Nanotechnology and Green Nanotechnology: A Road Map for Sustainable Development, Cleaner Energy and Greener World

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Abstract:-Imagine the chips embedded in the human body reporting every body movement and just waiting to strike at those nasty bacterial invaders, clothing smart enough to monitor out health and save us from environmental hazards, huge buildings and machines having the capability to repair and adjust themselves to the vagaries of the environment, or a regular wristwatch doubling up as a supercomputer. Thanks to nanotechnology, all of these wonders, and many more, are possible. Scientific discoveries and inventions have in fact propelled man to challenge new frontiers. And with his superior brain, man has been able to deliver most of these goodies. Nanotechnology is one such technological wonders that we are experiencing now. Scientists and engineers are working round the clock to achieve breakthroughs that could possibly be the answer to human misery. This paper is mainly about Nanotechnology, its synthesis, characterization and various applications. This also tells about the history of Nanotechnology and its necessity and also discusses how it will improve our lives. This will also explore the less explored field of Green Nanotechnology.

I. INTRODUCTION

“Nanotechnology is an art, the science of manipulating matter at nanoscale”

For millennium, we humans have viewed the world simply by what was readily seen, easily observed, for example: a waterfall, a forest, a rock, the sky above us, and a beach. But as scientific expedition bolstered, so did other ways of perceiving our surroundings. Theories on atoms, molecules and their sub-divisions became established and how we looked at and interfaced with our world changed forever [1]. Today, the scrutiny has delved even deeper to that of the nanometer. A nanometer is one billionth of a meter ($1×10^{-9}$)[2]. To understand just how small that is, let us consider these two examples: The length of a typical bacterium is 200 nm and the diameter of a strand of DNA is a mere 2 nm. Consider this another example to understand the concept clearly: If an average highway lane represents a string of nanometers, it would take more than half a million miles (568, 818 miles) of road to equal just one yard (0.9144 m). In other words, over 22 times around the globe, i.e., more than 2 times the distance from earth to our moon. If you compare the nanoworld to an orange, it would the same as comparing the same orange to earth. The concept of nanoscale can be easily observed in figure 1. By working at this tiny, microscopic scale, researchers are learning how to manipulate matter like never before. In this brave new science of nanotechnology, the increased surface area upon which to work is exponential and that opens up possibilities unimaginable until now.

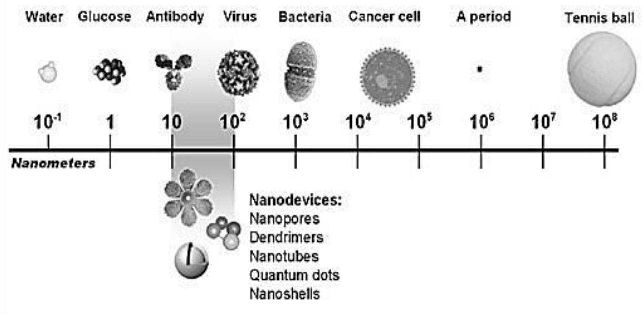

Figure 1: Size of things to understand Nanoscale Concept

When we say exploring this field of nanotechnology, we tend to play around with atoms. When we start playing with atoms, we could land into the world of Quantum Physics. May be we could build a quantum mechanical T-shirt. That sounds weird! Isn’t it? This is of course impossible until you were really small! But over the past few years, scientists have started developing materials with the use of very tiny atoms or group of atoms and so this technology is also known as atom technology. They have successfully developed materials that are capable of turning sunlight into electricity or using nanoparticles to deliver anti-cancer drug or even turning polluted water into potable water. They are even finding new ways to develop glass that doesn’t break when you drop it, batteries that last longer and T-shirts that smell fresher even after you have worn them for few days [3].

Now, why do we bother with these small things when our world is so much larger? Well, it turns out that some big mysteries can be explained by looking at the details on the nanoscale. Take a surface for instance. By manipulating its building blocks, we can give a huge variety of surface properties to the object. We can make it repel water like the lotus flower. We minimize the adhesion on the surface to attain the so-called ‘Lotus effect’. By manipulating the surface in another way, we can copy the structure that the gecko lizard has under its toes, enabling the gecko walk upside down.

When we talk about nanotechnology, we are talking about Physics, Chemistry and Biologyalong with engineering and design at the same time as shown in figure 2. It is a very powerful technology which can create wonders in future. But before we delve into this field, we must answer the 3 basic questions:

- How can it be used for good?
- Could it accidentally cause harm?
- Could it intentionally be used to harm people?

