

APPLICATIONS OF FUTURISTIC TRENDS OF CHEMICAL MATERIAL SCIENCES & NANO TECHNOLOGY

Abstract

Nanotechnology is no longer just a catchphrase in material sciences as the 21st century progresses; it is a concrete reality. This is demonstrated by the exponential growth in the production of market-ready nanoproducts as well as the accompanying revenues in different industries. The advancements in nanotechnology offer an exclusive opportunity to create novel categories of materials while achieving sustainable growth. Nevertheless, the promising future of nanotechnology is far from being realized in the latest wave of nano-devices. The bulk of nanotechnology-related items are often utilized in various industries, including electronics, photonics, healthcare, aerospace, defense, automotive, and appliances. Millions of consumers and stores now have access to over 1827 items for consumption. These goods contained at least 39 nanomaterials derived from silica, metallic oxides like titania, carbonaceous compounds e.g. CNTs, and metals like gold and silver. In this chapter, we discuss the present as well as futuristic applications of Chemical Material Sciences & Nano Technology in all these important sectors.

Keywords: Nanomaterials, biomedicine, biosensor, nanofluids, pnictogens, photonics, electronics, energy, environment, carbon nanotubes (CNTs), aerospace, defense, consumers, automotive

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I. INTRODUCTION

Over the past 20 years, the discipline of nanotechnology has made enormous strides, bringing early promises to fruition and fostering economic expansion and social welfare. This has resulted directly from policymakers' and governments' interest in launching various projects for advancing cutting-edge nanotechnology and their potential uses, notably in medicine. Although advancements in studies on nanotechnology have been particularly noticeable since the beginning of the era, the long-term goal is to translate findings into widely used goods and gadgets that benefit mankind. Nanomaterials are present in every aspect of our lives and provide opportunities for societal improvement [1]. The need to comprehend how nanotechnology will affect society is becoming more widely acknowledged [2]. According to market predictions, nanotechnology might have a \$1 trillion impact on goods for consumers and businesses over the next ten to fifteen years. These markets include energy, medical care, household goods, infrastructure, safeguards, and aerospace. Nanotechnology in these sectors has mostly been relegated to specialized microelectronics technologies or the incorporation of nanoparticles into existing goods like sunscreens [3]. The distribution of major nanomaterials in our daily products is shown in Figure 1.

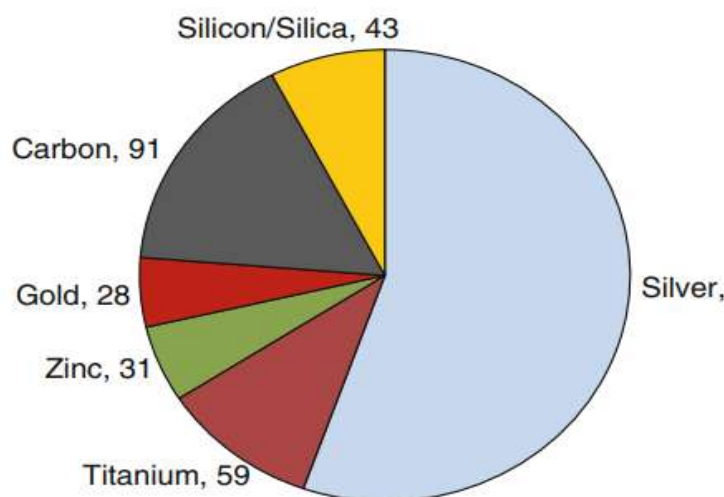


Figure 1: Distribution of major nanomaterials in consumer products (Reprint with permission from [4])

This chapter focuses on the futuristic trends of nanotechnology and material sciences and their applications in electronics and photonics, energy and environment, biomedical and healthcare, aerospace and defense, consumer goods, and automotive.

II. ELECTRONICS AND PHOTONICS

Photonic computing uses light particles (photons) instead of electrons to process and transmit data. This technology has the potential to revolutionize computing speed and energy efficiency. We may soon see photonics integration in traditional electronic circuits, leading to faster and more power-efficient computers. It's important to note that these applications are

speculative and might have evolved differently or expanded significantly. As technology progresses rapidly, witnessing the real-world impact of these futuristic trends in electronics and photonics is always exciting.

Here are some potential applications of futuristic trends in electronics and photonics:

