

# Nanomaterials and its use in Nanotechnology: A Short Review

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**Abstract:** Nanotechnology is science, engineering, and technology conducted at the nanoscale, which is about 1 to 100 nanometers. Many technical and industry sectors are benefiting from nanotechnology, including information technology, energy, environmental science, medicine, homeland security, food safety, and transportation, to name a few. Nanotechnology today takes advantage of recent advances in chemistry, physics, materials science, and biotechnology to generate novel materials with unique properties due to their nanometer-scale structures. The numerous applications of nanotechnology in recent decades are summarized in this text.

**Keywords:** Nanotechnology, Nanomaterials, Electronics, Agriculture, Food processing

**Introduction:** The use of materials on an atomic, molecular, and supramolecular scale for industrial purposes is known as nanotechnology. The first widespread definition of Nanotechnology pertained to the specific technical goal of precisely manipulating atoms and molecules for the fabrication of macroscale products, also known as molecular nanotechnology. The National Nanotechnology Initiative, which defined Nanotechnology as the manipulation of matter having at least one dimension sized from 1 to 100 nanometres, later came up with a more generalised

definition. This definition evolved from a specific technological goal to a research category that encompasses all forms of study and technologies that deal with the unique properties of matter that occur below a certain size threshold. The concept of seeding nanotechnology was initially mentioned by renowned physicist Richard Feynman in his talk "There's plenty of room at the Bottom." [1] But something as small as an atom is impossible to see with the naked eye. In fact, it's impossible to see with the microscopes typically used in a high school science classes. In the early 1980s, the microscopic scopes required to

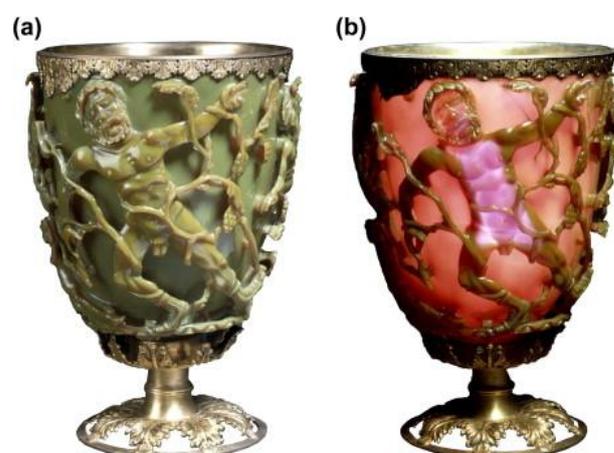
see things at the nanoscale were developed. The age of nanotechnology began when scientists had the necessary tools, such as the scanning tunnelling microscope (STM) and the atomic force microscope (AFM). Nanotechnology's application in food science will have an impact on the most critical areas of food production, from food safety to the molecular synthesis of novel food products and components [2]. Nanotechnology is predicted to help with the creation of genetically modified crops, livestock and fisheries input, chemical pesticides, and precision farming approaches in the future. Nanotechnology is already being employed in a variety of new types of batteries that are less flammable, charge faster, are more efficient, are lighter, have a greater power density, and maintain an electrical charge for longer [3-5]. Various Nano science-based possibilities for converting waste heat in computers, automobiles, residences, and power plants to useful electrical power are being researched [6].

Researchers are creating thin-film solar electric panels that can be fitted onto computer cases and flexible piezoelectric nanowires woven into garments to generate usable energy on-the-go from light, friction, and/or body heat in order to power mobile electronic devices. Through

rapid, low-cost identification of pollutants in water, as well as filtration and purification, nanotechnology could assist address the demand for affordable, safe drinking water [7].

### **History of Nanoparticles and Nanotechnology:**

The Romans, in the 4th century AD, were the first to utilise nanoparticles and their structures. Their application exemplifies one of the most fascinating examples of nanotechnology in the ancient world. The Lycurgus cup, from the British Museum's collection, exemplifies one of the ancient glass industry's most notable achievements. It is the most well-known example of Dichromic glass. Dichroic glass refers to two forms of glass that change colour in different lighting conditions. When light falls directly on the glass, it appears green, and when light shines through it, it appears red-purple [8].