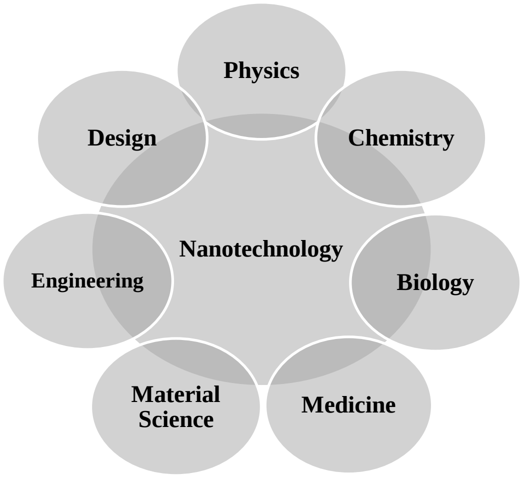

Figure 2: Combination of Various Branches

By and large it depends upon us to decide how much we want nanotechnology abled products in our lives and how do we use them responsibly. Only our imagination can limit where nano will take us. In this chapter, we will venture into this new frontier of nanotechnology and understand its potential power for re-shaping our future by exploring ‘The Science of Small’.

II. HISTORY

Richard P. Feynman, the brilliant and jovial scientist, a former member of the American Atomic Bomb Programme, Manhattan and future Nobel Physics Prize Winner in 1965, gave a lecture entitled ‘Plenty of Room at the Bottom’ on December 29, 1959. In this lecture, Feynman elaborated on the feasibility of manipulating individual atoms. Feynman suggested that the laws of physics as we know them do not prohibit manipulation of matter at the atomic scale.He developed his theory on nanosciences according to which it would one day be possible to organize atoms like bricks which would enable us to write an encyclopaedia on a pin head. The problem was that he didn’t yet have the tools to achieve his vision.

The concept of nanotechnology was further theorized by American Engineer Eric Drexler. In 1986, Drexler wrote a book entitled ‘Engines of Creation-The coming era of nanotechnology’. Drexler explained that our ability to arrange atoms lies at the very foundation of technology. As our physical world is governed by molecular behaviour, the ability to arrange and assemble molecules in the desired order would have an unprecedented effect[4].

The first nanometal containing human artifacts predates modern science by many centuries. Perhaps the oldest object is the Lycurgus chalice from fifth-century Rome, which contains gold nanoparticles [5]. The Maya Blue pigment found in the eleventh-century Chichen Itza ruins owes its colour in part to nanoscopic iron and chromium particles [6]. Many sources credit Johann Kunckel with developing the first systematic procedures for incorporating gold into molten silica, thus producing the well-known ‘ruby glass’ [7].

The term nanotechnology was coined by Norio Taniguchi, Professor of Tokyo University of Science in 1974 to describe semiconductor processes such as thin film deposition and ion beam milling exhibiting characteristic control on the order of a nanometer.Taniguchi wrote, ‘Nanotechnology mainly consists of the processes of separation, consolidation, and deformation of materials by one atom or one molecule’ [8].

III. SYNTHESIS OF NANOPARTICLES

There are basically two general approaches to the synthesis of nanoparticles and the fabrication of nanostructures:

- Bottom-up approach
- Top-down approach

A. Bottom-up Approach.

This approach include the miniaturization of materials components (up to atomic level) with further self-assembly process leading to the formation of nanostructures. During self-assembly, the physical forces operating at nanoscale are used to combine basic units into larger stable structures. Typical examples are quantum dot formation during epitaxial growth and formation of nanoparticles from colloidal dispersion.Here, we start with atoms or molecules and build up to nanostructures. Fabrication is also much less expensive.

B. Top-Down Approach.

This approach use larger (macroscopic) initial structures, which can be externally controlled in the processing of nanostructures. Typical examples are etching through the mask, ball milling, and application of severe plastic deformation. Here, we begin with a pattern generated on a larger scale, then reduce them to nanoscale. By nature, they aren’t cheap and quick to manufacture. It is slow process and is not suitable for large scale production. Figure 3, 4& 5 shows various methods for the preparation of nanoparticles, nanoclusters, nanolayers and nanostructures and its profiling [9].

