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Nanomanufacturing in the 21st Century: A Review of Advancements, Applications and Future Prospects

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ABSTRACT

The demand for nanomanufacturing is driven by the current trend of decreasing product sizes and the energy consumed by large modules, which will be surpassed by the creation of nanoscale products with the same qualities and functionalities as large-scale products that consume little energy and have demonstrated functional results. Putting things together atom by atom is now possible because to new kinds of microscopes and innovative techniques for manipulating tiny amounts of materials. New solvents are actively sought for by green technology to replace common organic solvents, which have a high volatility and inherent toxicity that causes volatile organic chemicals to evaporate into the atmosphere. The number of reported publications has increased meaningfully over the preceding 20 years as a result of the scientific community's intense interest in ionic liquids. In this research nanomanufacturing is considered as a viable alternative in the 21st century, the uses of nanotechnology or nanomanufacturing in the twenty-first century were reviewed. This study explores various applications of nanomanufacturing, encompassing robotics, ultrasound, agriculture, and medicine.

1. INTRODUCTION

The process of producing items on a nanoscale is known as nano-manufacturing. This might be on the scale of between one and one hundred nanometers. The need for nanomanufacturing is driven by the current trend of shrinking product sizes and the energy used by large modules, which will be surpassed by the production of nanoscale products with the same properties and functions as large-scale products that consume little energy and have proven functional results [1]. Due to advances in engineering and nanoscale research, the first ten years of the twenty-first century saw the acceleration of invention and discovery. A larger degree of matter reformation at the molecular and atomic levels was made possible by nanoscale developments in knowledge about natural and man-made objects. This sparked the growth of nanotechnology, which then gave rise to the creation of nanomanufacturing.

Nanomanufacturing is described as the large-scale, economically viable manufacture of 1D, 2D, or 3D materials, structures, systems, and devices that can be scaled up commercially [1, 2]. In terms of research, nanomanufacturing differs from nanofabrication in that time to market, throughput, and cost are new parameters that are added to it. Nanomanufacturing relies on processes like top-down and bottom-up procedures, mass or replication conservation methods, additive or subtractive manufacturing, and top-down or bottom-up approaches [2]. Studies and advancements in the fields of nanoscience and nanotechnology have led to a fundamentally new knowledge of the behavior of materials and physical processes at the nanoscale. Discoveries of novel materials, structures, and gadgets have been made as a result of this understanding. It is anticipated that such expenditures in fundamental research will now result in new goods and applications. The consensus is that nanotechnology needs to transition from its core concepts to its practical applications, from the laboratories to the market. The general view is that in order to speed up the transformation of nanotechnology and the transfer of technology, we need to invest more quickly in study and development in the field of nanomanufacturing. Such an initiative will deliver on the promise of nanotechnology, which is to help society and the economy [3]. Nanomanufacturing entails the fabrication of materials or components at the nanoscale and the integration of their properties and resolution into systems that are built to meet specific requirements.

Nanoscale manufacturing enables the creation of unique properties, features, and functionalities with the highest degree of accuracy and control over both the methods and the materials used. Overcoming the difficulties posed by nanomanufacturing is also crucial if these goals are to be realized. Cost-effectiveness, product quality, intended functionality, process repeatability, and production scale are just a few of the issues that nanomanufacturing faces. Furthermore, it has become increasingly important to meet demand due to developments in the fields of materials, nanotechnology, manufacturing technology, and rising industrial demands [4]. Manufacturing is the main sector of international trade and the foundation of export-led growth. The hallmark of economic growth for more than two centuries has been a country's ability to convert physical raw materials into goods prized by end users around the world. No country has yet been able to successfully transition from exporting raw commodities into the global information economy without "producing goods" for external markets along the way, despite the fact that trade in intangibles and services has increased fast in recent decades [5]. There are numerous approaches that can create nanostructures, each with a different level of quality, speed, and cost.

Nanomaterials are more than just a subsequent stage in the material's miniaturization. These frequently need for quite distinct production techniques. A few nanomaterials are being commercialized, despite the fact that the majority are still being created in laboratories. Atom-by-atom or molecule-by-molecule construction of structures is a component of bottom-up manufacturing [6]. Nanotechnology is a field of applied science with practical uses at the nanoscale. Applications which benefit society can be made with nanomaterials' unique physical and chemical properties.

A megatrend that serves as a general-purpose technology is nanotechnology [7]. Because new technologies are developed daily, life is becoming more interesting. With a population that is expanding, it is vital to progress technology, conduct in-depth scientific research, and assure the widespread use of new cutting-edge technologies. One of today's most cutting-edge technologies, nanotechnology indicates that this will be the century of nanotechnology. The entire field of science and technology is concentrating its research on shrinking and compacting material. The approach for manipulating individual atoms and molecules called nanotechnology. It is described as the research and application of structures with a size between one and one hundred nanometers. To put that in perspective, the breadth of a human hair would require 800 100 nanometer particles placed side by side [8]. Top-down or bottom-up manufacturing are the two main methodologies used in nanomanufacturing, which produces new and improved materials. Similar to someone carving a figure out of a block of wood, top-down fabrication reduces big chunks of material to the nanoscale, although this can produce waste. Items are built at the atomic level from smaller-scale components in bottom-up nanomanufacturing and molecular levels. While being more time-consuming than the top-down approach, it is less wasteful [9].

2. NANOMANUFACTURING

Ikumapayi and Akinlabi [9] investigated the characteristics and functionality of 2D nanomaterials depends on their topology. Due to the extensive restacking of the nanosheets, membranes and films made of 2D nanomaterials typically exhibit high tortuosity and are therefore only marginally useful for electrodes for supercapacitors and batteries, which need ion transport through the nanosheet thickness. Table 1 shows the categories of nanomaterials.

