

# **APPLICATION OF NANOMATERIALS IN MODERN DAY FIELDS AND SCIENCES**

Literature Review Report

By

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FIELDS AND SCIENCES**

## **CERTIFICATE**

This is to certify that the dissertation entitled “Application Of Nanomaterials In Modern Day Fields And Sciences” is a bonafide work carried out by Ms.Priyanka Vithal Birajdar during the year 202122 under my supervision and guidance in partial fulfilment of the requirement for the award of the degree of Master Of Science in Chemistry at the School of Chemical Sciences, Goa University.

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Dean Of School Of Chemical Sciences,

Goa University.

## **DECLARATION**

I hereby declare that the matter presented in the dissertation report titled “Application Of Nanomaterials In Modern Day Fields And Sciences” was carried out by me during the year 2021-22 under the guidance of Mr. Vishnu Chari. In keeping with the general practice of reporting scientific observations and references, due acknowledgements have been duly gratified.

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I wish to express my hearty thanks to my friends. I am extremely grateful to my parents and my sister for their love, prayers, caring and sacrifices for educating and preparing me for my future.

Priyanka Birajdar.

## **AIMS AND OBJECTIVES**

### **Aim:**

This literature review aims to create a gist of major advancements in the field of nanomaterials and nanotechnology across various applications.

### **Objective:**

1. To find latest major advancements in the field of nanomaterial and nanotechnology.
2. To segregate applications based on their fields.
3. To create an evaluative literature survey report of the found applications.

## **ABSTRACT**

Nanomaterials is an emerging field of study due to the scale of operation and access that other conventional approaches fail to affect or are extremely inefficient and yield poor results. With nanomaterials, it's become possible to achieve targeted results with near zero fidelity rates however, newer nanomaterials are still in the stage of their preliminary evaluations and know-how that makes them bear both immense potential but also have greater risks. This literature review aims to display the major latest applications of nanomaterials in the fields of medical sciences, technology and other areas and how they offer reformed and improved functionality over conventional modes of operations and applications.

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# **CHAPTER 1**

## **INTRODUCTION**

Nanotechnology is an interdisciplinary study which allows us to develop new materials with new, interesting and useful properties. These new materials are nanomaterials made from nanoparticles [1].

Nanoparticles are ultra-small particles with exceptional properties which can direct medicines straight to the place where the human body needs them, they can make materials stronger and they can convert solar energy more efficiently. Nanoparticles possess different properties and behave differently to the classical, larger building blocks of substances.

From a scientific point of view, these interesting new properties are not so much the results from the fact that nanoparticles are small, but they result from the fact that a particle consisting of a relatively limited number of molecules behaves and interacts differently with its surroundings for fundamental physical reasons.

Nanoparticles and nanomaterials have gained prominence in technological advancements due to their adjustable physicochemical characteristics such as melting point, wettability, electrical and thermal conductivity, catalytic activity, light absorption and scattering resulting in enhanced performance over their bulk counterparts. By controlling the shape, size and internal order of the nanostructures, properties (electrical conductivity, color, chemical reactivity, elasticity, etc.) can be modified [2].

## **TYPES OF NANOPARTICLES**

Based on construction, nanomaterials are currently classified as [3]

1. Carbon-based
2. Metal-based
3. Semiconductor
4. Dendrimers
5. Composites

- 1) Carbon-based nanomaterials:

Main component of these nanomaterials is carbon, nanotubes of carbon and fullerenes are related to these nanomaterials. Carbon nanotubes are embedded with graphene sheets that are then rolled into tubes. These are significantly stronger than steel and are viable for use in enhancing structural strength. CNTs are of single-walled type and multi-walled type depending on the need for enhancement.

Fullerenes are hollow cage structure of carbon atoms with 60 or more carbon atoms arranged in a hollow football like structure with pentagonal and hexagonal carbon units organized in regular periodic fashion. These exhibit good electrical conductivity, electron affinity and high strength.

2) Metal-based nanomaterials:

The base materials for these nanomaterials are divalent and trivalent metal ions. Major methods of synthesizing these is chemical and photo-chemical. Using reducing agents metal ions are reduced to metal nanoparticles [4]. Characteristic features of these are high surface area, greater adsorption of smaller molecules. Used in different research areas like bio-imaging and environmental studies. Size control is achievable by mixing of different metals and by adding of different elements, constituents and properties can be varied too.

3) Semiconductor nanomaterials:

These have metallic and non-metallic properties. They possess wide band gaps that can be altered to change properties of the nanomaterial. Majorly these find application in photocatalysis and electronic devices. Graphene and gallium nitride based nanomaterials are evidently finding greater applications in battery and cooling systems of hand-held and portable devices like smartphones and laptops. [4]

4) Dendrimers:

These are branched components that form polymers and whose surface exhibit chain ends are suited for chemical manipulation as tools. Dendrimers are combinable to create hollow cavities or used as part of a catalysis. Dendrimers represent a half step between molecular chemistry and polymer chemistry [5]. The application of dendrimers is through biomedicine with applications as anticancer drugs, pain management, and timed released medications such as a transdermal patch or in gene-therapy.