Growth of colloidal nanocrystals by reduction in the presence of surfactants was studied by Frens, G. in his work on Gold nanocrystals[10]. Synthesis of nanoparticles in reverse micelles was carried out by Shchukin et al. [11]. Work on shape growth over the growth of colloidal nanocrystals was done by Yin et al. [12]. Shaped nanoparticles plays important role due to the noval properties: size and shape dependent, optical, electrical, etc. Several scientists have worked on shaped nanoparticles. Xia et al. worked on shaped control synthesis of gold and silver nanoparticles [13]. Catherine et al. worked on synthesis of cylindrical gold nanorods [14]. Paul et al. contributed in this field by their work on branched nanocrystals [15].

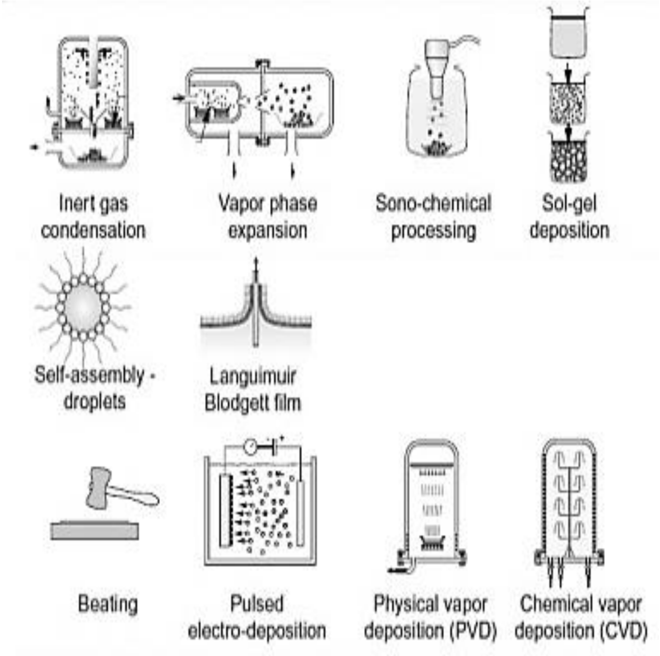

Figure 3: Methods for Making Nanoparticles, Nanoclusters and Nanolayers

New chemical synthesis methods for producing nano-sized iron oxides particles and producing biocompatible polymer coated nanoparticles in the solution has been investigated. A new particle processing device for making high performance nanomaterials as well as their applications in medicine has been developed by applying electrohydraulic technique for nanohomoganization. Magnetite nanoparticles have also been synthesized by chemical precipitation of mixed iron (III) chloride hexahydrate and iron (II) chloride tetrahydrate with iron ions by Kekutia et al. [16]. The Inert Gas Condensation (IGC) process is one of the most known and simplest technique for production of nanoparticles (in particular, Me nanopowders). Decahedral gold nanoparticles were generated from an IGC source using helium and deposited on amorphous carbon film by Koga et al. [17]. Polymer/Silica nanocomposites have wide range of advantages and applications in market. This work has been done by Zou et al. [18].