A more practical method to enhance molecular transport is to construct holey 2D nanomaterials through the nanosheets while retaining the 2D-related features, as opposed to traditional porous 2D nanomaterials [10]. Here, the fundamental structure-property relationship as a result of defect-enabled hole generation is studied using graphene as a model. In order to investigate specific phenomena of high value for technological applications in interdisciplinary domains includes biotechnology, medicine, and advanced materials using ad hoc nanostructured platforms as templates with controlled morphology and chemical characteristics. The creation of integrated methods for their synthesis and characterization is given a lot of attention [11]. Nanoparticle manufacturing is essential for possible commercialization and translation. This demand can be met by continuous flow devices by continuously producing nanoparticles. Here, we show how a mesofluidic, continuous flow approach may be used to scale up the synthesis of spherical nanoparticles functionalized with biomedical cargos from the tobacco mosaic virus (TMV), a rod-shaped plant virus [12]. Semiconductor 2D films that are atomically thin have shown promise as components for electrical, optoelectronic, sensor, energy-conversion, and storage systems in the future. The unique physical properties of semi-conducting transition metal dichalcogenide (TMDC) components, such as $WSe2$, $MoSe2$, $WS2$, and $MoS2$ have attracted considerable interest due to their dependence on the number of layers. Unlike other 2-dimensional substances such as zero-bandgap graphene, these sorts of materials undergo a transition from an indirect bandgap in the bulk phase to an enhanced, direct bandgap in the monolayer. As an illustration, monolayer $MoS2$ possesses a direct bandgap of 1.8 eV, but bulk MoS 2 has an indirect bandgap of 1.2 eV [13].

Table 1. Categories of nanomaterials

	Categories of Nanomaterials	Examples
1	One dimensional nano-materials	Thin films, multi-layers, surface coatings, and platelets. They have been produced and used over numerous years, namely in the field of electronics.
2	Two dimensional nano-materials	Nanofibers and nanowires are composed of several elements, excluding carbon. Carbon nanotubes are a specific type within this category.
3	Three dimensional nano-materials	Nanoparticles encompass several types such as forms precipitates, colloidal particles, miniaturized quantum dots (minute particles of semiconductor and material), and nanocrystalline substances.

The difficulty of developing low-cost, high-throughput, and highly repeatable scalable nanomanufacturing procedures to generate functional materials is a significant barrier to the practical inclusion of nanostructured materials into emerging applications [14]. Graphene and carbon nanotube roll-to-roll manufacturing has finally made it possible to continuously produce high-quality coatings and filaments, which has led to the development of flexible and wearable electronics, woven textiles, and cables. These applications frequently call for particular electrical characteristics, necessitating exact control over the micro- and nanostructure of the material. Although closed-loop processing techniques can theoretically be used to achieve such control, there aren't many options for detecting the electrical properties of materials on a moving web at the speed required for modern nanomanufacturing that are noncontact and nondestructive [15]. The capacity to strategically design and produce large quantities of one-dimensional nanowires through advanced engineering and nanomanufacturing techniques has the potential to facilitate the utilization of nanostructured materials in various domains, such as energy conversion and storage, catalysis, sensing, medicine, and information technology [16]. Scatterometry basic samples of high quality have been developed to facilitate the accurate measurement of crucial dimensions in lithographic nanomanufacturing. These samples also aim to enhance the compatibility between different scatterometry approaches and instruments, as well as with high-resolution microscopic methods such as scanning electron microscopy or atomic force microscopy [17]. The objective is to develop planar arrays of silicon electrospinning emitters that are externally fed, and then analyze their properties for the purpose of producing polymer nanofibers in large quantities. The measurement involved using a solution consisting of PEO dissolved in a mixture of water and ethanol. The arrays that were examined contained a maximum of 225 emitters, with an emitter density of up to 100 emitters per square centimeter. Devices with emitter concentrations of up to 25 emitters per cm2 create consistent impressions composed of fibers that are a few hundred nanometers wide or smaller [17]. A thorough investigation was conducted on the chemical vapor deposition process using aluminum (Al) and ammonia (NH_3) as source materials. The study focused on the development of aluminum nitride (AlN) nanowires, both with and without the use of catalysts. The majority of growth experiments have been performed at a temperature of 1100°C, using hydrogen gas as the carrier gas. The presence of a catalyst facilitated the formation of short nanowires measuring 3-5 m, while the absence of a catalyst resulted in the creation of long (40 m) and tightly packed sheets of AlN nanowire arrays. The processes of growth have been explained. The Raman spectroscopy of the catalyst-free generated nanowires revealed the presence of robust and highly symmetrical phonon modes, particularly the strong E2 (high) phonons. This observation indicates the excellent crystal quality of the grown AlN nanowires. Simply put, catalyst free growth prevents catalyst contamination and produces long nanowires that are of exceptional quality and density. This is especially advantageous for the potential of scaling up the production of AlN nanostructures [18].