**Fig. 1:** The Lycurgus cup. The glass appears green in reflected light (A) and red-purple in transmitted light (B) [8].

To explain the phenomenon of Dichroism, scientists used a transmission electron microscopic (TEM) analysis of the cup in 1990. The presence of nanoparticles with diameters of 50–100 nm causes the observed phenomena Dichroism (two colours). X-ray examination revealed that these nanoparticles are silver-gold (Ag-Au) alloys with an Ag: Au ratio of around 7:3 and around 10% copper (Cu) scattered in a glass matrix [9]. As a result of light absorption (520 nm), the Au nanoparticles produce a red colour [10]. The red-purple colour is caused by larger particles absorption, while the green colour is caused by light scattering by colloidal dispersions of Ag nanoparticles larger than 40 nm. Due to the incorporation of Au and Ag nanoparticles into the glass, late Medieval church windows shine with a luminescent red and yellow hue [11]. More than 4000 years ago, the Ancient Egyptians used NMs for hair dye, relying on a synthetic chemical technique to produce 5 nm diameter PbS NPs [12]. Similarly, "Egyptian blue" was the first synthetic pigment created and utilised by Egyptians in the 3rd century BC [13] using a sintered blend of nanometres-sized glass and quartz. Egyptian blue is made up of a

complex combination of  $\text{CaCuSi}_4\text{O}_{10}$  and  $\text{SiO}_2$  (both glass and quartz). During archaeological excavations in ancient Roman Empire geographical regions such as Egypt, Mesopotamia, and Greece, the extensive use of Egyptian blue for decorative purposes has been observed. Red glass tinted by surface Plasmon excitation of Cu NPs has been discovered at Frattesina di Rovigo (Italy) originating from the late Bronze Age (1200-1000 BC) [14]. Similarly, it has been found that Celtic red enamels from the 400-100 BC period contain Cu NPs and cuprous oxide (cuprite  $\text{Cu}_2\text{O}$ ) [15]. Furthermore, clay minerals with a nanometer-thickness are the best evidence of natural nanomaterials use since antiquity. Clay was reportedly used to bleach wools and clothing in Cyprus as early as 5000 BC [16] Michael Faraday published the synthesis of a colloidal Au NP solution in 1857, which was the first scientific description of nanoparticle manufacture and began the scientific history of NMs. He also discovered that the optical properties of Au colloids are different from those of their bulk counterparts. This was most likely one of the first papers to notice and characterise quantum scale effects. Mie (1908) later revealed the explanation for metal colloids' distinct colours [17].  $\text{SiO}_2$  NPs were developed in the 1940s as a carbon black alternative for rubber

reinforcement [18]. Today's manufactured NMs can significantly improve the strength, conductivity, durability, and lightness of bulk materials, as well as provide useful properties (e.g., self-healing, self-cleaning, anti-freezing, and antibacterial) and serve as reinforcing materials for construction or safety sensing components. Samsung debuted Silver Nano™, an antibacterial technology that uses ionic Ag NPs, in their washing machines, air conditioners, refrigerators, air purifiers, and vacuum cleaners in 2003. NPs and NSMs are widely employed in the automotive industry, including as fillers in tyres to increase road traction, fillers in automobile bodies to improve stiffness, and clear layers for heated, mist-free glass panes [19]. Mercedes-Benz began mass production of an NP-based clear coat for both metallic and non-metallic paint finishes by the end of 2003. Scratch resistance and gloss are also improved by the coating. TiO<sub>2</sub> NPs are commercially available in dye-sensitized solar cells [20].

### **Classification of Nanomaterials:**

The majority of contemporary NPs fall into one of four material-based categories.

