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Review Article

Recent advances in nanotechnology

Mahendra Kumar Sahu[1,2]*, Rajni Yadav[3] and Sandeep Prasad Tiwari[3]

[1]Department of Pharmacology Columbia College of Pharmacy, Raipur, Chhattisgarh, 492001, India

[2]Department of Pharmaceutical Sciences Kalinga University Raipur, Chhattisgarh 492001, India

[3]Faculty of Pharmacy Kalinga University Raipur, Chhattisgarh 492001, India

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***Corresponding author:** Mahendra Kumar Sahu, Department of Pharmacology Columbia College of Pharmacy, Raipur, Chhattisgarh 492001, India,
Tel: 8109794919;
E-mail: mahendrapharma0310@gmail.com

ORCiD: https://orcid.org/0000-0002-1339-2408

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Abstract

Introduction: Recent advances in nanotechnology have shown significant progress in various fields. Nanotechnology involves the manipulation and control of matter at the nanoscale, typically ranging from 1 to 100 nanometers. This field has the potential to revolutionize industries such as electronics, medicine, energy, and materials science. Nanotechnology has led to the development of smaller and more efficient devices in electronics. Nanoscale transistors and memory chips have increased computing power and storage capacity. Additionally, nanomaterials like carbon nanotubes and graphene have shown promise in creating flexible and transparent electronics.

Method and materials: In medicine, nanotechnology has opened new possibilities for targeted drug delivery and imaging. Nanoparticles can be designed to specifically target cancer cells, delivering drugs directly to the affected area while minimizing side effects. Nano-sensors can also be used for early detection of diseases and monitoring of patient health. Energy is another area where nanotechnology has made significant advancements. Nanomaterials such as quantum dots and nanowires have improved the efficiency of solar cells, making them more cost-effective and sustainable. Nanotechnology also plays a role in energy storage, with the development of high-capacity batteries and supercapacitors. Materials science has also benefited from nanotechnology. Nanocomposites, which are materials with nanoscale fillers, have enhanced mechanical, thermal, and electrical properties. These materials find applications in the aerospace, automotive, and construction industries.

Conclusion: Overall, recent advances in nanotechnology have paved the way for exciting possibilities in various fields. Continued research and development in this area hold the potential for further breakthroughs and advancements in the future.

Introduction

Nanotechnology is a cutting-edge field of science and engineering that deals with materials and structures at the nanoscale, typically between 1 to 100 nanometers in size. At this tiny scale, unique properties and behaviors of materials emerge, enabling scientists and engineers to manipulate and engineer them for various applications [1]. Nanotechnology has broad implications across multiple industries, including electronics, medicine, materials science, and energy, and it holds great potential for revolutionizing technology and addressing some of the world's most pressing challenges. This field has opened up new possibilities for creating innovative materials, devices, and systems with unprecedented precision and efficiency [2].

The utilization of matter on an atomic, molecular, and supramolecular scale for industrial purposes is known as nanotechnology [3]. The first and most popular definition of nanotechnology, currently known as molecular nanotechnology, focused on the specific technological objective of accurately manipulating atoms and molecules for the creation of macroscale objects [4,5]. The National Nanotechnology Initiative later created a broader definition of

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nanotechnology, defining it as the manipulation of matter with at least one dimension scaled from 1 to 100 nanometers (nm) [6]. This definition reflects the fact that quantum mechanical effects are significant at this quantum-realm scale, and as a result, the definition changed from a specific technological aim to a research category inclusive of all forms of research and technologies that deal with the unique challenges that arise in quantum mechanics [7].

A size-based definition of nanotechnology encompasses a variety of scientific disciplines, including surface science, organic chemistry, molecular biology, semiconductor physics, energy storage, engineering, microfabrication, and molecular engineering [8]. The related research and applications include a wide range of topics, from modifications of traditional device physics to entirely novel strategies based on molecular self-assembly, from creating novel materials with nanoscale dimensions to precise control of matter at the atomic level [9].