Scale-up research for nanomanufacturing (NM) has emerged as a new area of study to keep up with the growing demand for NM. Establishing modeling, simulation, and control approaches that permit and support profitable manufacturing at commercial scale is a part of the scale-up methodology study. In order to explore several process modeling approaches for scalable NM, semiconductor nanowire growth is utilized as an example. NM process modeling serves as the foundation for process monitoring and control, guided inspection and sensing strategy, and more-efficient experimental design strategy [19]. New materials, broadly construed to encompass molecules and devices, can be created using nanomanufacturing processes. These novel materials can be nanoscale in one dimension, such as nanowires and nanotubes, or tiny in two dimensions, such as very thin films, layers, and surfaces (nanoparticles) as illustrated in Table 1. It is projected that many manufacturing businesses would make extensive use of this abundance of new nanoscale surfaces, wires, and particles [20]. The term "nanomanufacturing" refers to the high-volume, low-cost, and reliable production of products based on nanotechnology at industrial scale. These developments will hasten the manufacture of commercial goods and open the door for the development of a new generation of uses in a variety of diverse commercial fields, such as cosmetics, biomedical implants, electronics, optical parts, automotive, and aerospace components, as well as medicine delivery [21]. The development of carbon nanopipettes and endoscopes to examine individual living cells has received a lot of attention. These gadgets have been employed as single cell injectors, electrodes, and sensors with success. One carbon nanotube is attached to the end of a drawn glass capillary in each of these devices [22]. One way for producing nanodots, nanolines, and two- or three-dimensional nanostructures on flat or even curved surfaces is the tip-based nanomechanical technique of the atomic force microscope (AFM). This approach has unique qualities including low cost, simplicity, great accuracy, and variable control. Prior to reviewing the applications of these structures, the advancements in these fields are first evaluated. Second, new nanomanufacturing techniques are developed in order to broaden the use of the TBN techniques by integrating chemical and thermal energy with mechanical effects [23].

Materials have a distinctive electronic band structure when they approach the size of 10 nm, which is not seen in conventional bulk materials. Because the changed band structure displays unheard-of electrical, optical, and magnetic capabilities that are missing in their bulk equivalents, it opens up new possibilities for technological innovation in the future. In the past few years, fabrication and manufacture of such unique nanomaterials have greatly advanced [24]. Nanofabrication and nanomanufacturing are terms used to describe the production of materials, structure, devices, and processes at the nanoscale. The two primary classifications of fabrication—top-down and bottom-up or self-assembly processes—use an increasing number of physical and chemical methods, including synthesis method, chemically vaporized deposition, molecular beam epitaxy, successive ionic layer epitaxy, lithography, and countless newly developed techniques. Due to its extremely coherent feature, laser-assisted nanomanufacturing stands out among these techniques [25]. Facilitating the ability to incorporate nanotechnology's inventive and added value into applications is crucial from the standpoint of growth. This means that in order to design, create, sell, adopt, and execute nanotechnology-based customer-oriented applications, the knowledge of nanotechnology generated in knowledge-intensive businesses must be transformed and/or transmitted [26]. The innovation development process is not linear, but rather cyclical with concurrent and repeated loops at the organizational level, from R&D to invention to market-ready applications. As a disruptive technology, nanotechnology has the potential to open up hitherto untapped markets. This gives new procedures for the development and commercialization of nanotechnology in a global market arena additional dimensions and obstacles, particularly for small nanotechnology enterprises [27]. Fast, affordable, in high-volume nanomanufacturing, nondestructive and accurate feature measurements are particularly beneficial. To provide effective process control. The high throughput, low cost, and minimum sample damage of optical scatterometry make it one of the most appropriate methods out of all those that may be used. Unfortunately, this method is fundamentally constrained by the instrument's illumination spot size and the poor efficiency in mapping the sample over a large area [28]. A potent method for creating unique nanomaterials is self-assembly, which relies on a variety of noncovalent interactions, including electrostatic, hydrogen bonding, hydrophobic, and aromatic stacking. Size and form of nanoparticles are connected to their fundamental features. Size affects material absorption and biodistribution by determining the surface-to-volume ratio. For instance, drug-loaded nanoparticles can only be used for site-specific drug delivery when blood circulation and absorption are possible. Due to issues with size, overcoming Blood Brain Barrier and Blood Retina Barrier-like issues remains a difficult undertaking for site-specific medication delivery [29].

2.1 Nanomanufacturing applications in the 21st century

With a population that is expanding, it is vital to progress technology, conduct in-depth scientific research, and assure the widespread use of new cutting-edge technologies. One of today's most cutting-edge technologies, nanotechnology indicates that this will be the century of nanotechnology. Particle size reduction and material compacting are the main research areas for science and technology [29]. The approach for manipulating individual atoms and molecules called nanotechnology. It is described as the research and application of structures with a size between one and one hundred nanometers [30]. To put that in perspective, the breadth of a human hair would require 800 100 nanometer particles placed side by side. The capacity to observe nanoscale materials has made a wide range of commercial and scientific initiatives possible. Nanotechnology has a wide range of uses because it is simply a collection of methods that enable property manipulation on a very small scale. This paper addressed the following applications of nanomanufacturing: robotics, ultrasound, agriculture, and medicine.

2.1.1 Application of nanotechnology in robotics

According to Xi et al. [28], robotics has significantly impacted various industries in the last century, leading to substantial global prosperity by increasing production and efficiency. However, the global integration of the economy and the rapid progress of emerging technologies such as information technology, nanotechnology, and biomedical technology, have presented robotics with fresh challenges and prospects in the early years of the twenty-first century. Ultra-robotics is an emerging technology that enables automation to exceed its traditional limitations and operate in distant and tiny environments that were previously inconceivable [31]. Unmanned systems are gaining acceptance in various new domains and applications, in addition to their increasing popularity in the fields of robotics, aerospace, defense, and military. The unmanned systems sector is expanding due to several aspects, including the benefits of autonomous mobility, enhanced safety, remote operation, remote data collection, and improved repeatability. The Micro Electro Mechanical System (MEMS) is considered the most advanced technology following Very Large Scale Integration (VLSI) [32]. Soft robots have emerged as a new field of research in robotics, thanks to their impressive performance achieved through the use of functional materials and advanced fabrication processes. Recent breakthroughs in functional materials have significantly expanded the possible uses of soft robots in several industries, enhancing their functionality. Researchers have shown significant interest in applications within the biomedical sector, which has subsequently led to its growth as an industry. There is currently a need for biomedical soft robotics and integrated manipulatable devices that are on a submillimetre scale, have strong controllability, and are compatible with the human body. The functionalities of these biomedical soft robots are mostly dominated by nanomaterials and nanotechnology [33]. Automation has been the focal point in biomedical research. Effective liquid management is an essential element of every nanotechnology laboratory. Previously, the manipulation of liquids included a tedious procedure where the user manually dispensed liquid chemicals using a pipette. Manual labour is often associated with limitations in time and space, human error, and practical trial and error. Errors can occur in human performance during repetitive tasks, leading to a range of issues [34]. Figure 1 depicts AI-powered workstation.