#### **(i) Carbon-based nanomaterials:**

These NMs are generally carbon-based and come in morphologies such hollow

tubes, ellipsoids, and spheres. The carbon-based NMs group includes fullerenes (C<sub>60</sub>), carbon nanotubes (CNTs), carbon nanofibers, carbon black, graphene (Gr), and carbon onions. The main production processes for these carbon-based compounds include laser ablation, arc discharge, and chemical vapour deposition (CVD) (except carbon black) [21].

#### **(ii) Inorganic-based nanomaterials:**

Metal and metal oxide NPs, as well as Nano semiconductors, are among these NMs. Metals like Au or Ag NPs, metal oxides like TiO<sub>2</sub> and ZnO NPs, and semiconductors like silicon and ceramics can all be made from these NMs.

#### **(iii) Organic-based nanomaterials:**

These are NMs made mostly of organic stuff, as opposed to carbon- or inorganic-based NMs. Organic NMs can be transformed into desired structures such as dendrimers, micelles, liposomes, and polymer NPs by using noncovalent (weak) interactions for self-assembly and design.

#### **(iv) Composite-based nanomaterials:**

Composite NMs are multiphase NPs and NSMs with one nanoscale dimension that can mix NPs with other NPs or NPs with bigger or bulk-type materials (e.g., hybrid nanofibers) or more sophisticated

structures, such as metal-organic frameworks. Any combination of carbon-based, metal-based, or organic-based NMs with metal, ceramic, or polymer bulk materials can be used in the composites.

### **Classification of nanomaterials based on their dimensions:**

The nanoscale manufacture of conventional products is currently assisting and will continue to assist multiple countries' economic prosperity. Many different forms of NPs and NSMs have been identified, and many more are expected to emerge in the future. As a result, the time has come for them to be classified. Gleiter et al. [22] were the first to propose NM categorization. The crystalline shapes and chemical makeup of NMs were used to classify them. The Gleiter approach, however, was incomplete because the dimensionality of the NPs and NSMs was not taken into account [23]. The categorization value of NMs is determined by the ability to predict their properties. Gleiter's classification notion of "grain boundary engineering" states that the properties of NMs are greatly influenced by grain borders. As a result, grain boundary engineering will increase the classical inner size effects, such as melting point lowering and diffusion amplification. According to

Pokropivny and Skorokhod's categorization, the features of NMs are assigned to particle form and dimensionality, as per the "surface engineering" idea, and thus the NMs are classified. To broaden the use of NSMs, these explanations focus on particle shape and dimensionality engineering, as well as grain boundary engineering [23].

### **Classification of nanomaterials based on their origin:**

NPs and NSMs can be classed as natural or synthetic depending on their origin, in addition to dimension and material classifications.

Natural nanomaterials are created by biological species or manmade activity in nature. Natural resources can be used to create artificial surfaces with unique micro and nanoscale templates and features for technological applications. NMs exist naturally in all of the Earth's spheres (i.e., the hydrosphere, atmosphere, lithosphere, and even the biosphere), regardless of human actions. The atmosphere, which includes the entire troposphere, the hydrosphere, which includes oceans, lakes, rivers, groundwater, and hydrothermal vents, the lithosphere, which includes rocks, soils, magma, or lava at various stages of evolution, and the biosphere, which includes microorganisms and higher

organisms, including humans, are all made up of naturally occurring NMs [24-25].

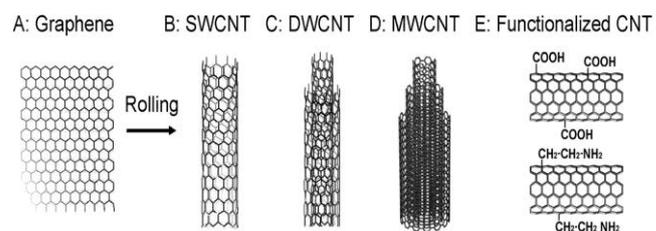
Mechanical grinding, engine exhaust, and smoke, as well as physical, chemical, biological, and hybrid processes, are used to create synthetic (designed) nanomaterials. As the manufacture and subsequent release of engineered NMs, as well as their use in consumer products and industrial applications, has expanded, the subject of risk assessment methodologies has arisen. These risk assessment methodologies are extremely useful for predicting the behaviour and fate of manufactured NMs in a variety of environments. The main question with designed NMs is whether existing information is sufficient to predict their behaviour or if they behave differently from natural NMs in relation to their surroundings. Engineered NMs are now produced using a variety of sources connected to possible applications [26].