- 1. Quantum Computing:** Quantum computers leverage the principles of quantum mechanics to perform complex calculations exponentially faster than classical computers. We might see the emergence of more powerful and commercially viable quantum computers, leading to breakthroughs in cryptography, drug discovery, optimization problems, and machine learning.
- 2. Neuromorphic Computing:** Inspired by the human brain's architecture, neuromorphic computing systems aim to perform cognitive tasks more efficiently. There might have been significant progress in developing neuromorphic hardware and algorithms, leading to advancements in artificial intelligence, robotics, and brain-computer interfaces.
- 3. Photonic Computing:** Photonic computing uses light particles (photons) instead of electrons to process and transmit data. This technology has the potential to revolutionize computing speed and energy efficiency. We may see photonics integration in traditional electronic circuits, leading to faster and more power-efficient computers.
- 4. Wearable Electronics:** Wearable devices have become increasingly popular, and we might have seen more advanced and versatile wearable electronics. These devices could have integrated sensors for health monitoring, augmented reality interfaces, and seamless integration with everyday clothing.
- 5. Flexible and Stretchable Electronics:** Flexible and stretchable electronics are poised to revolutionize the design of electronic devices. We could have witnessed the development of more robust and versatile flexible electronic components, enabling innovative applications in wearable devices, flexible displays, and electronic skins for robotics.
- 6. Integrated Photonics:** Integrating photonics with traditional electronic components could lead to higher-speed data transfer and reduced power consumption in data centers and telecommunications. We might see advanced integrated photonic circuits enabling faster internet connectivity and improved performance of electronic devices.
- 7. Light-based Medical Imaging and Therapeutics:** Photonics has significant potential in medical applications. We might have seen more advanced light-based imaging techniques, such as optical coherence tomography (OCT) and photoacoustic imaging, which could enhance early disease detection and improve treatment outcomes.
- 8. Li-Fi (Light Fidelity):** Li-Fi is a wireless communication technology that uses visible light to transmit data. This technology could have matured, offering high-speed, secure, and energy-efficient wireless communication in indoor environments where traditional Wi-Fi may face limitations.

9. **Terahertz Technology:** Terahertz waves, lying between microwaves and infrared in the electromagnetic spectrum, have various potential applications in security screening, non-destructive testing, and high-speed wireless communication. Advancements in terahertz technology might have led to practical applications in these areas.
10. **Energy Harvesting:** Photonics could be employed in energy harvesting systems that convert ambient light into electrical energy to power low-power electronic devices. We may soon see more widespread adoption of energy harvesting technologies in IoT devices, wearable electronics, and remote sensors.

These applications are speculative and represent potential developments based on the futuristic trends in electronics. The electronics industry could have evolved in unexpected ways, bringing about exciting new applications and possibilities

- **Pnictogen-based Photonic Substances:** Pnictogen-based substances have been able to exert a significant influence on a range of therapeutic illnesses, including acute promyelocytic leukemia, leishmaniasis, and gastrointestinal problems, thanks to their coordinated interactions with biological systems. Repurposing ancient pnictogen-based medications is another "old drugs, new applications" example that goes back to the basics and will help to strengthen attempts to screen current medications for successful new therapies. This is because it has undergone comprehensive pharmacologic as well as clinical investigations. Developing layered pnictogens, a recently identified type that benefits from materials science and nanotechnology has sparked extensive research for various applications thanks to their beneficial optoelectronic and photonic properties, atomic-scale thickness, and numerous surface attributes[5].
- **Optical Sensors:** The use of optical sensing for chemical, physical, as well as microbiological sensing on the microscopic and nanoscales, has recently become one of the foremost active fields in micro or nanofiber(MNF)-based optics and technology. The field is still in its early stages of development, though, as only a few MNF detectors are being applied outside the lab. Several problems, such as those with production, functionality, and packaging of MNF structures, must be resolved to close the gap and considerably improve consistency and reproducibility: creating highly reproducible techniques along with systems for functioning MNFs with specified shapes and substances; enhancing manufacturing method to produce MNFs with defined variables, high accuracy, and more excellent reproducibility and ensuring outstanding consistency and resilience in MNFs and equipment packaging. Due to the rapid micro-/nanofabrication technological advances and the emergence of robot technology and computer-assisted design and manufacturing (e.g., 4D printing), a path to the mass production of MNF sensing may now be available. MNF-based optical detectors will offer new prospects due to the quick development of MNFs with novel functional architectures and materials with novel principles or consequences for optical monitoring[6].

- 2D material-based liquid crystals:** It was recently demonstrated that the organization of liquid crystal mesogens may order the scattered particles by distributing nanoparticles or molecules within the liquid crystal substrate. Due to the energy favorability of this kind of alignment, it is being demonstrated both theoretically and experimentally that the nanomaterials coordinate with the liquid crystal's disclinations. Since structured mesophases in graphene oxide mixes exhibit a strong polarised dependency on photoluminescence, the various phases of liquid crystalline material can be distinguished using photoluminescence studies. The liquid's crystalline phase has also been noted in various other organic solvents, such as acetone, dimethylformamide, ethanol, cyclohexyl pyrrolidone, and tetrahydrofuran. For every solvent, a particular concentration of particles is needed to produce the liquid crystal state. The number of particles required to form the liquid crystal phase varies depending on the chemical solvent; however, there is additionally some variation in the threshold levels seen for a similar solvent because of the impact of the graphene oxide particles' dimensions, form, and the polydispersity in the resulting solution. The liquid crystal state was also seen for graphene exfoliated and distributed in chlorosulfuric acid. For graphene and small graphitic particles, a comparable phase has only been seen in other solvents, including stabilizing surfactants or polymeric coverings. It was recently noted that graphene dispersion in water exhibits an extrinsic flexibility linked to a cholesteric liquid crystal state. In recent years, the discovery of a liquid crystal phase for molybdenum disulfide dispersions at elevated concentrations within the water raises the potential that liquid crystalline phases might be present for a much wider variety of 2-D mixtures[7][8]. Futuristic application areas of 2-D crystals have been enlisted in Figure 2.