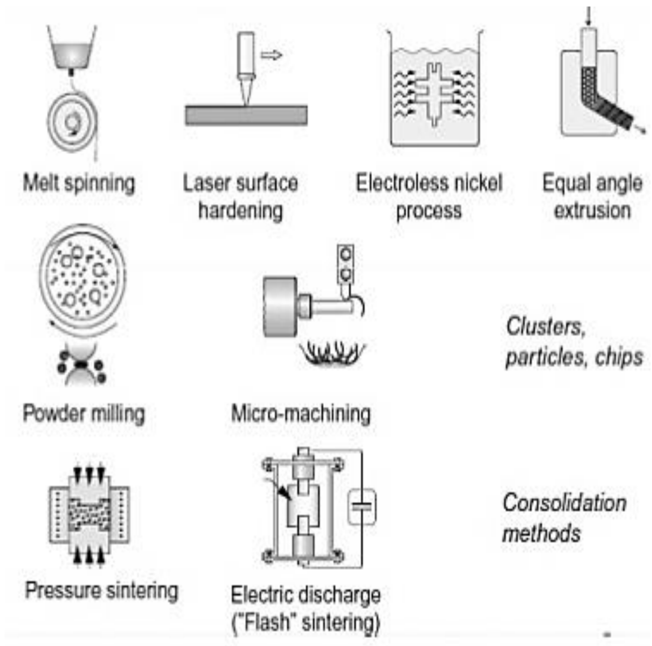

Figure 4: Methods for Making Bulk Nanostructures

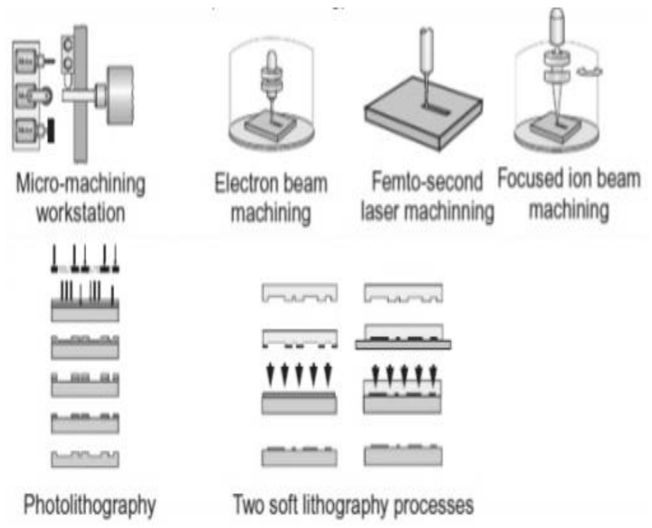

Figure 5: Methods for nanoprofiling

IV. CHARACTERIZATION OF NANOPARTICLES

To understand the potential of nanoparticles, a deeper knowledge of their synthesis and applications is needed. Characterization is done by using a variety of different techniques, mainly drawn from materials science. Figure 6 shows different types of characterization techniques that are used by the researchers all over the world [19]. Developments of measurement and calibration technologies are in practice for particle size, distribution and concentration of manufactured nanoparticles from 1nm to 100nm using practical methods [20]. Technologies statistically analyse the shape and size of manufactured nanoparticles such as carbon nanotubes, fullerenes and titanium oxides in tissue samples from electron microscope images. In addition, some methods are also used to filter capture efficiency of manufactured nanoparticles in air.

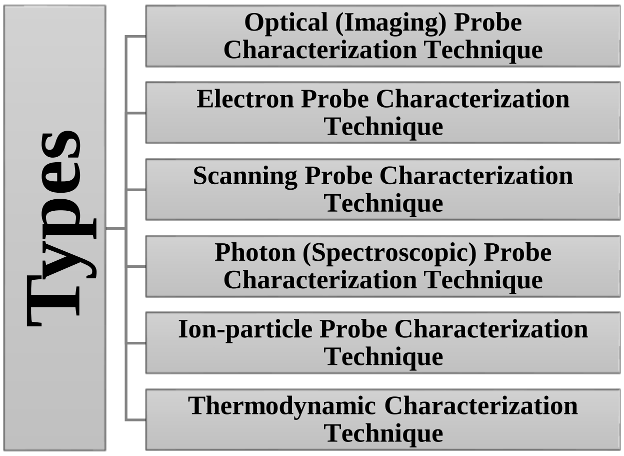

Figure 6: Types of Characterization Techniques

A. *Optical (Imaging) Probe Characterization Techniques*

Acronym	Technique	Utility
CLSM	Confocal Laser Scanning Microscopy	Imaging/Ultrafine morphology
SNOM	Scanning Near-Field Optical Microscopy	Rastered images
2PFM	Two-Photon Fluorescence Microscopy	Fluorophores/ Biological systems
DLS	Dynamic Light Scattering	Particle sizing
BAM	Brewster Angle Microscopy	Gas-liquid interface imaging

Table 1: Different OPCTs

B. *Electron Probe Characterization Techniques*

Acronym	Technique	Utility
SEM	Scanning Electron Microscopy	Raster imaging/ Topology morphology
EPMA	Electron Probe Microanalysis	Particle size/Local chemical analysis
TEM	Transmission Electron Microscopy	Imaging/Particle size-shape
HRTEM	High Resolution Transmission Electron Microscopy	Imaging structure chemical analysis
STEM	Scanning Transmission Electron Microscopy	Biological samples
LEED	Low-Energy Electron Diffraction	Surface/Adsorbate interactions
EELS	Electron Energy Loss Spectroscopy	Inelastic electron interactions
AES	Auger Electron Spectroscopy	Chemical surface analysis