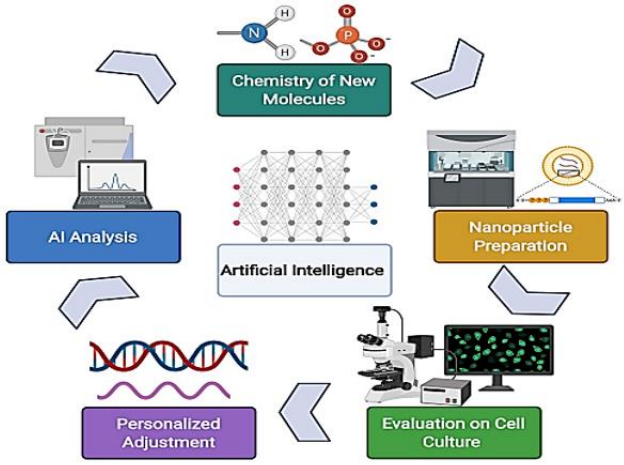

Figure 1. Diagrammatic representation of an AI-powered workstation

The genetic evaluation of specific patients and the personalization of treatment options will serve as the foundation for a viable AI-guided robotic nanoparticle manufacturing and analysis system. The nanoparticle will then be created and put through its paces in automated systems in cells and organs on chips. The AI system will eventually be able to identify the ideal formulation and treatment for specific patients in order to maximize responsiveness and get the greatest results [35].

The term "nano-robots" refers to any robot that can be controlled at the molecular or nano (10^{-9} meter) size and is made up of nano-components. More specifically, the term "nano robotics" refers to the as-of-yet entirely speculative technical profession of creating nanorobots. Although there are many commonalities in design and control approaches that could potentially be projected and used, the area of nano robotics is fundamentally distinct from that of macro robots due to the variations in scale and substance [36]. Modern technological advancements have made it possible to try building nanorobotic systems and interface them with the larger environment for control. There are innumerable examples of these machines in nature, and it is possible to create more by copying nature. These nano robots are becoming extremely important in the field of biomedicine. Particularly in the treatment of cancer, the removal of kidney stones, the treatment of cerebral aneurysms, the removal of cancerous kidney stones, the removal of the defective portion of our Genetic structure, and some other treatments that are most effective in saving human lives [37].

2.1.2 Autonomous ultrasound

Consider scanning tissue for anomalies. Due to substantial advancements in microsystem and signal analysis, new technology utilizing acoustic holography is now feasible for the early diagnosis of diseases like cancer. Although holography technology has been around for more than 25 years, its utility in the clinical/diagnostic setting has not yet been realized due to a lack of cutting-edge microsystems and signal analysis technologies. What has been lacking is a conversion component that can record the ultrasound interference patterns, reconstruct them using a real or artificial ultrasound interference pattern, and then reconstruct them using actual or artificial ultrasound frequency waves that can be converted directly into a visible image [38]. Nanotechnology is a multidisciplinary scientific field that is quickly developing and involves the systems/device production at the molecular level. The development of nanotechnology was spurred on by the potential for revolutionary improvements in robotics, communications, genetics, and medicine. Miniaturization looks to offer mechanical, chemical, and biological components that are more readily available and operate more swiftly. The less apparent nature of the amazing self-ordering and assembly behaviors exhibited by nanoscale items is due to the influence of forces that differ significantly from those acting on macroscale structures [39]. Nano-robots are controlled machines at the nano (10^{-9}) meter or molecular scale, composed of nano-components. Nano robotics is a branch of nanotechnology that especially deals with the design and construction of minuscule robots. However, it is important to note that the field is mostly based on theories and concepts rather than practical applications at present. Although nano robotics and macro robots differ in scale and material, there are significant similarities in design and control methodologies that can potentially be extrapolated and implemented. Recent scientific developments have enabled the creation of nano robotic devices that can be connected to and controlled by the wider environment [40]. Nanorobots are expected to have remarkable prospects for use. An intriguing application is the utilization of nanorobots to establish connections with migratory white blood cells or inflammatory cells, allowing them to reach inflamed regions and facilitate the process of healing. Nanorobots will be employed in chemotherapy to cure cancer by precisely giving specific chemical doses. A comparable approach could be utilized to enable nanorobots to dispense anti-HIV drugs. Freitas uses the term "pharmacytes" to describe nanorobots that are responsible for delivering drugs [41]. Nanorobots are of such minuscule size that they possess the ability to navigate effortlessly within the human body. Scientists claim that diamond is the preferred material for the outer surface of nanorobots due to its strength and inertness. Super-smooth surfaces can decrease the likelihood of immune system activation, enabling the nanorobots to operate without interference. The nanorobot may utilize oxygen, glucose, or other physiological sugars as a means of locomotion, depending on its intended function. Additionally, it could contain various biological or molecular constituents [42].

2.1.3 Applications of nanomanufacturing in agriculture

Kokabi and Yousefzadi [40] narrated that Nanotechnology in agriculture is seen to be a new, promising strategy to improving the safety and production of food globally. In all phases of agricultural product development, manufacture, processing, packing, storage, and transportation, equipment and instruments such nanoparticles, nanocomposites, nanocapsules, and sensors can be used. Figure 2 illustrates the generation of Metal ion reduction, metal ion entrapment, and nanoparticle.