5) Composite nanomaterials:

Composites are combination of nanoparticles or nanoparticles and other materials [6]. Nanoparticles, such as nanosized clays, are already being added to products ranging from auto parts to packaging materials, to enhance mechanical, thermal, barrier, and flameretardant properties [7].

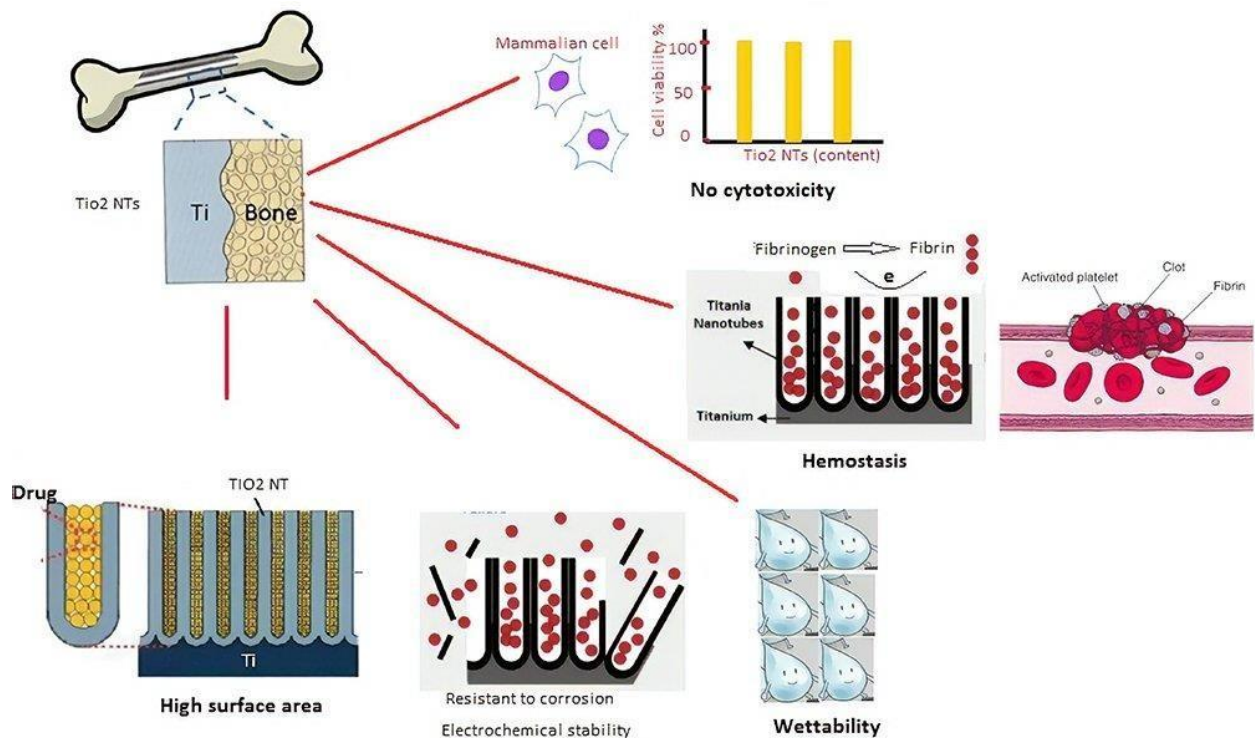
## CHAPTER 2

### **LITERATURE REVIEW**

#### 1) APPLICATION OF NANOMATERIALS IN MEDICAL SCIENCES

##### 1. Tissue engineering:

In the human anatomy, naturally occurring bone tissues have surface irregularities of the range 100nm. However achieving the same in polymer and synthetic implants is challenging but absence of which increases the chances of body rejecting the implant due to the growth of a fibrous layer of tissues that causes loosening of the implants and inflammation in affected area. It was observed that creating nano-sized irregularities on implants, the chances of rejection by body was reduced as well as it causes stimulation of osteoblasts, these are cells that are responsible for growth and repair of bone. The same was observed experimentally by Luke G. Gutwein and Thomas J. Webster [8] using polymeric, metallic and ceramic nanomaterials which showed 90% adhesion rated of human bone cells to the nanomaterial substrate from the suspension.