Scientists are currently debating how nanotechnology will affect society in the future. Nanotechnology may be able to develop a wide variety of new items, including consumer goods, nanomedicine, nanoelectronics, biomaterials, and energy generation [10,11]. On the other hand, nanotechnology raises many of the same problems as any new technology, such as worries about the toxicity and environmental impact of nanomaterials as well as their ability to have an impact on the world's economies and the speculative possibility of numerous apocalypse scenarios [12]. These worries have sparked a discussion about the need for special regulation of nanotechnology among advocacy groups and governments [13].

History

In 1959, renowned physicist Richard Feynman first outlined the ideas that would eventually give rise to nanotechnology in his lecture There's Plenty of Room at the Bottom. In this discussion, he described the prospect of synthesis by the direct manipulation of atoms [14,15]. Although it was not well known, Norio Taniguchi coined the phrase "nanotechnology" in 1974. K. Eric Drexler coined the term "nanotechnology" in his 1986 book Engines of Creation: The Coming Era of Nanotechnology, which put forth the concept of a nanoscale "assembler" capable of creating copies of itself and other objects of arbitrary complexity with atomic precision. Drexler was inspired by Feynman's ideas [16]. To promote a better understanding of the concepts and implications of nanotechnology among the general public, Drexler also co-founded The Foresight Institute in 1986. He is no longer a part of this organization [16].

Drexler's theoretical and public work, which created and popularized a conceptual framework for nanotechnology, came together with high-profile experimental developments that increased public awareness of the potential for atomic control of matter in the 1980s to give rise to nanotechnology as a field [17,18]. Two significant discoveries in the 1980s were the catalyst for the development of nanotechnology in the present era. First, in 1981, the scanning tunneling microscope was created. It allowed for the first time an unmatched level of atom and bond viewing, and in 1989 it was successfully used to manipulate individual atoms. The creators of the microscope, Gerd Binnig and Heinrich Rohrer at the IBM Zurich Research Laboratory, were awarded the 1986 Nobel Prize in Physics [19]. A similar atomic force microscope was also created that year by Binnig, Quate, and Gerber. Second, the discovery of fullerenes in 1985 by Harry Kroto, Richard Smalley, and Robert Curl, who shared the 1996 Nobel Prize in Chemistry, is noteworthy. Nanotechnology was not first used to describe C60; instead, it was used to refer to later research on closely similar carbon nanotubes (also known as graphene tubes or Bucky tubes), which showed possible uses for nanoscale electronics and gadgets [20]. Iijima was awarded the first Kavli Prize in Nanoscience in 2008 for his role in the discovery of carbon nanotubes, which is widely credited to Sumio Iijima of NEC in 1991 [21].

Early in the new millennium, the field attracted more scientific, political, and commercial interest, which sparked debate and promoted advancement. The Royal Society's study on nanotechnology is an example of the debates that have arisen around the definitions and potential effects of nanotechnologies [22,23]. The public argument between Drexler and Smalley in 2001 and 2003 was the result of issues being raised about the viability of the applications that proponents of molecular nanotechnology had envisioned. While this was going on, the commercialization of goods based on developments in nanoscale technologies started to emerge. These goods do not involve atomic manipulation of matter and are restricted to mass uses of nanomaterials [24]. Examples include the silver nano platform, which uses silver nanoparticles as an antibacterial agent, transparent sunscreens based on nanoparticles, silica nanoparticles used to reinforce carbon fiber, and carbon nanotubes used in stain-resistant textiles [25].

The National Nanotechnology Initiative in the United States, which formalized a size-based definition of nanotechnology and established funding for research on the nanoscale, and the European Framework Programmers for Research and Technological Development in Europe are two examples of how governments have taken action to promote and fund research into nanotechnology [26]. By the middle of the 2000s, new and significant scientific interest started to take off. The creation of roadmaps for nanotechnology, which focus on the atomically precise manipulation of matter and outline current and projected capabilities, aims, and applications, has become a priority [3].