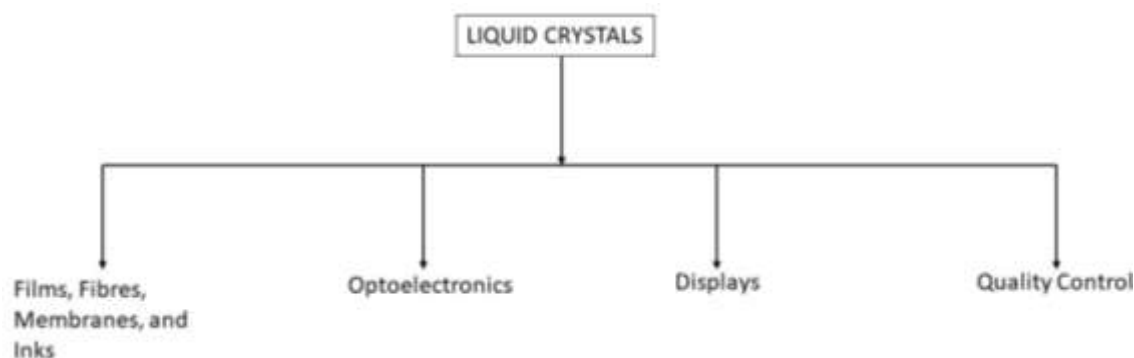


Figure 2: Futuristic application trends of 2-D material-based liquid crystals

- Tellurium Nano particles:** Due to their unique semiconducting properties, tellurium nano particles could be used in electronic devices and optoelectronics. Among other applications, they may be employed in transistors, sensors, and photo-detectors. In nano electronics, Tellurium nano particles could be used to develop advanced nano devices and nano circuits, enabling miniaturization and improved performance. Tellurium nano particles could enhance the efficiency of solar cells due to their ability to absorb and convert sunlight into electricity. They might be incorporated into thin-film solar cells to increase their performance.

- **2D materials in space use:** Space exploration is given a powerful boost by the new generation of photonics technology based on nonlinear optical materials and systems. This is significant for military use and socioeconomic development. Mode-locked lasers, field effect transistors, photovoltaic cells, and other crucial space-use components can all be made from 2D materials with atomic thickness, limited flaws, and enormous surface areas. Surprisingly, research has revealed that 2D materials can withstand radiation harm because of their ability to resist energy accumulation and thinness. There is currently a dearth of knowledge about how space radiation affects the nonlinear optical characteristics of 2D materials. Researchers recently started looking into how space radiation affects 2D materials. We have identified several possible anti-radiation materials, such as MoS₂ and Bi nanosheets, whose optical limiting performance is only slightly degraded following intensive Co gamma-ray irradiation. It is also possible to use radiation to change the optical characteristics of 2D materials. We discovered that electron radiation significantly affects the nonlinear optical properties of substances and may modify the saturable absorption of 2D Sb[9].
- **Ultra short Pulse Generation:** A different non-parametric as well as non-linear photonic management, saturable absorption can be used by mode-locking to generate extremely energetic and ultrashort pulses. The mode-locked fiber lasers' ultra-short pulse can not only be employed as the most effective light sources in prospective fiber-optic communication systems, but they also have a wide range of potential applications in other industries, including defense, biomedicine, nonlinear optics, and biotechnology. Mode-locking technology is one of the most crucial methods for producing ultra-short light pulses. A semiconductor-saturable absorber is put into the cavity in a passively mode-locked fiber laser. This typical all-fiber nonlinear technique produces pulses with a picosecond or fem to second width. Numerous criteria, including high modulating depth, big optical nonlinear behaviour, minimal unsaturated damage, broadband tunability, and substantial threshold damage, ought to be met by an efficient saturable absorbing material. In contrast to saturable absorber regulators like dyes as well as semiconductor saturable absorbers, 2D materials exhibit high optical nonlinear behaviour, broadband absorption, rapid carrier time to recovery, etc.[9-10].

III. ENERGY AND ENVIRONMENT

Energy and environment sector shows significant progress, leading to various practical applications that address energy challenges and promote environmental sustainability. Here are some potential applications of futuristic trends in energy and environment:

1. **Renewable Energy Integration:** Integrating renewable energy sources like solar, wind, hydro, geothermal, and tidal power could have become more seamless and widespread. Advanced grid management systems and energy storage solutions might have facilitated the efficient integration of variable renewable energy into the power grid.
2. **Smart Grids and Energy Management:** Smart grid technologies could have been further developed and, enable real-time monitoring, control, and optimization of energy

distribution. Smart grid systems might have allowed for better demand-side management, load balancing, and increased grid resilience.