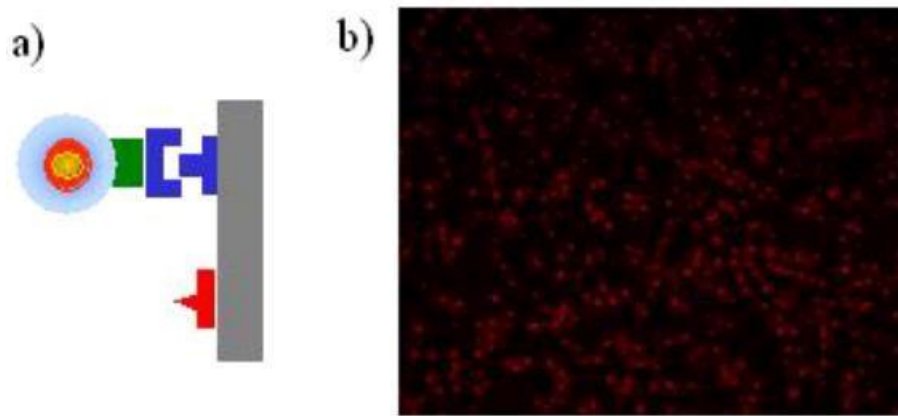
Biomimetic processes have attracted huge attention in recent years due to their significant applications in biomedical areas such as bone tissue engineering. In the present study, a biomimetic process was employed to form a nanocrystallite apatite coating on metal. A thin bone-like apatite layer was coated onto titanium (Ti) metals via an alkali pre-treatment by J Ma, Huifen Wong and team [9]. This was followed by immersion in a simulated body fluid. Analysis of the coating by thin film x-ray diffraction and scanning electron microscope has shown that the apatite layer grown in this way exhibits nanostructure and has similar stoichiometry to that of natural bone. It is observed that the thickness of the apatite layer increases as the immersion period increases. The growth kinetics and mechanism are also discussed. A cross-sectional study has also shown that a uniform coating of carbonate-containing apatite (hydroxyapatite) is firmly adhered on the Ti metal. The adhesion of the apatite layer on the Ti substrate was further confirmed by a shear test, which has shown an average value of 9.5 MPa. The bioactivity of the coating was finally examined by cell culturing experiments. The results have shown that the nanocomposite prepared using the present method possesses good mechanical properties and bioactivity. Real human bone is a composite made of hydroxyapatite crystallites as matrix with collagen fibers giving it immense physical strength but at the same time enough plasticity to withstand mechanical stresses and plastic deformations. A Browstow W [10] and team researched on an artificial hybrid material prepared with 15-18nm ceramic nanoparticles and poly (methyl methacrylate) copolymer and tribology techniques showed that these nanoparticle composites have the ability to showcase healing or recovery feature till a certain degree of abrasion and wear when used in places as implants for bone grafting and teeth replacements.

## 2. Quantum dots as bio-tagging agents:

For researching of proteomics and genomic codes and sequences, the amount of uniqueness offered by biological organic markers is limited. With most techniques reaching saturation due to several million array elements to be represented by a unique combination of bio-markers characterized by unique fluorescence.

Single quantum dots of compound semiconductors were successfully used as replacement of organic dyes in various bio-tagging applications by W.J Parak [11]. Fluorescence labelling of specific compartments in cells is a widely used method in biology to visualize structural units that, due to a lack of contrast or resolution, cannot be distinguished by just recoding an image. The idea is to chemically link a fluorescent dye to receptor molecules that specifically and selectively bind to the desired compartment in the cell. This receptor molecule typically is an antibody against the structure to be labelled. Another very popular receptor is avidin or streptavidin: first, the structure to be labelled is incubated with a biotinylated antibody, which is then recognized by the dye–avidin construct. Often, even more complex labelling schemes involving multiple steps and secondary antibodies are employed. In order to label gene sequences in the nucleus of a cell, oligonucleotide–dye constructs are used (FISH: fluorescence in situ hybridization). In addition to organic fluorophores, fluorescent silica nanospheres are typically used as dyes. Due to their properties, fluorescent semiconductor nanocrystals offer several advantages compared to other dyes and therefore have already been used in labelling experiments. Since all colours of emission can be excited with a single wavelength (preferably UV) and the bandwidth of the emission spectra is narrow, many colours can be used in parallel. In the most pessimistic case, assuming a bandwidth of 40 nm, at least five different colours of emission can be individually distinguished (e.g. 500, 540, 580, 620 and 660 nm) [12]. All of these colours originate from the same type of fluorescent dye: the nanocrystals are identical but for their size. By labelling different sizes of nanocrystals with different antibodies, multicolour staining of several compartments in cells should be possible. So far, only two colours in parallel have been demonstrated, but there is the potential for at least five [13]. Furthermore, compared to many organic dyes, nanocrystals suffer less from photobleaching, which suggests their use for labelling of dynamic processes. In addition, the decay time of the fluorescence of nanocrystals is longer than that of typical organic dyes and,

most importantly, also longer than the decay time of autofluorescence. In this way, using time-gate imaging can reduce the autofluorescence background in fluorescence imaging of cells.