### Nanomaterials and its use in Nanotechnology in the field of Electronics:

Electronics is a major industry in which nanotechnology is widely employed, from capacitors to transistors, with dimensions of only a few nanometres. To put this into perspective, one nanometre is equal to one billionth of a metre. There is a proper

terminology for the use of nanotechnology in electronic components, which is called 'Nano electronics,' and to understand the use of nanotechnology in electronic components, we must first understand the very basic part of these Nano devices, which are called nanoparticles or nanomaterials. "Carbon nanotubes" and "quantum dots" are two of the most commonly studied nanomaterials in electronics. So let's take a closer look at these nanomaterials:

#### 1. Carbon Nanotubes:



**Fig. 2:** Carbon Nanotubes [27]

Carbon nanotubes frequently inquire about single-wall carbon nanotubes with sizes in the nanometres range. Single-wall carbon nanotubes are a kind of carbon that falls somewhere between fullerene cages and flat graphene. Single-wall carbon nanotubes are often idealised as cutouts from a two-dimensional hexagonal lattice of carbon atoms rolled up along one of the space lattice vectors of the hexagonal lattice to produce a hollow cylinder, even though they are not made. Double-walled carbon nanotubes (DWCNT) are made up

of two layers, whereas multi-walled carbon nanotubes (MWCNT) are made up of several layers (Figure 2). Carbon nanotubes have a variety of physical and chemical properties (e.g., conductivity, tensile strength, flexibility, and chemical reactivity) as well as physical and chemical characteristics (e.g., length to diameter ratios, atomic configuration, impurities, defects, and functionalization) [28]. Impurities may contain a variety of carbon allotropes (e.g., graphite, soot, amorphous carbon, and various CNT types) as well as a variety of transition and heavy metal catalyst nanoparticles (usually Fe, Ni, Co, Au, and Pb as well as Al as the catalyst substrate). The metal impurities in the CNT side walls and tube voids could be related material or embedded metal or metal oxide particles.

## 2. Quantum Dots:

Quantum dots are semiconductor nanocrystals with unique optical and electrical properties that are 3-15 nm in size. A quantum dot is made up of a metalloid crystalline core and a 'cap' or 'shell' that protects the core. Metal conductors such as semiconductors, noble metals, and magnetic transition metals are frequently used to make quantum dot cores. The shells are also made up of a variety of materials. As a result, not all

quantum dots are the same, and they cannot be considered a consistent group of medications. So, now that we've grasped the fundamentals of a Nano device, we're ready to dive into the applications of nanotechnology in electronics. Let's look at the application and use of nanomaterials and nanotechnology in electronics, specifically the use of nanomaterials in the fabrication of Nano devices for use in electronics.

## 3. Spintronic:

The demand for spintronic products has surged, which is very evident from the above chart. Spintronics take into account together of the foremost important emerging research areas with an immense potential to supply high speed, low power and high density logic and memory electronic devices, and low threshold current and high-power lasers (optoelectronic devices) as a source for circularly polarized light. Some of the very important spintronic devices are spin valves, spin current amplifiers, spin capacitors, spin-based integrated circuits, spin LEDs and spin lasers.

## 4. Optoelectronics:

Electronic devices that source, detect and

control light – i.e. optoelectronic devices – are available many shapes and forms. Highly energy-efficient (less heat generation and power consumption) optical communications are increasingly important because they need the potential to unravel one among the most important problems of our information age: energy consumption. In the field of nanotechnology, materials like nanofibers and carbon nanotubes are used and particularly graphene has shown exciting potential for optoelectronic devices.

