a-chip systems
- Nanocatalysts
- Nanocomposites (nanoclay and carbon nanotube composites)

- Paints
- Polymers
- Tire pressure sensors
- Wireless sensor networks

The defense organization is gaining a lot of benefit from these nanoproducts and is now incorporating them in defense-related devices. In the future, nanotechnology can offer soldiers better equipment, higher security and safety and effective operational capacities. It will also provide better warships, better advanced weapons and vehicles.

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