3. **Energy Storage Solutions:** Advancements in energy storage technologies might have addressed the intermittency of renewable energy sources. We might have seen improved battery technologies for efficient and scalable energy storage, such as solid-state and flow batteries. Decentralized Energy Systems: Decentralized energy systems, such as microgrids and off-grid solutions, could have gained popularity. These systems might have provided reliable and clean energy access to remote and underserved areas, reducing dependence on centralized power infrastructure.
4. **Electrification of Transportation:** The trend towards electrifying transportation could have accelerated. Electric vehicles (EVs) might have become more affordable and widely adopted, contributing to reduced greenhouse gas emissions and improved air quality.
5. **Hydrogen Economy:** Hydrogen might have gained momentum, using hydrogen as a clean energy carrier. Hydrogen fuel cells could have applications in various sectors, including transportation, industrial processes, and power generation.
6. **Carbon Capture and Utilization (CCU):** Carbon capture and utilization technologies might have been further developed and deployed. CCU could have helped reduce carbon dioxide emissions from industrial processes while utilizing captured CO₂ for various applications, such as in producing synthetic fuels and materials.
7. **Sustainable Construction and Green Building:** The construction industry might have prioritized sustainability, using innovative materials and designs to create energy-efficient and environmentally friendly buildings. Green building practices could have become more standard in construction projects.
8. **Circular Economy Initiatives:** The concept of a circular economy could have gained traction, promoting resource efficiency, recycling, and waste reduction. Circular economy principles might have been integrated into various industries to minimize environmental impact and maximize resource utilization.
9. **Climate Modeling and Predictive Analytics:** Advanced climate modeling and predictive analytics might have played a crucial role in understanding and responding to climate change impacts. These technologies could have helped inform climate adaptation and mitigation strategies.

It's important to note that these applications are speculative and might have evolved differently or expanded significantly. The energy and environment sectors continuously evolve, and ongoing technological advancements and policy initiatives will shape the future.

- **Nano Fluids:** The possibility of creating nano particles with particle sizes below 100nm has been made possible by the development of nanotechnology. A new class of heat transfer fluids is called nano fluids. It was discovered that nanoparticles with typical sizes in the order of 1-100 nm by dispersing and suspending them. Nanofluids

are mostly used to achieve improved thermal characteristics and consistent, stable dispersions of nanoparticles. The corresponding applications of nano-fluids attributed to thermal conductivity, electrical conductivity, and particle size distribution are enlisted below in Table 1. The following characteristics of nanofluids make them superior to traditional solid-liquid suspensions during thermal transfer intensifications: a broad surface area, providing a larger heat transfer surface between particles and fluids; excellent dispersion equilibrium with a predominance of Brownian movement. Reduced pumping force compared to pure liquids for achieving comparable heat transfer intensification, adjustable properties and minimized particle obstruction compared to traditional slurries, resulting in compact systems[10].

Table 1: Applications of nanofluids based on its properties

Application Based On	Use
Thermal conductivity	<p>A) Convective heat transfer performance of Al_2O_3 nanofluids[11].</p> <p>B) Heat transfer of polyaniline-based(PANI)nanofluids using water base fluid[12].</p> <p>C) CuO/water nanofluids in a carradiator cool an tunder laminar conditions[13].</p> <p>D) Al_2O_3/water nanofluid to be used in a heat sink by Investigating its stability[14].</p>
Electrical conductivity	<p>A) During the proton exchange membrane fuel cell (PEMFC)process, the Al_2O_3/water/ethyleneglycol nanofluid that serves as coolant receives ions due to contamination of the bipolar plate and degradation of ethyleneglycol, which is the base fluid of the nanofluid, during the process[15].</p> <p>B) Higher thermo-electrical conductivity(TEC)nano fluids are Used in fuel cell.</p>
Particle size distribution	The size distribution of the nanoparticles in in the nanofluid determines how much of a wavelength it absorbs.

- **Biogenic nanoparticles:** A biological process uses microorganisms, fish, plants, and other living things to produce biogenic nanoparticles. There are no hazardous chemicals or solvents used in this biological process. "Green synthesis" refers to creating soil nanoparticles [16]. The various applications of biogenic nanoparticles have been listed in Table 2.