#### **5. Wearable flexible electronics:**

Smart watches, fitness trackers, smart garments, smart medical attachments, data gloves – the marketplace for wearable electronics is quickly evolving beyond health care, fitness and wellness into infotainments, and commercial and industrial applications. This all would have not been possible if nanotechnology didn't play its part. Wearable electronics consists of several areas: sensors, actuators, electronics and power supply or generation. Whereas the primary generation consisted mostly of detachable components, the second generation is moving towards textile-embedded sensors, actuators, and therapeutic solutions.

#### **6. Display:**

It all started with the invention of CRT (cathode ray tube), which has a single electron gun to scan back and forth across and down the screen to selectively illuminate a phosphor coated screen. But as we can observe it ourselves, displays with CRT has been completely replaced by LCD which indeed is going to be replaced by FED, electronic paper, electrochromatic screens and carbon nanotube screens. Field Emission Displays (FED) and nanotube screens are high-definition colour displays with screen like vibrant colour, rich contrast and fast response – but they're flat. These screens actually work similarly to a standard screen. In nanotube screens the metal pint based electron arrays of FEDs are replaced with a self-assembled array of carbon nanotubes. The tips of every of these emitters is merely 3 nanometers in diameter. Electrochromatic screens are composed of a sandwich of layers. The outer layers are glass and therefore the inner layer's electrodes, ion storage layers and therefore the electrochromatic layer. Applying electricity moves electrons from the ion layers into the electrochromatic layer changing its colour or from clear to dark.

#### **7. Fuel cells and photovoltaic cells:**

Nanotechnology  
has made a major breakthrough in phot-

electrochemical cells by replacing of bulk semiconductor materials with nano-crystalline films. Nano-crystalline films are made of nano-particles ranging in size between 7 and 10 nm in diameter, with a high surface roughness, thereby providing a greater surface area, and facilitating the injection of electrons and reduction reactions. Furthermore, these nano-crystalline films are also mesoporous, which further increases the surface area, thus allowing the maximum possible area to absorb the sensitizing dye. Nanotechnology has enhanced harvesting from photons through the embedding of nanoparticles (400 nm in diameter) within the electrode material. We have therefore achieved very high efficiency of solar panels with efficiencies going up to 25%.

### **Nanotechnology in Human health:**

In the subject of nanotechnology, there have been rapid breakthroughs recently. A nanoparticle (or Nano powder) is a microscopic particle having a diameter of less than 100 nanometers. Due to a wide range of potential applications in biomedical, optical, and electronic sectors, nanoparticle research is currently a hot topic in science. The ability to work at these levels to build nanostructures with fundamentally different molecular

organization is the essence of nanotechnology. Ceramics, polymer composites, filler materials, pigments, electronics, catalysts, and many other applications require finely dispersed nanostructures or nanoparticles.

### **1. Nano-medicine:**

The medical application of nanotechnology is known as Nano medicine. It includes topics like nanoparticle drug delivery and potential future applications of molecular nanotechnology (MNT) and nano-vaccinology. Current nano-medicine challenges include gaining a better knowledge of concerns such as toxicity and environmental impact of materials. In the not-too-distant future, advances in nano-medicine will provide a beneficial set of research tools and clinically useful technologies. Nano medicine sales reached 6.8 billion dollars in 2004, and Nanobiotechnology: A New Science for Human Welfare 23 over 200 companies and 38 products worldwide, a minimum of 3.8 billion dollars is invested in nanotechnology R&D each year.

### **2. Nano-capsules:**

The word nano-capsule refers to a sandy nano-particle made up of a shell and a space where desired components can be

put. Antibodies or cell-surface receptors that attach to cancer or other cells and release their biological compound when they come into contact with that tissue can be used to cover drug-filled nano-capsules. Nano-capsules are also one of the few ways to get medications through the blood-brain barrier for the treatment of disorders affecting the eyes, brain, and other parts of the central nervous system. Similar capsules termed liposomes (literally, fat bodies) are utilized to transport substances inside the cells. Nano-capsules can be made directly from monomers or through nano-deposition of pre-formed polymers.