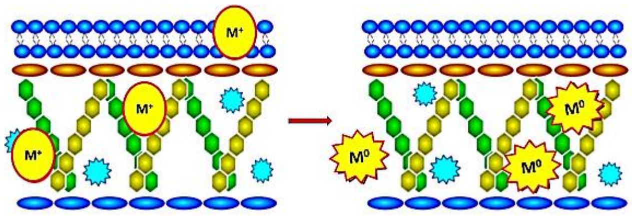

Figure 2. Metal ion reduction, metal ion entrapment, and nanoparticle creation [43]

The use of biosynthesized nanomaterials in agriculture, utilizing biological reducing agents such as plant extract, biowaste, and microorganisms like bacteria, fungi, and algae, has been suggested as a potential alternative to chemical and physical methods [43]. The synthesis of diverse nanomaterials holds significant potential for harnessing abundant sources of novel bioactive compounds, such as micro- and macroalgae. A wide range of algae species have been proven to have the ability to create environmentally friendly metal nanoparticles, such as silver, zinc, gold, palladium, and others [44]. Nanotechnology can be used to precisely control the distribution of pesticides, herbicides, and fertilizers, which can improve the safety of agricultural products, increase food production efficiency, and reduce environmental pollution. Currently, nanotechnology plays a crucial role in cutting-edge agriculture. Illustrations encompass intelligent delivery systems capable of pinpointing precise places and nano carriers for controlled release of chemicals. Biopesticides and biological nanomaterials are crucial in pest management, and numerous research endeavors worldwide are presently transitioning from chemical-based agriculture to environmentally-friendly agriculture. However, there is limited data regarding their environmental behavior, making it challenging to evaluate the novel hazards and benefits with those of the currently used agrochemicals [45]. Various industries are presently showing interest in diverse molecular nanomaterials, along with their manufacturing, analysis, and notable applications [46]. Nanomaterials have several applications in agriculture, such as nano transport, nanosensors, nanopesticides, nanofertilizers, and nanoencapsulation of insecticides. Nanosensors are employed for disease and toxin detection in water, whereas nanodelivery is utilized for the administration of veterinary products to fish food. Nanosensors have the capability to detect nutrients, herbicides, pollutants, and monitor post-harvest management of agricultural products to extend their shelf lives. Nanoscale pesticides enable the efficient management of plant diseases, precise delivery of nutrients and biomolecules, retrieval of nutrients, sanitization and purification of water, agronomic fortifications, and intelligent distribution of fertilizers [46, 47].

In order to enhance productivity while utilizing cost-effective resources, it is imperative to enhance the food and agriculture sector. To enhance the use of water in different situations, we can utilize nanomanufacturing techniques to develop a wastewater filtration system capable of eliminating salt particles from the water [47]. Nanomanufacturing enables the production of nanoscale pesticides, which can be applied in the field at lower rates and are quickly absorbed. By utilizing nanoparticles [48], we are able to distribute fertilizers and pesticides precisely and timely to the specified spot. Non-industrialized remnants, namely (products), are manufactured in large quantities, making them the most thoroughly studied biomasses due to their composition of lignin, fiber, and hemi fiber. The utilization of rice waste for the purpose of consolidating large quantities of materials was initially seen. However, in recent times, there has been significant progress in the development of versatile nanostructures derived from residual rice, which are currently gaining considerable interest due to their affordability. The potential applications of carbon-based nanomaterials, including graphene, carbon nanotubes, carbon dots, fullerenes, and carbon nanofibers, are highly promising [49]. Nanoscience and nanotechnology have emerged as a distinct field of study due to their wide range of applications, garnering global attention. In the past, nanoparticles were typically produced using conventional physical and chemical methods. The recent development and use of new technologies have led to a new trend known as the nano-revolution. This movement highlights the significance of plants in the bio- and green production of nanoparticles. This tendency has clearly drawn significant attention to the production of stable nanoparticles [50]. Plants, because of their vast biodiversity, serve as an abundant source of natural resources on our planet. Since ancient times, humans have utilized plants for their personal advantage, thereby influencing the biosphere and its inhabitants. Throughout history, plants have provided humanity with a multitude of benefits, and humans have constantly utilized them to fulfill various requirements. Enhanced utilization of plants relies on a more profound understanding of the interconnection between individuals and the plant life in their surroundings. The recent adoption of new technologies and enhanced scientific understanding in the field of plant biology has garnered significant attention due to its potential for bioprospecting and reformulating plants for diverse purposes. Nanoparticle synthesis analysis is a field that is becoming increasingly important [51]. In the current nanomanufacturing techniques of the CNMs. Thermal treatment was applied to waste tire chips, post-consumer polyethylene (PE) and polyethylene terephthalate (PET) bottle shreds, agricultural sugar cane bagasse and corn residues. The thermal treatment methods used included solo pyrolysis, sequential pyrolysis, and partial oxidation. The gaseous carbon-bearing effluents were subsequently directed in a heated reactor. Catalytic synthesis of carbon nanomaterials, such as carbon nanotubes, was performed on stainless steel meshes [52]. Plant-mediated nanoparticle synthesis is advantageous due to its simplicity, cost-effectiveness compared to microbial alternatives, eco-friendliness, safety, and potential for long-term commercial viability. This method involves using both entire organisms and cell-free extracts. A microwave-assisted methodology has been devised to manufacture dendritic silver nanostructures using silver nanoparticles (AgNPs). This method is uncomplicated, ecologically benign, affordable, and rapid. This technique utilizes an aqueous extract derived from white grape pomace (WGPE) as both a reducing and capping agent. In order to accomplish this, different proportions of WGPE and $AgNO3$ (1 mM) were mixed together, and the resulting mixture was exposed to microwave radiation at a power of 700 W for duration of 40 seconds [53].