Table 2: Futuristic application trends of biogenic nanoparticles

Applications	Use
Wastewater treatment	Regarding waste water treatment, nanotechnology primarily offers three types of benefits: treatment and remediation, sensing and detection, and pollution control. Removing pollutants and cleaning waste water streams. Because these technologies are quick, precise, and effective ways to remove contaminants, waste water treatment for chemicals that are harmful or difficult to treat was promised. Remediation of the soil and ground water sedimentation were also major issues. Nano coagulants to remove water contaminants from waste water streams are some recent examples of biogenic treatment of waste water. Recently, abiomimetic micellarnano-coagulant that resembles A ctinia was employed to remediate groundwater. This technology mostly purifies water and generates water free from impurities [17].
Battery recycling	Batteries still contain various chemicals and dangerous heavy metals, such as mercury, lead, copper, nickel, cadmium, and others, which pollute the environment and offer several health problems when incorrectly disposed of. Pure zinc oxide nanoparticles are now employed to create recyclable batteries. These days, Zn-MnO ₂ alkaline batteries protect the environment [18].
Hydrogen production by using photosynthesis	Artificial photosynthesis ,which produces hydrogen from sunlight, is a green technology that is ecological, biodegradable, and good for the environment. Through artificial photosynthesis, solar energy is employed in this system to separate hydrogen and oxygen from water, providing a clean and environmentally friendly energy source [9].
Biosensors	Various biogenic and non-biogenic nanoparticles are utilized when building biosensors, such as oxide and metals. These nanoparticles play a significant role in detection and sensing systems[19].

- **Tellurium Nanoparticles:** Tellurium nanoparticles, microscopic particles with special features, are gaining popularity in nanotechnology research. Their fascinating semiconducting, thermoelectric, and catalytic properties bring up new possibilities in electronics, solarcells, biological disciplines, and other domains. Ongoing research looks into the prospects of using these nanoparticles for revolutionary developments in various sectors.
- **Solar Cells:** Tellurium nanoparticles could enhance the efficiency of solarcells due to their ability to absorb and convert sunlight into electricity. They might be

in corporate into thin-film solar cells to increase performance[20].

- **Thermoelectric Devices:** Thermoelectric materials can convert heat into electricity and vice versa. With their distinct thermoelectric properties, Tellurium nanoparticles could be utilized in thermoelectric devices for waste heat recovery and energy Generation[21].
- **Catalysis:** Tellurium nanoparticles could serve as catalysts in chemical reactions. They might increase reaction rates, reduce energy requirements, and improves electivity in various catalytic processes.
- **Biomedical Applications:** Some studies have explored the potential of Tellurium nanoparticles in biomedical applications, such as imaging and drug delivery. These nanoparticles might be engineered to carry drugs to targeted sites or used as contrast agents in medical imaging techniques.
- **Lubricants and Coatings:** Tellurium nanoparticles could find application in lubricants and coatings due to their unique surface properties, which may reduce friction and wear in moving parts[22].
- **Nanoelectronics:** In nanoelectronics, Tellurium nanoparticles could be used to develop advanced nanodevices and nanocircuits, enabling miniaturization and improved performance[23].

It is essential to note that many of these applications are still in the early stages of research and development.

IV. BIOMEDICAL AND HEALTHCARE

1. **Clinical Diagnostics:** Gold nanoparticles (AuNPs), one of the noble metal NPs readily obtainable, are crucial for biomedical applications. AuNPs are easily coupled with antibodies or oligonucleotides to increase the biological activity and targetability of NPs to detect target biomolecules. Gold nanoparticles are also available for drug encapsulation by creating hydrophobic or hydrophilic pockets by the monolayer of polymers like polyethylene glycol (PEG). Diabetes mellitus (type-I) is one metabolic condition for which AuNPs are employed. It is a metabolic condition marked by persistently elevated blood sugar levels. Every year, it affects more than 0.3% of the world's population due to the loss of insulin-secreting beta cells in the pancreatic islets of Langerhans. Magnetic resonance imaging (MRI) contrast agents called AuNPs are used. T gadolinium chelates currently used in clinical diagnostics are transported using AuNPs as templates[24].
2. **Cellular imaging:** Silver nanoparticles are capable of in vivo cellular imaging. It is extensively researched in the study of immune response, malignancies, inflammation, and the impact of stem cells. By altering the surface and bioconjugating the NPs, the contrast agents are conjugated or encapsulated to NPs. Ag is useful in imaging because of its stronger and sharper Plasmon resonance. Silver-based biosensors have recently been developed for the clinical retention of serum P53 in head and neck squamous cell carcinomas. Due to its ability to speed up wound healing, silver nanoparticles are commonly utilized in antibacterial lotions. By destroying the bacteria' unicellular membrane and ensuing disruption of their enzymatic processes, it also exhibits a broad biocidal effect against them. The localization of drug molecules inside cells also uses biosynthesized silver NPs. Their distinctive fluorescence is brilliant crimson. Because of its plasmonic characteristics, nano silver aids in bioimaging[25].