Recent advances in nanotechnology [27-30]

Nanotechnology is a rapidly evolving field with continuous advances and breakthroughs. While it was not possible to provide information on developments that have occurred after that date, some recent trends and areas of interest in nanotechnology can be mentioned up to that point. It is important to check more recent sources for the latest advancements. Here are some notable areas of recent progress:

Nanomedicine: Advances in targeted drug delivery systems using nanoparticles to improve the precision and effectiveness of cancer treatments.

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Development of nanoscale imaging agents for earlier and more accurate disease diagnosis.

Nanoelectronics: Continued efforts to push the limits of Moore's Law by developing nanoscale transistors and memory devices.

Research into new materials, like 2D materials (e.g., graphene), for electronic components and interconnects.

Quantum nanotechnology: Progress in quantum computing and quantum communication using nanoscale quantum bits (qubits).

Development of quantum sensors and detectors for applications in fields such as metrology and cryptography.

Energy applications: Advancements in nanomaterials for more efficient solar cells, including perovskite solar cells.

Research on nanomaterials for high-capacity and fast-charging batteries and supercapacitors.

Environmental remediation: Use of nanomaterials, such as nanocatalysts, for efficient pollution control and wastewater treatment.

Development of nanomaterial-based filtration systems for water purification.

Nanotechnology in materials science: Creation of novel nanocomposites with enhanced properties, such as increased strength and conductivity.

Advances in nanoscale fabrication techniques for manufacturing miniaturized devices and components.

Food and agriculture: Application of nanotechnology in food packaging to extend shelf life and reduce food waste.

Research into nanoscale delivery systems for precision agriculture, including targeted pesticide and nutrient delivery.

Nanorobotics: Progress in the development of nanoscale robots capable of performing tasks at the molecular level, including potential applications in medicine and manufacturing.

Nano-ethics and safety: Growing attention to ethical considerations, safety protocols, and responsible research practices in nanotechnology.

Advanced nanoscale imaging techniques: Development of cutting-edge imaging technologies, such as cryo-electron microscopy, for visualizing nanoscale structures and processes.

Nanotechnology in space exploration: Exploration of the use of nanotechnology in spacecraft materials, propulsion systems, and sensors for future space missions.

Nanotechnology in clean energy: Research into nanomaterials for improving energy conversion and storage technologies, such as thermoelectric devices. These are just a few areas where nanotechnology has seen significant recent advancements. The field continues to evolve rapidly, with the potential to transform various industries and address pressing global challenges. To stay updated on the latest developments in nanotechnology, it's advisable to consult scientific journals, news sources, and research institutions specializing in this field.

Advantages of nanotechnology [31-33]

Nanotechnology offers a wide range of benefits and has the potential to impact numerous aspects of our lives. Some of the key benefits of nanotechnology include:

Improved medical treatments

Targeted drug delivery: Nanoparticles can be designed to deliver drugs directly to specific cells or tissues, increasing treatment efficacy and minimizing side effects.

Early disease detection: Nanoscale sensors and imaging agents enable the early detection of diseases, improving diagnostic accuracy.

Regenerative medicine: Nanomaterials are used to create scaffolds for tissue engineering and regenerative therapies, offering hope for organ and tissue replacement.

Enhanced electronics and computing

Faster and smaller devices: Nanoscale transistors enable the development of smaller and more powerful electronic devices, driving advances in computing and telecommunications.

Quantum computing: Nanotechnology plays a critical role in the development of quantum computers, which have the potential to solve complex problems beyond the capabilities of classical computers.

Energy efficiency and renewable energy

Solar cells: Nanomaterials, like quantum dots, improve the efficiency of solar cells, making renewable energy more accessible.

Energy storage: Nanotechnology contributes to the development of high-capacity batteries and supercapacitors, enhancing energy storage solutions.

Fuel cells: Nanomaterials are used to improve the efficiency of fuel cells, which can be an eco-friendly alternative to conventional power sources.

Cleaner environment

Water purification: Nanotechnology is employed in water treatment processes, removing contaminants and providing clean drinking water.

Pollution control: Nano-catalysts facilitate more efficient conversion of pollutants into less harmful substances, aiding in environmental cleanup.