2.1.4 Application of nanomanufacturing in medicine

Molecular nanotechnology will unquestionably serve as the fundamental technology for medicine in the 21st century. Nanotechnology enables meticulous manipulation of biologically relevant structures at the molecular level as depicted in Figure 3. Nanomedicine is now exploring the application of carbon buckyballs, dendrimers, and other precisely engineered nanoparticles in novel therapeutic approaches to combat viruses, germs, cancer, and medication delivery. Medical nanorobots, which are the size of microbes, will possess built-in sensors, computers, manipulators, pumps, pressure tanks, and power supplies, enabling them to self-replicate. In order to develop complex molecular machine systems, nanofactories will require the usage of massively parallel assembly lines for molecular manufacturing [54].

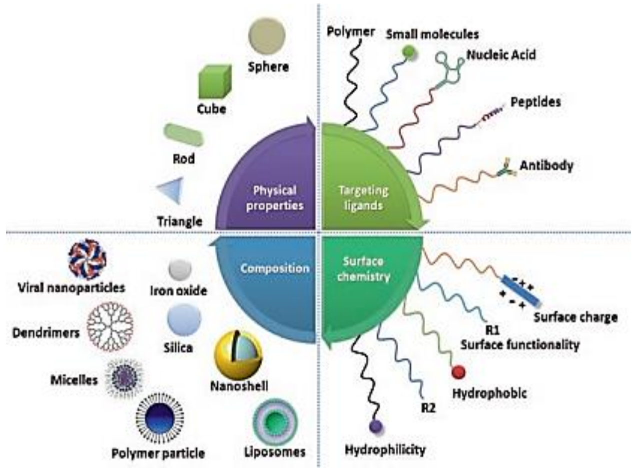

Figure 3. Composition, physical properties, targeting ligands and surface chemistry of nanotechnology [55]

The several types of medication delivery techniques based on nanotechnology are shown in this graphic. There are many different kinds of ligands, including peptide, antibody, adjuvants, nucleic, sugars, and small compounds. Nanotechnology used in medicine typically entails precise molecular control over medically important structures. Dendrimers, which are spherical molecules resembling trees, carbon buckyballs, and other skillfully created nanoparticles are currently being studied in nanomedicine in an effort to develop new medications that can fight cancer, viruses, and bacteria. But, we might discover how to create the first medical nanorobots in 10–20 years [55]. There will be microscopic objects with built-in sensors, computers, manipulators, pumps, pressure tanks, and power sources, but they won't be able to reproduce themselves. In order to construct advanced molecular machine systems, it will be necessary to have the capability to create objects with atomic precision, preferably using materials like diamond that are rigid [56]. Additionally, the ability to create large quantities of precise objects will be required, which can be achieved through massively parallel assembly. There is increasing optimism that the application of nanotechnology in the fields of dentistry and medical may lead to substantial advancements in disease detection, treatment, and prevention. The growing interest in the potential medical applications of nanotechnology has led to the development of a new field called nanomedicine [57]. In order to enhance our comprehension of the underlying mechanisms of disease, provide more sophisticated diagnostic options, and develop more potent therapies and preventive measures, nanomedicine needs to overcome the barriers that hinder its utilization. With the introduction of medical robots, doctors will have the capability to efficiently cure the majority of known diseases that today cause severe disability and mortality. Additionally, they will be able to promptly repair most physical injuries that our bodies can endure, leading to a substantial increase in human lifetime. Molecular technology [58] will serve as the fundamental technology for the future.

2.4 The impact of nanomanufacturing in the 21st century

The developments in manufacturing technology and quantum physics have led to a daily influence of nanotechnology and nanomanufacturing on our lives. These advancements have led to the development of nanosensors. A nanosensor is a device that has at least one dimension on the nanoscale and is capable of converting a signal to detect materials or phenomena at the nanoscale. Nanotechnology is poised to become the primary driver of economic growth and prosperity in the future as seen in Figure 4. Nanotechnology has recently been incorporated into various domains of life, encompassing hydrogen fuel cells, medical applications, solar cells, electronics, food production, energy generation, and environmental preservation.

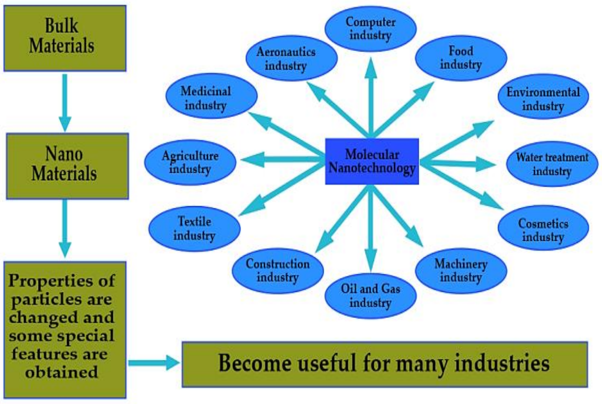

Figure 4. Impact of nanotechnology in the 21st century

Nanosensors can be used independently or as integral parts of bigger systems as depicted in Table 2. Nanosensors, despite their relatively recent development of just over a decade, have already exhibited their potential in various areas such as homeland security, imaging, health (see Figure 2), the food industry, and environmental protection [59]. Nanoscale materials, structures, electronics, and systems can be manufactured in large quantities, with a high level of dependability, and at an affordable cost. Nanomanufacturing techniques encompass additive, subtractive, and replication/mass conservation procedures, which can be classified into top-down and bottom-up methods. The term "nanotechnology" refers to a field that involves several techniques such as nanomachining, nanofabrication, and nanometrology. These techniques are used to develop components for nanotechnology and evaluate them [60]. The developments in manufacturing technology and quantum physics have led to the daily impact of nanotechnology and nanomanufacturing on our lives. The introduction of these advancements has led to the development of nanosensors. A nanosensor is a device that has at least one dimension on the nanoscale and is capable of converting a signal to detect materials or phenomena at the nanoscale. Nanosensors can be used independently or as integral parts of bigger systems.