- 3. Cancer Detection:** A few nanometers in size, quantum dots (QDs) are minuscule semiconductors. In contrast to LED particles, they exhibit various electrical and optical characteristics. When exposed to electricity or light, these quantum dots produce light at frequencies that can be precisely controlled by altering the dot's size, shape, and substance, opening up a wide range of possibilities for use. For the sensitive detection of cancer biomarkers such as breast cancer, ovarian cancer, and prostate cancer, quantum dots have extremely high efficiency. Alpha-fetoprotein and carcinoembryonic antigen in human serum, two tumor biomarkers, were found using quantum dot-based nanosensors. Since QDs have strong fluorescence characteristics, fluorescent imaging (FI) can be employed to detect transplanted stem cells in vivo. This offers superior sensitivity compared to other imaging techniques [26].
- 4. Biosensors and Resonance Imaging:** The most advanced uses for iron NPs are biosensors and resonance imaging. The imaging and treatment of cancer have made substantial use of superparamagnetic iron oxides (SPIONs). Size, form, magnetism, crystallinity, and flexibility are only a few of their numerous attributes and controlled characteristics. Targeting ligands, medications, and other substances uses multifunctional SPIONs with fluorescence. The most effective contrast agent for MR imaging techniques is SPIONs. The superparamagnetic SPIONs exhibit high magnetism when an external magnetic field is supplied, and it decreases to zero when the external magnetic field is removed, making them effective MR imaging probes and a surface coating with advanced functionality. To improve targeting, targeting ligands such as proteins, peptides, antibodies, polymers, carbohydrates, aptamers, DNA, RNA, and oligosaccharides are coated on magnetic NPs [27].
- 5. Drug Delivery:** Due to their unique properties, including a large surface area, a large pore size, a lack of toxicity, biocompatibility, and biodegradability, uniform distribution of target molecules on the porous space, controllable superficial charge, and free dissemination throughout the body, silica nanoparticles exhibit desirable properties to be used as multifunctional nanoplatforams for drug delivery. Mesoporous silica nanoparticles (MSN), a common nanomedicine nanoparticle type, may have additional benefits, such as exceptional resistance to abrasion and corrosion and a high density of modifiable active sites on their surface. The cross-linked network between the polymer and MSN stopped the encapsulated compounds from escaping from the nanoparticles [28].
- 6. Neural prosthetics:** The nanotube's excellent electrical and mechanical characteristics, large surface area and a non-faradaic electrochemical response cause the nanotube's muscles actuation behavior. Bulky paper (macroscopic sheets) created an axial strain of up to 0.2% while changing the electrochemical potential from 0.5 V to 1.0 V. The construction of systems for administering antibiotics to various types of cells uses the multifunctionalities of carbon nanotubes (CNTs). A novel strategy for controlling the therapeutic effects is proposed that uses selective transport through the membranous membrane. The excellent electrical properties of carbon nanotubes have made them valuable in the field of neural prosthetics [29].

V. AEROSPACE AND DEFENSE

- 1. Enhanced Safety and Security:** The most extensively investigated nanotechnology has been carbon nanotubes, which have several unique features that could be used in military equipment[30]. Although the maximum measured tensile strength of single-walled carbon nanotubes (SWCNTs) is 52 GPa and that of multi-walled carbon nanotubes (MWCNTs) is 62 GPa, carbon nanotubes (CNTs) may theoretically possess tensile strengths of up to 120 GPa. The issue, though, is keeping its strength. Due to its extreme lightness, CNT has been proposed as the weight material of future generations for headgear and body armor. Now, a novel strategy known as quantum cryptography has lately been created. For the first time, impenetrable security is now feasible thanks to a technique that uses quantum physical effects to safeguard data, audio, or video connections. Using quantum cryptography, the transmitter sends a series of bits with values transmitted by individual photons to reach the receiver. Even if someone tries to catch it, their condition is irreversibly altered. While in digital cryptography, an intruder's meddling is undetectable and communications can be replicated, the sender and the recipient can ultimately determine that it was intercepted. The pinnacle of cryptographic communications is a single-photon detecting device. The synchronous synthesis of several photons seldom occurs in high-speed, single-photon generating systems, producing very little noise [31].
- 2. Camouflaging and Energy Storage:** Advances in materials science have led to active camouflage that may automatically modify its appearance in reaction to environmental changes. Researchers supported by the Office of Naval Research have developed an object that responds to and responds to light sources—a beginning in creating more improved camouflage for warfighters—even if this technology is not yet deployable in the field. More hypothetically, research in nanotechnology might lead to the development of cloaking tools that bend light, thereby making the target invisible. Both large armament platforms and specific warfighters could be hidden using such technologies. Finally, researchers are looking into how energy may be produced and stored using nanotechnology. To do this, silicon and carbon nanostructures have been employed to boost battery life as well as cost-effectiveness, while tiny particles of semiconductors known as quantum dots were utilized experimentally to enhance energy utilization by over 40%. By lowering dependency on potentially unstable supply networks and permitting prolonged deployment periods, these innovations increase energy autonomy for major military sites and forward operational forces [32].
- 3. Lightweight and Speedy Aircraft:** It plans to use nanotechnology to create light, intelligence-guided fighter jets and missiles with a low visual signature, fast maneuvering, and specialized weapon systems for detection and surveillance. Numerous nanomaterials have mechanical or ultrahigh strength characteristics. Particularly about CNTs, which have extremely high inherent strengths. CNTs offer stronger materials and a sizable weight decrease, whether utilized alone or combined with other materials like polymers. A lighter material will also support soldiers significantly in aviation and land vehicles. Nanotechnology is predicted to result in a 2-to-1 reduction in overall weight. Composites comprising polymers combined with various nano inorganic compounds, nanoplatelets, or nanotubes in a certain ratio have been produced for constructing lighter and stronger vehicles or aircraft. Polypropylene, polyethylene, and other common polymers are employed, and nanoparticles are added to improve their physical, electrical,

or chemical qualities. Different types of nanoparticles, such as spherical, platelet-like tubes, fibers, needles, etc., are employed [33].