Advanced materials

Stronger and lightweight materials: Nanomaterials, like

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carbon nanotubes and graphene, offer exceptional strength and lightness, leading to stronger and lighter materials for the aerospace, automotive, and construction industries.

Enhanced properties: Nanocomposites, created by incorporating nanomaterials into traditional materials, have improved properties like increased strength, conductivity, and thermal stability.

Precision manufacturing

Nanoscale fabrication: Nanotechnology enables the creation of nanoscale components with high precision, improving manufacturing processes and product quality.

Miniaturization: Nanoscale components allow for the miniaturization of devices and systems, leading to smaller and more efficient products.

Improved food and agriculture

Food Packaging: Nanotechnology is used to develop innovative food packaging materials that can extend the shelf life of products and reduce food waste.

Crop Protection: Nanoparticles can be used for targeted delivery of pesticides and fertilizers, reducing environmental impact and improving crop yields.

Enhanced consumer products

Stain-resistant fabrics: Nanocoatings can make fabrics stain-resistant, improving the durability and cleanliness of clothing.

Scratch-resistant coatings: Nanotechnology is used to create scratch-resistant coatings for eyeglasses, phone screens, and other consumer products.

Scientific advancements

Fundamental research: Nanotechnology provides tools and insights that advance our understanding of the fundamental principles of science, enabling discoveries.

While nanotechnology offers numerous benefits, it's essential to consider and address potential safety, ethical, and environmental concerns associated with the field to ensure responsible and sustainable development.

Disadvantages of nanotechnology [34-36]

Nanotechnology offers numerous advantages, but it also comes with its share of disadvantages and challenges. Some of the disadvantages and concerns associated with nanotechnology include:

Environmental impact: Nanoparticles can pose environmental risks when they are released into ecosystems, as their behavior and toxicity may differ from larger particles. This raises concerns about potential harm to aquatic and terrestrial ecosystems.

Health concerns: There is ongoing research to understand the health effects of nanoparticles when inhaled, ingested, or absorbed through the skin. Some nanoparticles have been linked to adverse health effects, raising questions about occupational safety and consumer exposure.

Regulatory and ethical issues: Nanotechnology presents challenges for regulatory agencies in terms of establishing safety standards and monitoring the release of nanomaterials into the environment. Ethical concerns also arise regarding the responsible use of nanotechnology, especially in areas like human enhancement and surveillance.

Unknown long-term effects: Due to the relatively recent emergence of nanotechnology, the long-term effects of exposure to nanoparticles, both in terms of human health and the environment, remain uncertain. Research is ongoing to address these knowledge gaps.

Cost and accessibility: The development and implementation of nanotechnology can be expensive, which may limit its accessibility to certain industries and regions. Ensuring equitable access to nanotechnological advancements is a challenge.

Nanomaterial toxicity: Some nanomaterials may exhibit unexpected toxicity, and their behavior can change based on size, shape, and surface chemistry. This variability makes it challenging to assess their safety comprehensively.

Ethical dilemmas: Nanotechnology raises ethical questions related to the potential for misuse, especially in areas like surveillance, privacy invasion, and human enhancement. Balancing innovation with ethical considerations is a complex challenge.

Risk of nanoparticle release: During the production, use, and disposal of nanomaterial-containing products, there is a risk of unintended release of nanoparticles into the environment, potentially impacting ecosystems and human health.

Nano-ethics and governance: The ethical issues surrounding nanotechnology require careful consideration and governance. Establishing ethical guidelines and frameworks to guide research and development is an ongoing concern.

Public perception and awareness: Many people may not fully understand nanotechnology or its potential benefits and risks. Effective communication and public education efforts are necessary to ensure informed decision-making and responsible use of nanotechnology.

Security risks: The development of advanced nanomaterials and nanoscale devices may pose security risks if used inappropriately, such as in the development of new weapons or surveillance technologies.

Intellectual property issues: Nanotechnology advancements often rely on innovative research and development. Intellectual property disputes can hinder progress and access to critical technologies.