Nanosensors have only been around for a little more than ten years, but in that short time, they have already demonstrated their potential in a wide range of industries, including homeland security, imaging, medicine, the food industry, environmental protection, and many more [61]. In addition to the demand for more and more complex novel devices and structures features, the trend of reducing product component sizes, material usages, and energy consumption also drives the need for nano-manufacturing. The development and widespread use of nanofabrication technologies is a logical next step to take in order in order to fulfill customer demands for product simplification and novel functionality enabled by nano-materials and structures [62]. For a number of years now, it has been acknowledged that items made possible by micro- and nanotechnologies (MNT) will play a significant role in the future of manufacturing and industry in developed nations. These items will investigate the opportunities that the developments in materials and structuring technologies will present for integrating functionality, mobility, and intelligence in gadgets [63]. The practical result of the nanotechnology revolution is nanomanufacturing, which is the mass manufacture of nanoscale materials and electronics that is economically viable and commercially scaleable. Processes used in nanomanufacturing must also adhere to extra cost, throughput, and time to market constraints, as opposed to those utilized in nanofabrication for research reasons. Using silicon integrated circuit production as a starting point, it is examined the characteristics and potential of top-down and bottom-up processes, as well as their combination, to determine the factors involved in matching processes with products [64].

Table 2. Standalone devices and functional components of larger systems

Devices	Area of Sensor/Operation Mode	Measured Parameters
PPG ring	Finger/reflective	Heart rate variability, SPO_2
Pulsar	External ear cartilage/reflective	Heart rate
Fore-head mounted sensor	Forehead/reflective	SPO_2
e-AR	Posterior and inferior auricular/ reflective	Heart rate
IN-MONIT system	Auditory canal/reflective	Heart activity and heart rate
Glove and hat based sensor	Finger and forehead/reflective	Heart rate and pulse wave transit
Ear-worm monitor	Superior auricular/reflective	Heart rate
Headset	Ear lobe/transmissive	Heart rate
Heart-phone	Auditory canal/reflective	Heart rate
Magnetic earing sensor	Ear-lobe/reflective	Heart rate
Eyeglasses	Nose bridge/reflective	Heart rate and pulse transit time
Ear-worm PPG sensor	Ear-lobe/reflective	Heart rate
Smart phone	Finger/reflective	Heart rate

One of the cutting-edge areas in the advancement of manufacturing technology is ultrafast laser micro/nano manufacturing. By interacting with materials, In order to regulate material for processing between millimeter to nanometer sizes or across scales, ultrafast lasers can modify their states and properties. Due to their extremely short time scales (1015 s) and high energy density (> 1014 W/cm^2), as well as the ability to focus into nanoscale spatial dimensions (109 m), femtosecond lasers are known to impose severe conditions in their interactions with target materials. Due to these properties, femtosecond lasers are able to fabricate complex three-dimensional structures and process practically any material with great quality and precision [65]. With additive manufacturing, it is now possible to produce unique parts and specialized components at a low cost. Such approaches are less common at the nanoscale. The majority of lithography equipment used in nanoscale manufacturing is out of reach for small and medium-sized businesses (SMEs). Smaller facilities may design, produce, and manufacture on their own thanks to additive nanomanufacturing (ANM), which also offers a greater variety of materials and flexible design. This is particularly crucial because, up until now, most nanomanufacturing has been limited to 2-dimensional patterning techniques, and being able to manufacture in 3-dimensions could lead to new ideas [66]. To fulfill the potential of nanotechnology, nanoscale manufacturing techniques are crucial; without ways to quickly produce and test new ideas, progress in this developing sector may be hindered. Rapid prototyping and low volume production using additive manufacturing are already used in industries including automotive, aerospace, fashion, and entertainment [65, 66]. In a variety of industrial areas, including the electronics, optics, medical, biotechnology, and automotive industries, the need for micro products and micro components has grown quickly. Examples of applications include medical implants, drug delivery systems, diagnostic tools, connectors, switches, micro reactors, micro engines, micro pumps, and printing heads. These microsystems-based products serve as essential value-adding components for many businesses and are thus crucial to a sustainable economy. There is a demand for improvements in micro and nano manufacturing technologies and their integration in new manufacturing platforms as a result of the present trend toward product miniaturization. These platforms must support both lengthscale integration and function integration, which involves combining the macro, micro, and nano dimensions, in order to in both new and old products, as well as the efficient use of a variety of resources in their production [67].

Cummins et al. [68] stated that in order to examine the environmental effects of nanomanufacturing, life cycle thinking must inexorably be incorporated into the development of nanotechnology. Although there have been many questions about the benefits of employing nanoproducts for human and ecological health, there hasn't been much focus on the production process. Nanomanufacturing methods, in contrast to many standard manufacturing methods, call for special facility and process design as well as operation and management. Because of this, many nanomanufacturing techniques may have a more negative impact on the environment than many other conventional approaches. If advancements in the use of polymer materials in electrical, magnetic, and optical devices are to be maintained, a key objective is the reproducible manufacture of nanostructures, or structures with feature sizes below 100 nm. Micrometer-sized features have been produced in large quantities using replica molding [69]. In many applications, nanomanufacturing is crucial for creating high-performance products. The inability to connect to and interface with nano/micro production equipment is a difficulty for the fabrication of products using nanomaterials [70]. In the 1990s, there was a discussion about using tip-based mechanical methods to remove material and build features at the nano-scale level. The utilization of surface characterization instruments such as scanning tunneling microscopes (STMs), atomic force microscopes (AFMs), and nano-indenters has been motivated by the flexibility, geometric capacity, and broad material suitability of mechanical removal methods. AFMs have been used to create basic features such as lines and pockets on semiconductor, metal, and polymer/photoresist surfaces. These features were produced by applying significantly greater force than what is typically used for measuring topography [71]. Bottom-up fabrication techniques are crucial for the advancement of nanomanufacturing. Nanomanufacturing is based on advanced techniques to produce economically and socially desirable things, specifically low-cost consumer goods that are both functional and power-efficient. A thorough understanding of nanoscale fabrication methods is crucial for the advancement of nanomanufacturing in order to produce functional everyday devices. This article explores emerging domains where nanostructured and nanopatterned surfaces can be utilized in innovative manners. These include the application of nanostructured biomaterial devices for health monitoring, the implementation of displays with nanotextured surfaces, the utilization of nanoporous membranes for ultrafiltration, and the employment of nanosensors for environmental analysis. This article explores further emergent concerns in nanomanufacturing, which has traditionally been centered around silicon manufacturing for semiconductor processing [72].