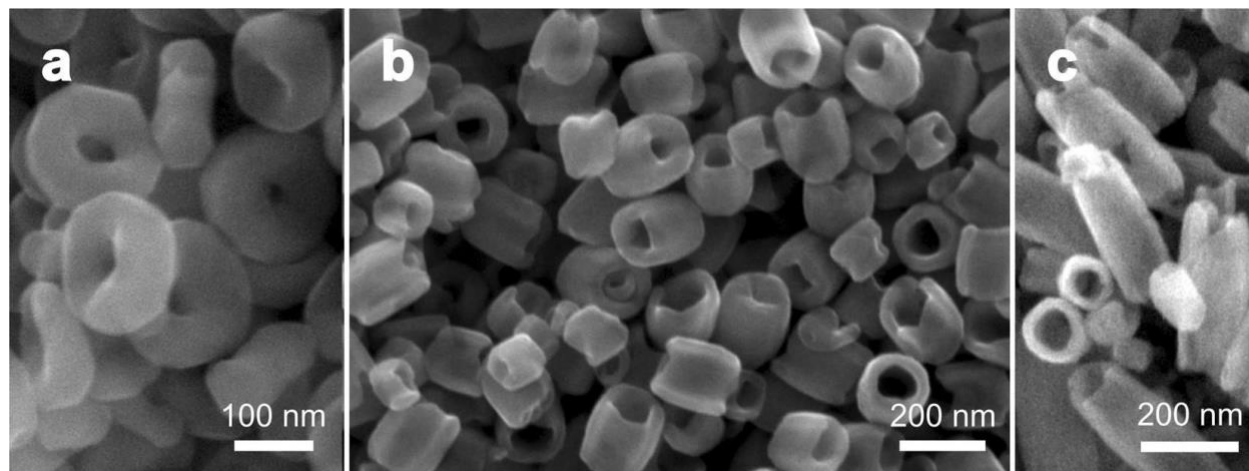
In figure: Fluorescence labelling of cells. (a) A biological molecule is attached to the surface of a silanized CdSe/ZnS nanocrystal. This receptor molecule binds specifically to certain ligand molecules. If a surface bearing several different ligand molecules is exposed to nanocrystals conjugated with receptor molecules, the nanocrystals will be directed to an area of the surface where the receptor and ligand molecules bind in a manner similar to the lock-and-key principle. (b) Staining of nuclear antigens on mouse kidney sections using red fluorescent streptavidin coated CdSe/ZnS nanocrystals that bind to the biotinylated antibodies.

### 3. Nanomaterials for treating cancer:

Hyperthermia is one of the promising approaches in cancer therapy [14]. Various methods are employed in hyperthermia, such as whole body hyperthermia, radiofrequency hyperthermia, and inductive hyperthermia using microwave antenna or implantable needles. However, the inevitable technical problem with hyperthermia is the difficulty of uniform heating of only the tumor region until the required temperature without damaging normal tissue. [15] [16]

Therefore, some researchers have proposed intracellular hyperthermia and developed submicron magnetic particles for hyperthermia. These magnetic particles are easily incorporated into cells and generate heat under an alternating magnetic field by hysteresis loss [17]. Especially, the colloidal magnetic iron oxide is metabolized and excreted from the body, so that they are more ideal materials than the others. We have also developed ‘magnetite cationic liposomes’ (MCLs) for intracellular hyperthermia. MCLs have been developed to improve adsorption and accumulation into the tumor cells and show ten-fold higher affinity for the tumor cells than neutrally charged magnetoliposomes. This is enabled by the electrostatic interaction with the negatively charged cell membrane [18] [19].

The hyperthermic effect of MCLs in in vitro study was examined using small pellets of rat glioma cells. Glioma cells were incubated with MCL-containing medium and were collected as a cell pellet, and then an alternating magnetic field was applied to the cell pellet. The temperature of the cell pellet increased to over 42°C, and no viable cells remained after 40-min irradiation.



## SEM image of iron oxide nanoparticles on various aspect scales.

The synthesis of IOMNPs (Iron oxide magnetic nano-particles) is carried out by polyol mediated synthetic route, as follows: [20]

0.27 g of  $\text{FeCl}_3 \cdot 6\text{H}_2\text{O}$  and a variable amount of NaAc (0–4.8 g) were mixed and dissolved in 40 mL PEG200. The solutions were stirred thoroughly via a magnetic stirrer at 50 °C, 500 rot/min for 30 min, and transferred in a 60 mL round-bottom flask, being part of a home-made stainless steel reaction vessel. Before sealing the reaction vessel using a Teflon gasket and five screws, the solutions were degassed by exposure to a flux of gaseous nitrogen for 5 min. The reaction vessel was introduced into an oven (Nabertherm GmbH, Lilienthal, Germany) equipped with a temperature controller (JUMO dTron 316) that allowed for programming the heating. The solutions were heated from room temperature to 300 °C with a constant heating rate of 3 °C/min and kept at this temperature for 1 h. The vessel was left to cool at room temperature, the excess liquid was discharged, and the obtained black precipitates were washed with ethanol/double distilled water, employing five ultrasonication/magnetic separation cycles to remove the excess ligands and unreacted precursors. The washing cycle consisted of ultrasonication of the black precipitates in 30 mL of ethanol/double distilled water ( $v:v = 1:2$ ) for 15 min followed by magnetic separation using a neodymium magnet. Furthermore, the IOMNPs were coated with citric acid according to a procedure adapted from [21]. Briefly, 20 mg of IOMNPs powder, obtained by drying the black precipitate in a rota-evaporator, was dispersed in a 40 mL aqueous solution of citric acid ( $c = 0.1 \text{ M}$ ). Afterward, the solutions were heated at a temperature of 80 °C for 30 min to ensure the grafting of citric acid molecules on the surface of the IOMNPs. Subsequently, the IOMNPs were magnetically separated and washed with double distilled water and re-dispersed in 5 mL of double-distilled water. Finally, the pH of the IOMNPs solutions ( $c = 4 \text{ mg}_{\text{IOMNPs}}/\text{mL}$ ) was adjusted to 7 with an aqueous solution of  $\text{HNO}_3$  ( $c = 0.01 \text{ M}$ ) for further analysis.