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It's important to note that while nanotechnology presents these disadvantages and concerns, ongoing research, regulations, and responsible practices are continuously evolving to address these challenges and maximize the benefits of nanotechnology while minimizing its risks. Ethical considerations and careful assessment of potential consequences are integral to the responsible advancement of nanotechnology.

Fundamental concept

Engineering functional systems at the molecular level is known as nanotechnology. This covers both the most recent research and more complex ideas. In its original sense, the term "nanotechnology" refers to the anticipated capacity to build things from the ground up utilizing currently being developed methods and tools to create finished, high-performing products [37].

One billionth of a meter, or 109, is a nanometer (nm). Comparatively, a DNA double helix has a diameter of around 2 nm, and average carbon-carbon bond lengths, or the spacing between these atoms in a molecule, are in the range of 0.12 - 0.15 nm [38]. The bacteria belonging to the genus Mycoplasma, on the other hand, are the smallest known cellular life forms and measure about 200 nm in length. According to customs, nanotechnology is understood to cover the size range of 1 to 100 nm, as per the National Nanotechnology Initiative's definition in the US. Since nanotechnology must construct its gadgets from atoms and molecules, the lower limit is set by the size of atoms (hydrogen contains the smallest atoms, which are around a quarter of a nanometer kinematic diameter) [39,40]. The top limit is arbitrary, although it roughly corresponds to the size below which phenomena not seen in bigger structures start to emerge and can be utilized in the nano device. These novel phenomena set nanotechnology apart from devices that are essentially scaled-down counterparts of a comparable macroscopic device; these larger-scale devices fall under the category of microtechnology [41].

To put that scale in another context, a marble's comparative size to the size of the earth is the same as a nanometer's relative size to a meter or to put it another way, a man's typical beard grows one nanometer in the time it takes him to bring the razor to his face [42,43].

In nanotechnology, there are two main methods. In the "bottom-up" method, materials and gadgets are constructed from molecular building blocks that chemically assemble themselves according to molecular recognition principles [44]. The "top-down" method involves building nano-objects from larger things without using atomic-level control. Over the past few decades, fields of physics like nanoelectronics, nano-mechanics, nanophotonic, and nanoionics have developed to provide a fundamental scientific foundation for nanotechnology [45].

A materials perspective of larger to smaller

Today's synthetic chemistry has advanced to the point where practically any structure can be created for tiny molecules. Today, a large range of valuable compounds, including medicines and commercial polymers, are produced using these techniques [46]. This raises the question of how to take this level of control even further, looking for ways to put these single molecules together into supramolecular assemblies, which are made up of many molecules arranged in a specific way [47,48].

These methods use a bottom-up approach to automatically arrange themselves into a useful conformation by utilizing the ideas of molecular self-assembly and/or supramolecular chemistry [48]. The idea of molecular recognition is particularly crucial since molecules can be made to favor a certain configuration or arrangement due to non-covalent intermolecular forces. The Watson-Crick base-pairing rules, the ability of an enzyme to focus on a particular substrate, or the precise way in which a protein folds are all directly related to this [49]. Therefore, it is possible to design two or more components so that they work well together and are attractive to one another, creating a more complicated and effective whole [50].

Such bottom-up approaches could be overwhelmed as the size and complexity of the desired assembly develop, but they should be far less expensive and capable of generating devices in parallel than top-down systems. Most practical structures need intricate and improbable thermodynamic atom configurations [51,52]. Nevertheless, biology has a wealth of instances of self-assembly based on molecular recognition, most notably Watson-Crick base-pairing and enzyme-substrate interactions. Is it possible to design new structures in addition to natural ones using these principles? This is the problem for nanotechnology [53].

A long-term perspective on molecular nanotechnology

Molecular nanotechnology, often known as molecular manufacturing, refers to molecular-scale machines that are engineered nano-systems. The molecular assembler, a device that can create a desired structure or device atom-by-atom utilizing the concepts of chemosynthesis, is particularly connected with molecular nanotechnology [54,55]. The conventional technologies used to create nanomaterials like carbon nanotubes and nanoparticles are unrelated to manufacturing in the context of productive nano-systems and should be segregated from them [56].