Table 2:Different Epcts

C. *Scanning Probe Characterization Techniques*

Acronym	Technique	Utility
AFM	Atomic Force Microscopy	Topology/Imaging/Surface structure
CFM	Chemical Force Microscopy	Chemical/Surface analysis
MFM	Magnetic Force Microscopy	Magnetic materials analysis
STM	Scanning Tunneling Microscopy	Topology/Imaging/Surface structure
APM	Atomic Probe Microscopy	Three-dimensional imaging
FIM	Field Ion Microscopy	Chemical profiles
APT	Atomic Probe Tomography	Position sensitive lateral location of atoms

Table 3:Different SPCTs

D. Photon (Spectroscopic) Probe Characterization Techniques

Acronym	Technique	Utility
UPS	Ultraviolet Photoemission Spectroscopy	Surface analysis
UVVS	UV-Visible Spectroscopy	Chemical analysis
AAS	Atomic Absorption Spectroscopy	Chemical analysis
ICP	Inductively Coupled Plasma Spectroscopy	Elemental analysis
FS	Fluorescence Spectroscopy	Elemental analysis
LSPR	Localized Surface Plasmon Resonance	Nanosized particle analysis

Table 4: Different PPCTs

E. Ion-particle Probe Characterization Technique

Acronym	Technique	Utility
RBS	Rutherford Back Scattering	Quantitative-qualitative elemental analysis
SANS	Small Angle Neutron Scattering	Surface characterization
NRA	Nuclear Reaction Analysis	Depth profiling of solid thin films
RS	Raman Spectroscopy	Vibration analysis
XRD	X-Ray Diffraction	Crystal structure
EDX	Energy Dispersive X-Ray Spectroscopy	Elemental analysis
SAXS	Small Angle X-Ray Scattering	Surface analysis/Particle sizing (1-100 nm)
CLS	Cathodolumine-cence	Characteristic emission
NMR	Nuclear Magnetic Resonance Spectroscopy	Analysis of odd no. nuclear species

Table 5: Different IPCTs

F. Thermodynamic Characterization Technique

Acronym	Technique	Utility
TGA	Thermal Gravimetric Analysis	Mass loss vs. temperature
DTA	Differential Thermal Analysis	Reaction heats heat capacity
DSC	Differential Scanning Calorimetry	Reaction heats phase changes
NC	Nanocalorimetry	Latent heats of fusion
BET	Brunauer-Emmett-Teller	Surface area analysis
Sears	Sears Method	Colloid size, Specific surface area

Table 6:Different TCTs

Other important techniques of characterization are as follows:

- Nanoparticle Tracking Analysis
- Tilted Laser Microscopy
- Turbidimetry
- Field Flow Fractionation
- Hydrophobic Interaction Chromatography
- Electrophoresis
- Isopycnic Centrifugation
- Zeta Potential Measurements

V. APPLICATIONS OF NANOTECHNOLOGY AND NANOPARTICLES

The 21st Century have been the era of the applications of nanotechnology in commercial products, although most applications are limited to the bulk use of lifeless nanomaterials. Examples include:

- Titanium dioxide and zinc oxide nanoparticles are extensively used in sunscreen, cosmetics and some food products.
- Silver nanoparticles in food packaging, clothing, disinfectants and household appliances such as Silver Nano.
- Cerium oxide as a fuel catalyst.
- Companies have developed nanotech solar cells that can be manufactured at significantly lower cost than conventional solar cells.
- Companies are currently developing batteries using nanomaterials. One such battery will be a good as new after sitting on the shelf for decades.

Nanotechnology is revolutionizing almost all the major technology and industrial sectors: information technology, medicine, homeland security, energy, environmental science and transportation, among many others [21]. By 2016, the global impact of products where nanotechnology plays a key role will be approximately $1 trillion annually, and will require a highly trained workforce of 2 million people. The applications of nanotechnology is shown in table 1.

Apart from various applications of nanotechnology, the major one is quantum dot. It is a relatively mature application of nanotechnology resulting in the quantum-dot laser presently used to read compact disks (CDs). If only one length of a three-dimensional nanostructure is of a nanodimension, the structure is known as a quantum well, and the electronic structure is quite different from the arrangement where two sides are of nanometer length, constituting what is referred to as a quantum wire. A quantum dot has all three dimensions in the monorange.

A single walled carbon nanotubes also have enormous application potential ranging from gas sensors to switching elements in fast computers. However, methods of manufacturing large quantities of the tubes will have to be developed before they will have an impact on technology. One major challenge deals with communication between the nanoworld and the macroworld.