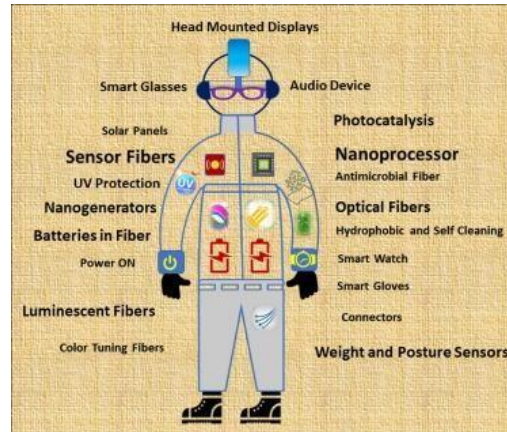


## 2) APPLICATION OF NANOMATERIALS IN NEXT-GEN TEXTILES

### 1. Smart Textiles

Recent years have seen the emergence of so-called ‘smart textiles’ which are derived from the combination of more conventional materials with smart nanomaterials [22]. A smart textile is one which can sense changes in the environment and respond by modifying one or more of its parameters to perform a function. There have been three generations in the development of smart textiles. First generation - or ‘passive’ - smart textiles are those that sense changes in the surroundings but cannot adjust their properties in response [23]. For example, fabrics coated with various metal oxide nanoparticles can produce IR/UV resistant clothes; cotton impregnated with silver nanoparticles has anti-microbial properties. Second generation – or ‘active’ - smart textiles include fabrics which first perceive the changes or stimuli from the environment and then respond accordingly [24]. Examples include thermochromic textiles which respond to changes in temperature by changing colour and shape-memory textiles which can respond to mechanical deformations. Third generation - also called ‘super-smart’ - active textiles are integrated with soft and smart electronics involving sensors, optical gadgets, nano-generators and energy storage devices [25]. For instance, on-body electronics can offer sensing to various pollutants, diseases or threats [26]. Also, attractive optical devices on a smart textile can be supported by nano-generators and energy storage devices.

The incorporation of nanotechnology enables manufacture of smart and multi-functional textiles with many innovative applications in the areas of health, pharmaceuticals [27], fashion, sports, military, advanced protection and transportation. Connection to the ‘internet of things’ offers yet further potential for advanced uses. Fabrication of microelectronic devices is now at a level where they can be combined into textiles and allow the unique capabilities of nanomaterials to be exploited to add high added-value functionality to fabrics and garments while retaining other desirable properties such as comfort, flexibility, lightness and aesthetic appearance [28].

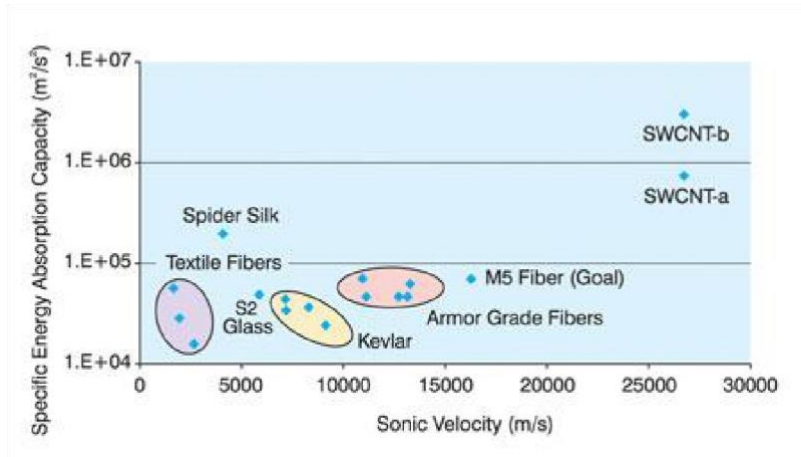


## 2. Ballistics and military gears

The conventional armors and ballistic gears like bulletproof vests and skin shields are made of Sglass, aramids (e.g., Kevlar 29, Kevlar 49, Kevlar 129, Kevlar KM2, Twaron), highly oriented ultra-high molecular weight polyethylene (e.g., Dyneema, Spectra), PBO (e.g., Zylon) which is a p-phenylene-2-6-benzobisoxazole, new polymeric fibers such as Polypyridobisimidazole (PIPD) (referred to as M5) etc [29]. These fibers are characterized by low density, high tensile and compressive strength, high modulus, high rupture strain, resistance to thermal degradation and high-energy absorption capacity. These work by distributing the impact from ammunition hits over a larger surface area by using multiple layers of reinforced thin layers stitched into the fabric of the vest or pad, thereby reducing trauma and damage to the area of impact. However with advancing times ballistics are getting stronger too increasing penetrability of the ammunitions, also the materials used today aren't exactly highly flexible when stacked in increasing layers of protecting films for thickening the outer shell, thus reducing efficiency, mobility and flexibility of on-field soldiers and vets.