The term "nanotechnology" originally referred to a future manufacturing technology based on molecular machine systems when it was independently invented and popularized by Eric Drexler (who at the time was not aware of an earlier usage by Norio Taniguchi) [56,57]. Because there are so many examples of complex, stochastically tuned biological machines in biology, it is known that molecular-scale biological parallels of conventional machine parts can show that molecular machines are feasible [58].

It is envisaged that advancements in nanotechnology may make it possible for their construction through a different method, possibly incorporating biomimetic principles. However,

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Drexler and other researchers have suggested that advanced nanotechnology, although it may be initially implemented through biomimetic methods, ultimately could be based on mechanical engineering principles, namely, a manufacturing technology based on the mechanical functionality of these components (such as gears, bearings, motors, and structural members), which would enable programmable, positional assembly to atomic specification. In his book, Nano Systems: Molecular Machinery, Manufacturing, and Computation, Drexler examined the physics and engineering performance of exemplary designs [5,59,60].

Since atoms of the same size and stickiness must be positioned on other atoms of similar size and stickiness, it is often highly challenging to manufacture electronics on the atomic scale. Carlo Montemagno offers a different perspective, arguing that future nano-systems would combine silicon technology with biological molecular machines [38]. Richard Smalley stated that the challenges of mechanically manipulating individual molecules make chemosynthesis impractical [40].

This resulted in a correspondence that was published in 2003's Chemical & Engineering News, an ACS magazine. Although molecular machine systems are demonstrably conceivable in biology, non-biological molecular machines are still in their infancy [61]. Alex Zettl and his team at UC Berkeley and Lawrence Berkeley National Laboratory are pioneers in the study of non-biological molecular machines. To regulate the motion of at least three different molecular devices, they have built nanotube nanomotors, molecular actuators, and nanoelectromechanical relaxation oscillators. There are more instances in the nanotube nanomotor [62].

Ho and Lee at Cornell University carried out a test that showed positional molecule assembly was feasible in 1999. They moved a single carbon monoxide molecule (CO) to a single iron atom (Fe) resting on a flat silver crystal using a scanning tunneling microscope, then utilized a voltage to chemically bond the CO to the Fe [23,63,64].

Current Research on nanotechnology [65]

Nanomaterials: The field of nanomaterials encompasses subfields that create or research materials with features brought on by their nanoscale dimensions [66].

Many materials that may be beneficial in nanotechnology, including carbon nanotubes and other fullerenes, as well as other nanoparticles and nanorods, have been developed thanks to interface and colloid science. Nanoionics and nanoelectronics are also connected to nanomaterials with rapid ion transport [67].

Most current commercial applications of nanotechnology are of this type, although nanoscale materials can also be used for bulk applications [41].

Utilizing these materials for medical purposes has advanced; see Nanomedicine.

To reduce the cost of conventional silicon solar cells, nanoscale materials like nanopillars are occasionally employed in solar cells [68].

The creation of semiconductor nanoparticle-incorporating applications for usage in the upcoming generation of goods, such as display technologies, lighting, solar cells, and biological imaging; see quantum dots [69].

Nanomaterials have recently been used in a variety of biological applications, including tissue engineering, medication transport, antibacterials, and biosensors [70].

Bottom-up strategies: These aim to assemble more intricate assemblies out of fewer components.

The precision of Watson-Crick base pairing is utilized in DNA nanotechnology for constructing well-defined structures out of DNA and other nucleic acids. In addition, "classical" chemical synthesis approaches, such as inorganic and organic synthesis, also aim to build molecules with well-defined shapes, such as bis-peptides [71].

Moreover, molecular self-assembly employs the concepts of supramolecular chemistry, specifically molecular recognition, to enable single-molecule components to spontaneously arrange themselves into useful conformations [72].

In dip-pen nanolithography, atomic force microscope tips can serve as a nanoscale "write head" to deposit chemicals in a desired pattern onto a surface. This technique is a part of the broader field of nanolithography [73].