### **3. Nanotechnology in Oncology and Surgery:**

When exposed to UV light, cadmium and selenide nanoparticles glow. When injected into tumors, they aid in the identification and spotting of tumors in preparation for surgery. Sensible test chips with thousands of nanowires can identify proteins and other biomarkers left behind by cancer cells, potentially allowing the detection and diagnosis of cancer in its early stages with just a few drops of blood. Nano-particles can be utilized to mend broken arteries, making it easier for surgeons to close deep and complicated wounds.

### **4. Nanotechnology in Neurology and Orthopedics:**

Nanoparticles have been used to interpret the actions of the human nervous system. Arthrobotics is the use of robotic technology to assist orthopedists in the healing, repair, and replacement of joint-related conditions. Arthroscopic surgery is a minimally invasive method of seeing and performing surgery on joints. The arthroscope is a fiber-optic tool that is introduced through a small incision and allows for remote viewing of the joint through an eyepiece or on a computer screen. Current arthrobotics applications include arthroscopic automation and place upgrades, such as automated arthroscope motion, position sensors to guide it, and force sensors for tissue proximity control. Future arthrobotic applications could include complete joint replacement with bionic bionics and neuro-computer interfaces for limb control based on neural impulses in the brain.

### **Nanotechnology in Agriculture:**

Nanotechnology has been utilized to change the genetic architecture of crop plants, allowing for their enhancement. Nanotechnology may have applications in agronomic activities, with a focus on important features, difficult issues, and research needs for professional risk

assessment and management in this rapidly evolving industry [29].

1. Single molecule detection for various substrate based enzymes.
2. Nano-capsules for spreading pesticides and insecticides more efficiently.
3. Nanosensors for monitoring soil conditions
4. Nanosensors for detecting animal and plant pathogens in soil.
5. Nanocapsules to deliver vaccines.
6. Nanoparticles used in genetic engineering.

### **Nanotechnology in Food Processing:**

Nanotechnology has been dubbed the "next industrial revolution," and both industrialized and developing countries are investing in it in order to gain a competitive advantage. Integration of nutraceuticals, gelation and viscosifying agents, nutrient propagation, mineral and vitamin fortification, and nano-encapsulation of tastes are some of the food processing methods that use nanomaterials [30]. As a result, systems with nanometer-scale physical structures could have an impact on everything from food safety to molecular synthesis. Nanotechnology has the potential to improve the quality and safety of food.

1. Nanoparticles help in improving of

bioavailability of nutraceutical substances like oils.