Enhanced catalytic properties of surfaces of nanoceramics or those of nobel metals like platinum and gold are used in the destruction of toxins and other hazardous chemicals [22]. Synthesis and characterization of collagen/hydroxyapatite: magnetite nanocomposite material are very useful for bone cancer treatment [23]. Silver nanoparticles are said to exhibit antimicrobial effects [24]. Arsenic (III) can be removed from groundwater by using different concentration of nanoscale zero-valent iron [25].

Nanoparticles have extensive use in targeted drug delivery. Silver nanoparticles are said to inhibit the binding of the virus to the host cells in vitro [26-27]. Cells and S layer protein nanoparticles of Bacillus sphaericus JG A12 have been found to have special capabilities for the clean-up of uranium contaminated waste water [28]. Magnetosome particles isolated from magnetotactic bacteria have been used as a carrier for the immobilization of bioactive substances such as enzymes, DNA, RNA, and antibodies [29]. The gold nanoparticles synthesized from E. coli may be used for realizing the direct electrochemistry of haemoglobin [30]. Metal nanoparticle embedded paints have been synthesized using vegetable oils and have been found to have good antibacterial activity [31].

Nanoparticles are also used in agrochemicals for enhancement of properties. Nano-encapsulated and solid lipid nanoparticles have been explored for the delivery of agrochemicals [32]. The development of organic-inorganic nanohybrid materials have been done for controlled release of the herbicide 2, 4-dichlorophenoxyacetate [33]. Porous hollow silica nanoparticles, developed for the controlled delivery of the water-soluble pesticide validamycin with a high loading capacity (36 wt.%), have been shown to have a multistaged release pattern [34]. The development of a nano-emulsion (water/poly-oxyethylene) non-ionic surfactant (methyl decanoate) containing the pesticide betacypermethrin has also been carried out [35].

Industry	Applications	Enhanced Properties	Nanoparticle
Polymer Composites	Baseball bats Tennis rackets Motorcycle helmets Automobile bumpers Luggage	Lightweight Stiff Durable Resilient	Al_2O_3 CNT SiO_2 ZnO
Electronics & Information Technology	Eyeglasses Computer displays Camera displays T.V. displays Cell phone displays	Water-repellent Anti-reflective Self-cleaning Resistant to ultraviolet or infrared light Antifog Scratch resistant Electrically conductive	CNT Fluoroacrylate SiO_2 (as matrix) TiO_2
Cosmetics	Sunscreens Cleansers Complexion treatments Creams & Lotions Shampoos Specialized makeup	Greater clarity or coverage Cleansing Absorption Personalization Antioxidant Antimicrobial	ZnO TiO_2
Sustainable Energy	Windmills	Longer Stronger Light weight	SiO_2 embedded in epoxy
Environmental Remediation	Paper Towel CNT scrubber & membrane	Absorption Cleaner environment as CO_2 gets separated from power plant exhaust	TiO_2

Table 7.Few Applications of Nanotechnology

VI. INTRODUCTION TO GREEN NANOTECHNOLOGY

“Green Nanotechnology is about doing things right in the first place & about making green nanoproducts and using nanoproducts in support of sustainability”

Encompassing nanoscale science, engineering and technology, nanotechnology involves imaging, measuring, modeling, and manipulating matter at this length scale. At this level, the physical, chemical, and biological properties of materials differ in fundamental and valuable ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed towards understanding and creating improved materials, devices, and systems that exploit these new properties. It is expected to result in cleaner and less wasteful methods of manufacture, stronger and lighter building materials, smaller yet faster computers, and more powerful ways to detect and treat disease. Nanotechnology promises exciting break through and sustainable future. Use of metal nanoparticles and nanoclay as additives in polymer nanocomposites have been done by many researchers [36].

Green nanotechnology is defined as the technology that is used to develop clean technologies in order to minimize human health and potential environmental risks. It is associated with the use of nanotechnology products and manufacturing process. Green nanotechnology encourages substitution of existing products in order to develop new nanoproducts. Production of new nanoproducts makes the environment friendlier [37].

The term 'technology' refers to the application of knowledge for practical purposes. The field of 'green nanotechnology' encompasses a continuously evolving group of methods and materials, from techniques for generating energy to non-toxic cleaning products [38]. The present expectation is that this field will bring innovation and changes in daily life of similar magnitude to the 'information technology' explosion over the last two decades [39]. In these early stages, it is impossible to predict what 'green nanotechnology' may eventually encompass.