Carbon nanotubes and graphene show promising results for application in the next-gen ballistic protection equipment and gears [30] [31].

Carbon nanotube (CNT) is an ideal candidate material for bulletproof vests due to its unique combination of exceptionally high elastic modulus and high yield strain. A Young's modulus of about 1000 GPa, strength ranging between 13-53 GPa, and strain at tensile failure predicted to be as high as ~16% typically characterize SWCNTs<sup>14</sup>. Assuming that the specific gravity of SWCNT is about 1.4 g/cm<sup>3</sup>, one can estimate the ballistic performance parameter to range between 2708 m/s and 4326 m/s. These values are in agreement with the previously reported value of 3000 m/s by Alan Windle for the ballistic performance parameter of carbon nanotubes. If one compares these values with those for other fibers suitable for ballistic applications, the enormous potential of CNTs as a candidate material for bullet-proof armor system is quite evident. [32]

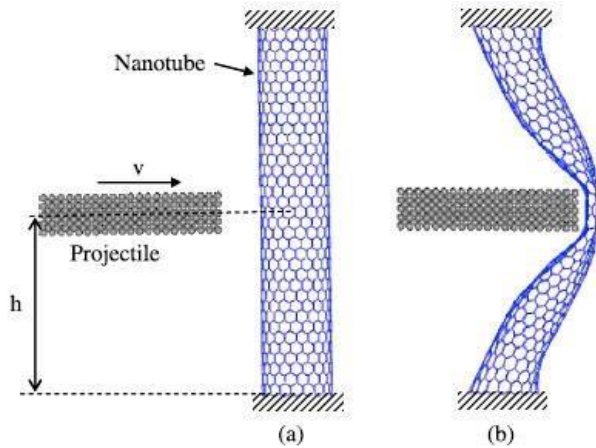


Specific energy absorption capacity as a function of sonic velocity for selected high performance fibers.

There are three different approaches for utilizing carbon nanotubes to enhance the ballistic performance of a body armor [33]. These are:

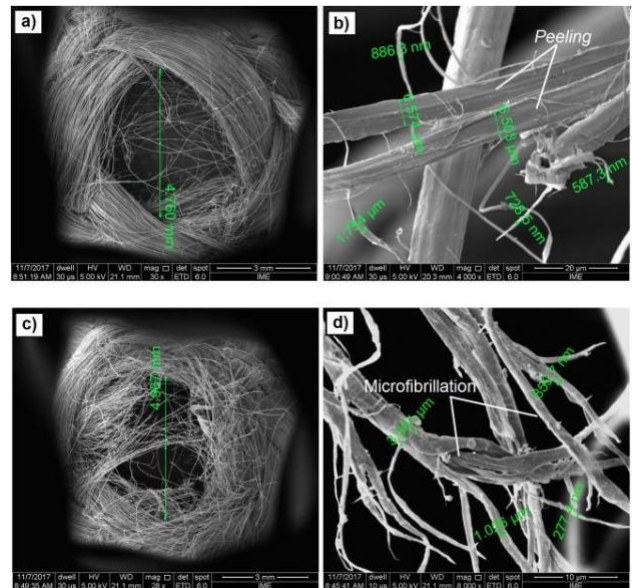
- 1) Incorporation of CNTs into PMCs, metals or ceramics to enhance their hardness or toughness and erosion resistance
- 2) Use of neat or composite fibers of CNTs in the form of woven or non-woven fabric, for achieving exceptional ballistic performance
- 3) Reinforcing the armor grade fibers like Kevlar, UHMWPE or PBO with CNTs to improve their elastic modulus and energy absorption capacity.

Graphene, previously only considered for their use in generation and storage of energy, have been found to showcase remarkable impact distribution features achievable with several inches thinner layer orientation and assembly [34]. This is possible as the nanomaterial has a remarkable surface area and yet seemingly compact arrangement and accessibility to nearby particles in its grid resulting in faster propagation of impact force and thus a more evenly spread area of effect [35]. In combination to aramid fibre ballistic layers, graphene can significantly increase armor durability and reduce penetrability with merely 2 layers of the nanomaterial less than the 1000 times the thickness of standard regular papers [36].



The molecular dynamics model of a carbon nanotube subjected to ballistic impact. (a) Initial model, (b) a deformed nanotube at its maximum energy absorption [37].

SEM fractures of tested ballistically samples with 9 mm ammunition. (a) The cone fracture surface of the Aramid Received sample, (b) “peeling” of the aramid fibers coated (4000×), (c) cone fracture surface in the Aramid + GO (2) and (d) microfibrillation of aramid fibers with GO after the ballistic test (8000×) [38].