- 4. Explosives/ Propellants:** The focus of modern high-powered material research has switched to nanoscale materials, also referred to by the term nano-energetic materials (nEMs). At first look, nEMs are predicted to have expanded their contact area due to size reduction under 100 nm and wider surface reaction space, leading to some previously unheard-of explosive, pyrotechnic, and propellant characteristics. These materials are very reactive because of the large ratio of surface to volume and the short release of oxygen caused by the drop in particle size to the nanodomain. As a result, it is discovered that nanoparticles respond more quickly and fully than larger ones at temperatures that are substantially lower. In certain situations, they can also improve the system's energy production. The nEMs' breakdown reaction rate is anticipated to release a significant quantity of energy quickly. For instance, incorporating super thermites, or nano-aluminum, increased the explosive capability of that exact explosive substance. Additionally, without sacrificing the explosives' reactivity, introducing nanosized compounds in explosives has increased tolerability and immune function by over 30% [34].
- 5. Materials for Aircraft and Space Vehicles:** About their distinctive recognition, carbon nanotubes have drawn the attention of numerous scientific sectors, making it more appealing to build military planes, spacecraft, unscrewed aerial automobiles, and satellite launchers. As a result, efforts are focused on expanding the use of CNT in lightning defense for aircraft and reducing the mass of spacecraft and frames. CNTs serve as a covering for active material components that are included as reinforcement of structural materials in applications in warfare. Direct covalent bonds attached CNT to carbon fibers to create a strong reinforcing structure. This novel chemical technique is known as covalent ester linking. The investigation revealed that CNTs are mechanically susceptible to fracture and that strong carbon-carbon covalent bonds frequently occur. Developing a composite framework for future advanced aircraft materials will allow for the further development of this powerful bonding [35].
- 6. Combat Armor and Suits:** Future fight suits will be light, safeguard against various risks, and track vital indicators with printed and rooted physiological indicators on fabrics (e.g., electrocardiography indicators that track blood pressure, respiration, temperature, and dehydration). Zinc oxide nanowires atop textile fibers are going to be used as piezoelectric nanotechnology in the electric network and energy-generating framework of these outfits. Carbon nanofibers, including CNTs are used in thermally managed textile technologies enabling heat conductivity, air circulation, insulation, and localized cooling to deal with high temperatures. For transmission and recognition, they will have exterior sensors. It's also being thought about to give sturdy, light shoes and rucksack smart armor qualities [33].

Figure 3 shows the other domains of aerospace and defense where nanotechnology and material science can become of great use in the future.

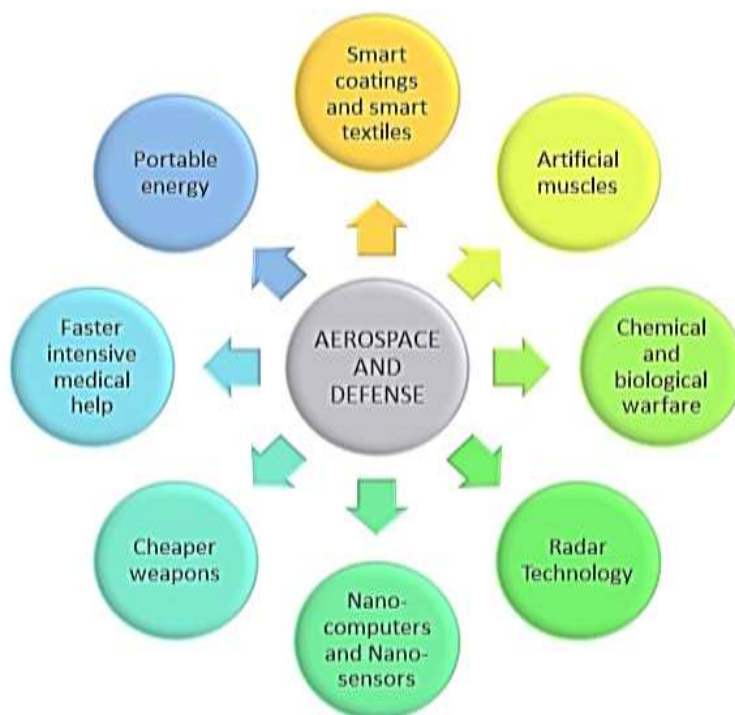


Figure 3: Futuristic applications of nanotechnology and material science in Aerospace and defense