VII. AIM OF GREEN NANOTECHNOLOGY

The ultimate aim of the Green nanotechnology is to create technologies enabling the production of nano-pigments in significantly more environmentally friendly ways using significantly more sustainable raw materials, in comparison with existing production technologies.

In order to achieve such an aim, the green nanotechnology must intend to achieve the following objectives:

- Preparation of nano-pigments based on the use of nano-clays and selected natural and synthetic dyes [40].
- Surface treatment technologies for nano-clays for improved fixation of dye molecules.
- Surface treatment technologies for coloured nano-clays for improved light-fastness, weather-resistance, fatigue cycle and dispersibility.
- Applicability of the greener nano-pigments in printing inks, paints and coatings [41].
- Applicability of the greener nano-pigments in photovoltaic devices.
- Evaluation of the environmental impacts of the greener nano-pigments.
- Commercial exploitation and dissemination of greener nano-pigments.

Green Nanotechnology, green chemistry and green engineering are inter-related terms. Enhancing the properties of one will automatically improvise the other two. Without green chemistry, one cannot think of achieving goals of green nanotechnology.

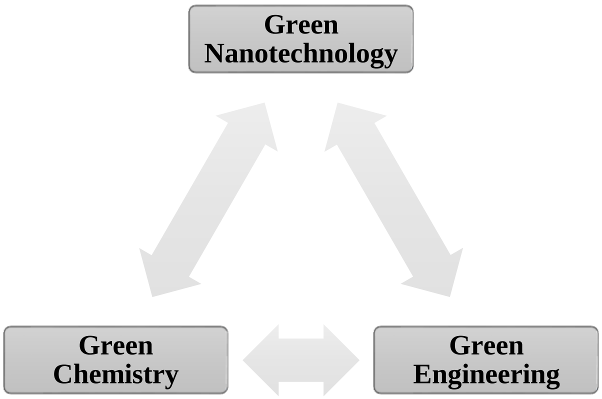

Figure 7:Interrelated terms-Green Nanotechnology, Chemistry & Engineering

VIII. TWELVE PRINCIPLES OF GREEN CHEMISTRY

Developed by Paul Anastas and John Warner, the following list outlines an early conception of what would make a greener chemical, process, or product [42].

- It is better to prevent waste than to treat or clean up waste after it has been created.
- Synthetic methods should be designed to maximize the incorporation of all materials used in the process into the final product.
- Wherever practicable, synthetic methods should be designed to use and generate substances that possess little or no toxicity to human health and the environment.
- Chemical products should be designed to affect their desired function while minimizing their toxicity.
- The use of auxiliary substances (e.g., solvents, separation agents, etc.) should be made unnecessary wherever possible and innocuous when used.
- Energy requirements of chemical processes should be recognized for their environmental and economic impacts and should be minimized. If possible, synthetic methods should be conducted at ambient temperature and pressure.
- A raw material or feedstock should be renewable rather than depleting whenever technically and economically practicable.
- Unnecessary derivatization (use of blocking groups, protection/deprotection, temporary modification of physical/chemical processes) should be minimized or avoided if possible, because such steps require additional reagents and can generate waste.
- Catalytic reagents (as selective as possible) are superior to stoichiometric reagents.
- Chemical products should be designed so that at the end of their function they break down into innocuous degradation products and do not persist in the environment.

- Analytical methodologies need to be further developed to allow for real-time, in-process monitoring and control prior to the formation of hazardous substances.
- Substances and the form of a substance used in a chemical process should be chosen to minimize the potential for chemical accidents, including releases, explosions, and fires.

IX. CONCLUSIONS

In summary, this brief review provides synthesis, characterization, applications of nanotechnology in current scenario. In particular, top-up approach and bottom-down approach were discussed. The understanding of green nanotechnology has significantly reduced the burden on future generations. Given that nanotechnology plays an important role in the development of novel polymeric materials, the next generation of the advanced materials will further utilize nanotechnology to improve the properties of the advanced materials. Overall, this review emphasizes the contribution of nanotechnology and green nanotechnology in modern functionalized advanced/smart materials.

Conflicts of Interest

The authors declare that there are no conflicts of interest regarding the publication of this paper.

Authors' Contributions

Both authors contribute to the manuscript equally. Neelam Jain contribute to intellectual discussions of the topics and review of the manuscript.

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