### 3) APPLICATION OF NANOTECHNOLOGY IN ELECTRONICS

#### 1. Semiconductors

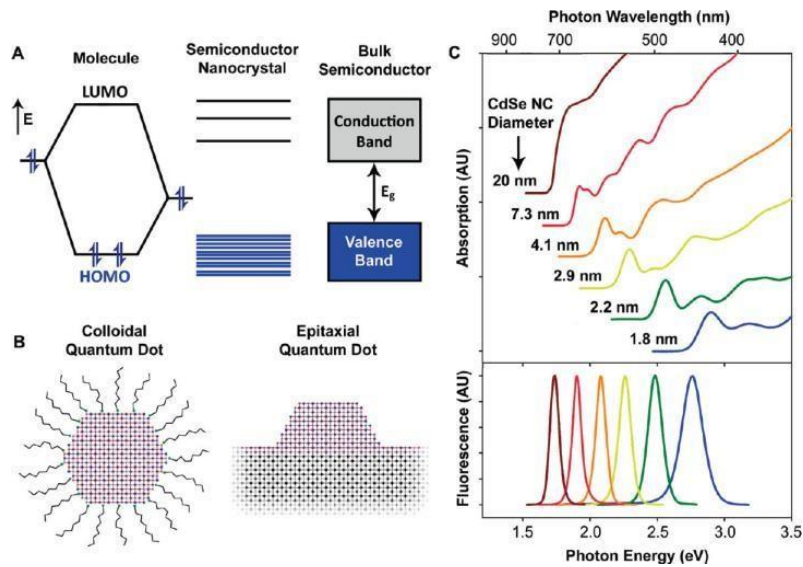
Semiconductor nanoparticles are the newest application in the field of modern micro-processors in latest smartphones or computing systems [39]. What makes them remarkable is that with improving generation of fabrication techniques making them smaller and finer, the tuned energy consumption rate decreases whilst increasing rate of transmission of data in the form of optical or light based data transmission.

Unlike conventional semiconductors, the nanoscale semiconductors don't have a closed pack structure and can be arranged or assembled within a board of conducting media in any orientation as per ease just keeping in mind the bare amount of doping provided to the nanocrystals.

Semiconductor nanocrystals (NCs) are made from a variety of different compounds [40].

They are referred to as II-VI, III-V or IV-VI semiconductor nanocrystals, based on the periodic table groups into which these elements are formed. For example, silicon and germanium are group IV, GaN, GaP, GaAs, InP and InAs are III-V, while those of ZnO, ZnS, CdS, CdSe and CdTe are II-VI semiconductors [41].

Semiconductor nanocrystals are tiny crystalline particles that exhibit size-dependent optical and electronic properties. With typical dimensions in the range of 1-100 nm, these nanocrystals bridge the gap between small molecules and large crystals, displaying discrete electronic transitions reminiscent of isolated atoms and molecules, as well as enabling the exploitation of the useful properties of crystalline materials [42]. Bulk semiconductors are characterized by a composition-dependent band gap energy ( $E_g$ ), which is the minimum energy required to excite an electron from the ground state valence energy band into the vacant conduction energy band. With the absorption of a photon of energy greater than  $E_g$ , the excitation of an electron leaves an orbital hole in the valence band [43]. The negatively charged electron and positively charged hole may be mobilized in the presence of an electric field to yield a current, but their lowest energy state is an electrostatically bound electron-hole pair, known as the exciton. Relaxation of the excited electron back to the valence band annihilates the exciton and may be accompanied by the emission of a photon, a process known as radiative recombination [44].



In Fig. (A) Electronic energy states of a semiconductor in the transition from discrete molecules to nanosized crystals and bulk crystals. Blue shading denotes ground state electron occupation. (B) Comparison of a colloidal quantum dot and an island-like, self-assembled quantum dot epitaxially deposited on a crystalline substrate. (C) Absorption (upper) and fluorescence (lower) spectra of CdSe semiconductor nanocrystals showing quantum confinement and size tunability. AU = arbitrary units [45].

Being able to transmit data in the form of quanta's of energy rather than in the form of varied electrical impulse, this property of the material allows faster networking speeds of data and thus makes modern day chipsets faster and at the same time energy efficient due to use of electronic excitation energy rather than bulk scale phase changing levels of energy as in the case of old-gen transistors and semiconductors [46] [47].

## 2. Component cooling systems.

With compact designs and high power consumption ratios in terms of delivering better performance and faster computational timings [48], modern day handheld devices need to keep up with the battery life as well as component life in-check secure by ensuring proper cooling of these components as higher temperatures relate to sustained damage or degradation of life of the components.

Heat generated in most handheld device components are usually sinked into heat exchanger systems embedded within the body of the devices for example mobile phones with copper coils and PCM or phase change materials & laptop and pocket systems having PCM and cooling array fluids. However the problem lies within the domain of application where cooling systems need to relatively cater to higher amounts of generated heats with reducing component sizes due to bottlenecking of the physically available space in the devices [49].

With Li-ion batteries being the most commonly used material; type in batteries, its effective healthy operating temperature is 2°C - 30°C. Both low temperatures and high temperatures that are outside of this region will lead to degradation of performance and irreversible damages, such as lithium plating and thermal runaway [50]. Similarly, temperature rise in photovoltaic (PV) systems leads to considerable efficiency drop. Studies show that the electrical efficiency of the PV module decreases by 0.5% with every unit degree increment in the temperature of the module above 25°C.