VI. CONSUMER GOODS AND AUTOMOTIVES

The most common nanomaterials used in consumer items are metallic ones. Depending on the place they are found, metallic nanoparticles in consumables can be divided into three categories: disseminated in the bulk of the goods; deposited on the surface; and bonded in the goods themselves. For instance, nanosilver can be disseminated in supplements, bound to surfaces in cosmetic tools and dinnerware, or deposited on textiles like socks as well as shirts. Thus, the many uses of consumer goods dictate where nanoparticles are present, affecting human exposure pathways to engineered nanomaterials. The exposure assessment to individuals and their surroundings also considers other elements such as nanomaterial concentration, form, and chemical entities [36]. When a consumer good is used by a human, exposure to engineered nanomaterials in the product can occur directly. The application routes—including breathing, eating, cutaneous absorption, and a combination—contribute to the degree of exposure. Human exposure to nanoparticles needs to be thoroughly assessed, especially given that the supply of nano goods is expected to rise. Health and wellness items include the most nanomaterials compared to all other products. In the manufacturing sector, there are more workplaces where employees are directly exposed to nanomaterials, including those that make colors, coatings, beauty products, catalysts, and polymeric composites [4]. Futuristic application routes of nanomaterials and material sciences in consumer products can be seen in Figure 3.

Due to their antimicrobial and antibacterial attributes, ag nanoparticles are commonly used in various medical commodities and home goods, including food preservation and packaging utensils, household cleaners, fabrics, water purifiers, humidifiers, and spray[37].

Foods-grade ZnO and TiO₂ nanoparticles are frequently employed in food packaging materials to preserve flavors, stop food from spoiling, and whiten and change food texture. Overview of how nanoparticles behave and how they affect the natural world and humanity by using consumer goods based on nanotechnology. Due to their ability to protect against ultraviolet (UV) light, they are widely included in beauty products and sunscreens [38]. The futuristic trends of nanomaterials in consumer products are shown in Figure 4.



Figure 4: Futuristic trends of nanomaterials in consumer products

Brake squeal is a common issue brought on by dynamic turbulence in cars, which is impacted by the unsteadiness of the structure and slight disruption brought on by changes in friction force. Depending on their molecular dynamic methodology and laboratory validations, improving the pad materials increased the effectiveness of the braking materials, resulting in reduced brake squeals. As part of braking performance, brake efficacy has recently become necessary for vehicle safety. The level of comfort is also being affected. It has been demonstrated that using nanoparticles in the design of new brake materials can lengthen the lifetime of the brake and eliminate brake squeals. Investigations have been conducted on a wide range of topics, including tribological behavior, lubrications, coefficient of friction, hot hardness, surface roughness, residual stress, adhesion, damage tolerance, as well as resistivity. Another issue with reducing friction and wear is mechanical damage. In automobile engines, the piston system is a significant source of friction. Nanoparticles or nanocrystals of metallic substances, semiconductors, and oxides are particularly intriguing. Nanoparticles are significant in polyvinyl chloride covering uses in the automotive sector because they bridge the separation between bulk material qualities and atomic or molecular organization. An automobile engine's size can be greatly reduced by omitting the liners. It is simple to save 1 kg for each engine, contributing to a smaller overall size. Each kilo of cargo decrease must be crucial for fuel economy[39-40].

VII. CONCLUSION

We have reviewed and briefed the futuristic trends on nanotechnology in the various fields of electronics, photonics, energy, environment, healthcare, aerospace, defense, consumer goods and automotive. Numerous biomedical uses of multifunctional photonic nanoparticles have been examined. The safety of photonic nanoparticles for future therapeutic uses is now the most crucial problem. According to recent studies, several parameters greatly influence nanomaterials' clinical viability. To start, photonic nanomaterials should be created using biocompatible materials. Carbon nanomaterials, polymeric melanoidins, and gold nanoparticles have undergone extensive biophotonic application research in this context. Many applications for nanofluids are based on their thermal characteristics, but very few are based on their electrical characteristics. Another characteristic crucial for understanding nanofluids' thermal and optical properties is particle size distribution. The particle size distribution is affected by several variables.

As covered in the sections above, nanomedicine has significantly impacted various diagnostic and therapeutic fields. Only 20 nanoparticle therapies are currently being used in clinical settings, despite many nanomedicines having progressed into preclinical and clinical studies. Other nanomedicines currently in the preclinical stage would soon hit the market. With the rising population and simultaneous improvements in smart technologies, nanotechnology, and its applications are becoming necessary in our daily lives. Important applications like camouflaging, radar communication, combat suits, and aerospace materials have been highlighted in aerospace and defence. Nanotechnology would soon significantly impact the health sector with persistent and ongoing research. It is necessary to establish quantitative evaluation methods and procedures for tracking different nanoparticles in real-time in the air, water, and soil. Till now, significant advancements might have been made in these areas, leading to transformative applications in diverse industries. These conclusions are speculative and represent potential developments based on the futuristic trends in materials science. The materials science field could have evolved unexpectedly, bringing about exciting new applications and possibilities for various industries and human endeavors.

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