Top–down approaches: These aim to produce tiny devices by assembling larger ones as a guide.

The term "nanotechnology" refers to a variety of processes that evolved from standard solid-state silicon methods for making microprocessors and are now capable of producing features smaller than 100 nm. This applies to existing giant magnetoresistance-based hard drives as well as Atomic Layer Deposition (ALD) technologies. In recognition of their contributions to the field of spintronics and the discovery of giant magnetoresistance, Peter Grünberg and Albert Fert was awarded the 2007 Nobel Prize in Physics [74].

Devices known as nanoelectromechanical systems, or NEMS, which are linked to microelectromechanical systems, or MEMS, can also be made using solid-state processes [75].

When adequate precursor gases are delivered simultaneously, focused ion beams can directly remove material or even deposit material. For instance, this method is frequently used to produce sub-100 nm material slices for transmission electron microscopy investigation [76].

Atomic force microscope tips can act as a nanoscale "write head" to deposit a resist, which is then removed via a top-down etching procedure [77].

Functional approaches: These aim to create components with the desired functionality without regard for how they will be assembled.

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The magnetic assembly allows the synthesis of anisotropic superparamagnetic materials such as magnetic nano chains, which were recently described [78].

The goal of molecular scale electronics is to create molecules with useful electrical characteristics. These single-molecule components might then be employed in a nano-electronic device. Rotaxane is one example [79].

Synthetic chemical processes can also be utilized to make synthetic molecular motors [80].

Biomimetic strategies: Bionics, also known as biomimicry, is the study and creation of engineering systems and modern technology using biological techniques and systems found in nature. One of the systems explored is biomineralization [81,82].

Bio-nanotechnology involves the use of biomolecules for nanotechnology applications, including the utilization of viruses and lipid assemblies. Nanocellulose, a nano-polymer commonly utilized for bulk-scale applications, is a green material that has piqued the interest of researchers in nanotechnology and green chemistry due to its beneficial qualities such as abundance, high aspect ratio, superior mechanical capabilities, renewability, and biocompatibility [83].

Conclusion

In conclusion, nanotechnology has emerged as a groundbreaking scientific discipline with profound implications for various fields. As we've explored, it has a rich history rooted in the manipulation of materials at the nanoscale, with significant contributions from visionaries like Richard Feynman and the coinage of the term "nanotechnology" by Norio Taniguchi in the 1970s. The scope of nanotechnology is vast and encompasses a wide range of applications, from medicine to electronics, energy, materials science, and environmental remediation. At its core, nanotechnology involves the deliberate control and manipulation of matter at dimensions typically between 1 and 100 nanometers, unlocking unique properties and behaviors that can be harnessed for innovative solutions.

Recent advances in nanotechnology have been nothing short of remarkable. In the realm of nanomedicine, researchers have made strides in targeted drug delivery and early disease detection, promising more effective treatments and improved diagnostic tools. Nanoelectronics continues to push the boundaries of miniaturization and computing power, while quantum nanotechnology holds the potential to revolutionize computing and communication. Energy applications have seen progress with nanomaterials enhancing solar cells and energy storage systems, contributing to sustainable energy solutions. Environmental remediation benefits from nanotechnology with efficient pollution control and clean water technologies. Additionally, advances in materials science have led to the creation of stronger, lighter, and more versatile nanocomposites.

Nanorobotics is on the horizon, offering the promise of molecular-level precision in fields such as medicine and manufacturing. Ethical considerations and safety protocols are receiving increasing attention to ensure responsible development and use of nanotechnology. Furthermore, the field has expanded its horizons into space exploration, where nanotechnology is being explored for various applications. In conclusion, nanotechnology's history is marked by visionary thinkers, its scope is limitless, and its recent advances are shaping a future filled with innovation and transformative solutions to some of humanity's most pressing challenges. As nanotechnology continues to evolve, it holds the potential to redefine industries, improve the quality of life, and address complex global issues. Keeping an eye on ongoing research and developments in nanotechnology is essential to fully grasp the extent of its impact on science, technology, and society.

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