The heat transfer capacity of these coolants can be improved by incorporating solid nanoparticles with high thermal conductivity. Such liquid-solid dispersions are named Nano fluids. Unlike micro solid particles, nanoparticles do not cause clogging, sedimentation, or erosion. Several different Nano fluids are considered promising coolants in battery systems. Water, deionized water, ethylene glycol, synthetic oils, or composites of these materials and PCMs are used as the base material in Nano fluids for battery cooling. Different nanoparticles are incorporated into Nano fluids in the hopes of improving the thermal properties. The most promising nanomaterials include Carbon Nanotubes (CNTs), Al<sub>2</sub>O<sub>3</sub>, Cu, CuO, SiC, ZnO, TiO<sub>2</sub>, and SiO<sub>2</sub>. Carbon nanotubes have especially attracted attention due to their extremely high thermal conductivity of 3500 W/mK. Studies report that the addition of carbon nanotubes to synthetic oil results in a 150% enhancement in the thermal properties of the base fluid. Studies show that Cu nanoparticles dispersed in ethylene glycol can increase the thermal conductivity of the base fluid up to 40%. The thermal conductivity of water increases 10-25% with the inclusion of alumina nanoparticles. Similarly, it is possible to obtain a 20-80% increase in thermal efficiencies with the above-mentioned nanoparticles. It is important to note that the thermal properties of Nano fluids are considerably affected by different parameters [51] [52]. This is why understanding and designing such parameters is important for the development of better battery thermal management systems. Another recent popular approach also suggests use of nanomaterials like GaN for light enhanced heat dissipation in close-bound and compact fine systems like cooling of intricate micro-controller networks and chip-terminals.



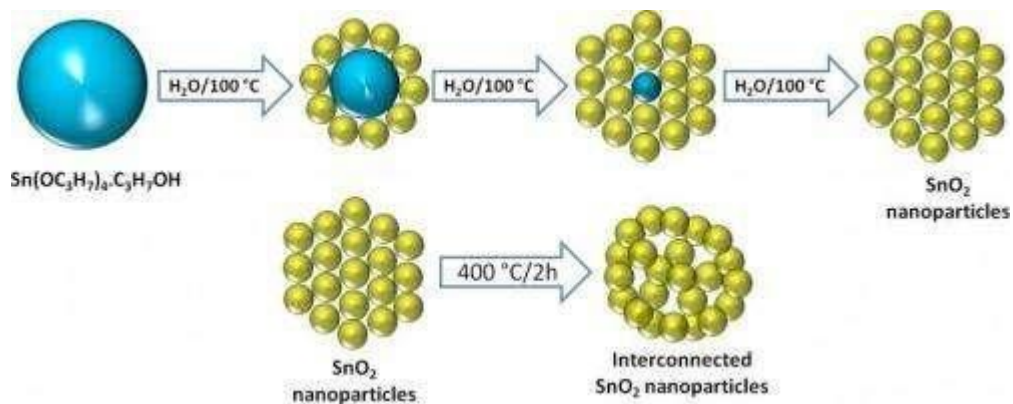




### 3. Battery technologies and applications.

Conventional Li-ion batteries have been using a graphite based anode whose theoretical maximum storage capacity is limited to 372 milliamp hours per gram [54]. The researchers performed experiments with a porous tin oxide based anode which has nearly twice the theoretical charge holding capacity compared to graphite. In the experimentation the tin-oxide anode was charged for 30 mins holding a capacity of 430 milliamp hours per gram ( $\text{mAh g}^{-1}$ ) which is greater than the theoretical maximum capacity for graphite when charged slowly for over 10 hours.

The synthesis of these nanoparticles is straightforward by just adding the alkoxide pre-cursor in boiling water followed by heat treating it at 400 degrees Celsius. The particles arrange themselves in a grid structure with a closed pack network enabling faster charging times and longer energy hold characteristics.



Using a layer of graphene oxide aerogel on conventional Li-ion batteries as electrode, it was seen that dendrite formation on the cells that are caused by running cycles of charge and discharge on batteries which eventually result in loss of charge holding capacity of the cells, was effectively reduced by 70% enabling increase in longevity of the batteries [55] [56].

GaN is also emerging as a major advancement in fast charging technology due to its high charge transference capacity with minimal heat generation due to close pack linear network of the nanoparticle grid arrangement [57] [58]. Charging bricks made of GaN are effectively smaller in footprint but have higher capacity of voltage and amperage output making them an ideal leap towards future device charging solutions [59] [60].

## **CHAPTER 3**

### **CONCLUSION**

With the onset of scale based technologies where approach and efficiency is prioritized, nanomaterials offer functionality and feasibility of providing targeted results with control over finer adjustments based on various applications [61]. Be in the field of medical science [62] or modern day electronics, nanomaterials offer a novel solution to road-blocks in the past like semiconductor sizing, enhanced spectroscopy limits and gene splicing or DNA tagging and modifications [63] [64]. With the degree of tunability, nanomaterials offer limitless potential with benefits like being more targeted and being more energy efficient when compared to conventional methods. Nanomaterials is the direction in which the future of fabrication and controlled synthesis is heading due to its weighed benefits over one disadvantage being its synthesis which can be cumbersome but offers payback on applicative field and result.

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