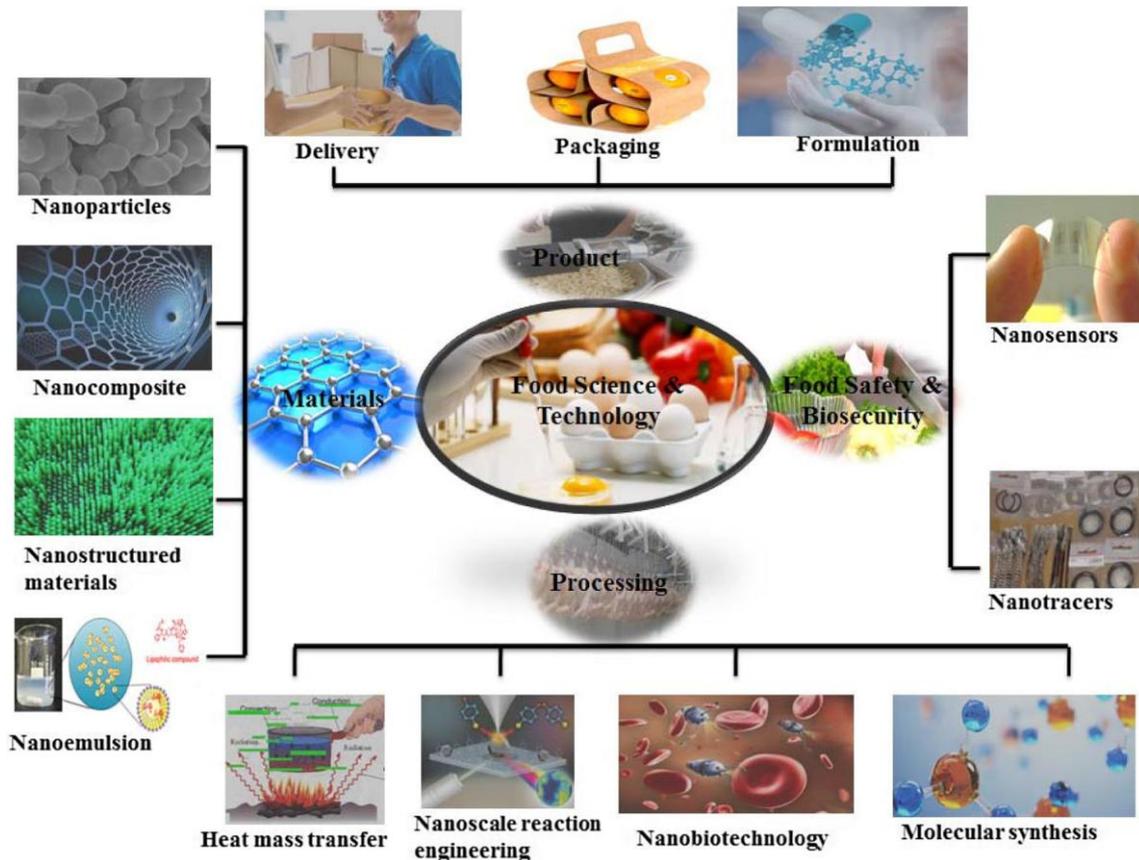
2. Nanocapsulated flavorencancers.
3. Nanotubes are used as gelatin and viscosifying agents.
4. Nanocapsulated infusions of plant based steroids to replace meat's cholesterol.
5. Nanoemulsions for better dispersion of nutrients.

### **Nanotechnology in Food Packaging:**

Food oxidation can be aided by bioactive packaging materials, which can help prevent the formation of off-flavors and undesirable textures. The food and packaging industries continue to encounter issues such as nonsustainable production, lack of recyclability, and poor mechanical and barrier qualities. Plastics are still popular due to their lightweight, formability, cost effectiveness, and versatility, despite the fact that metal and glass are good barrier materials that can be used to prevent unwanted mass transport in food packaging. Indeed, the packaging business accounts for more than 40% of all plastic usage, with food packaging accounting for half of that 40% [31].

1. Antibodies attached on fluorescent nanoparticles help in the detection of pathogens in packaged foods.

2. Biodegradable nanosensors for monitoring temperature and moisture in packaged food.
3. Nanoclays and nanofilms act as barriers to prevent spoilage and exposure to oxygen.
4. Electrochemical nanosensors to detect presence of ethylene.
5. Nanoparticle coating of silver, zinc and magnesium act as antimicrobial and antifungal.
6. Heat resistant films with silicate nanoparticles.



**Fig.3:** Food management involves numerous phases (processing, packing, and preservation), all of which are improved by nanotechnology using a variety of nanomaterials [32].

### Conclusions:

Nanotechnology has the potential to be the key to a completely new world in the sectors of food and agriculture, construction materials, mechanical, medicinal, and electrical engineering, according to the review in this study.

Although natural system replication is one of the most promising areas of this technology, scientists are still grappling with its incredible complexity. Furthermore, nanotechnology and nanomaterials is a rapidly expanding field of research in which new properties of

nanoscale materials can be exploited for industrial purposes, and a number of promising developments exist that have the potential to alter the service life and

life-cycle cost of construction infrastructure in the future to create a new world.

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