Nanoscale materials, structures, electronics, and systems are produced at scales that are reliable, cost-effective, and efficient. Nanomanufacturing techniques can be classified into top-down and bottom-up approaches, as well as replication/mass conservation, subtractive, and additive processes. Their activities encompass the manufacturing of nanotechnology components and the assessment of their performance by various methods, such as nanomachining, nanofabrication, and nanometrology [73]. Accurate nanomanufacturing at the nuclear level is essential for the advancement of nanoelectronics with new capabilities. In this study, we demonstrate the utilization of shear-induced mechanochemical mechanisms to selectively eliminate particular atomic layers from a surface of single crystalline silicon without the need for a mask or chemical agents as depicted in Figure 5. Chemical reactions only affect the topmost atomic layer visible at the interface. Therefore, it is conceivable to remove a single atomic layer without causing any damage to the crystalline lattice beneath the processed area [74].

Micro- and nanotechnology depend heavily on positioning systems with resolution and precision on the order of nanometers. Nanopositioning stages are frequently employed in many different applications, including optical alignment, micro-/nanomanipulation, and scanning probe microscopy. Flexure-based structures are used by the majority of cutting-edge nanopositioners because of their excellent durability without degradation or wear as well as their motion is frictionless and supple action. To achieve motion with nanometer-level resolution, flexure-based mechanisms are frequently combined with the use of high-resolution displacement sensors and piezoelectric actuators [75]. The importance of lightweight metal matrix nanocomposites (MMNCs) for automotive, aerospace, and a variety of other applications can't be overstated. The manufacture of bulk components of MMNCs based on aluminum would benefit from the development of efficient nanomanufacturing processes. But evenly dispersing nanosized ceramic particles in molten aluminum is incredibly challenging [76]. Since the wonderful discovery of graphene, there has been a great deal of interest in and research into two-dimensional materials. Van der Waals (vdW) materials have a tremendous amount of potential for use in upcoming optoelectronic devices because of their distinctive physical, mechanical, and optical characteristics. The atomically thin regime of nano-engineering and nano-manufacturing has further opened up a wide range of opportunities to investigate unique physical features. Among these, intricate superconductivity, orbital magnetism, flexible nanoelectronics, and incredibly efficient photovoltaics are just a few of the exotic and topological phenomena that have been made possible by moiré heterostructures, strain engineering, and substrate manipulation [77].

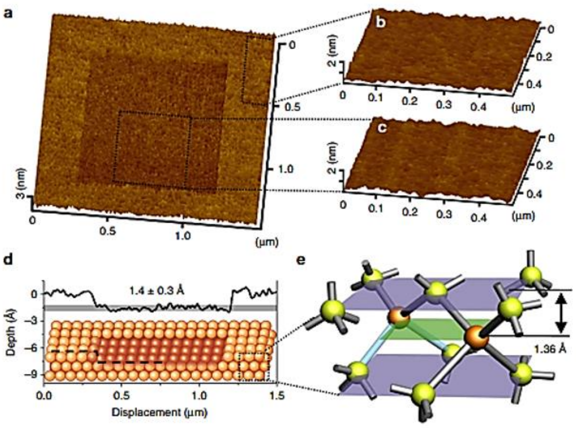

Figure 5. Si material is removed in a single atomic layer. (a) SPM image of the manufactured area, 1.5 m × 1.5 m. Topographic pictures of the created surface and, (b) the original surface, each measuring 0.5 mm by 0.5 mm, (c) The manufactured areas, (d) cross-section shape corresponding to the removal of a single atomic layer on Si (100), (e) Si's crystal structure (100) [74]

The characteristics and functionality of 2D nanomaterials depend on their topology. Due to the extensive restacking of the nanosheets, membranes and films made of 2D nanomaterials typically exhibit high tortuosity and are therefore only marginally useful for electrodes for supercapacitors and batteries, which need ion transport through the nanosheet thickness. A more practical method to enhance molecular transport is to construct holey 2D nanomaterials through the nanosheets while retaining the 2D-related features, as opposed to traditional porous 2D nanomaterials [78]. One of the few methods, focused electron beam induced deposition (FEBID), permits direct-write synthesis of free-standing 3-dimensional nanostructures. While simple trial and error has been used to fabricate simple architectures like vertical or curved nanowires, it is not practical to process complex 3D structures using this approach. This is caused in part by the dynamic interaction between precursor molecules that were absorbed on the solid surface and the electron-solid interactions [79]. Technological distinction in macro scale and nano scale can be seen in Table 3.

Due to the potential for some early-stage nanofabrication processes to mature into nanomanufacturing as technology advances, both top-down and bottom-up methods are employed in conventional nanomanufacturing technology. Top-down techniques, like optical or electron-beam lithography, begin by etching or exposing a base material at greater scales in order to produce nanostructures with the desired forms. In contrast, bottom-up strategies, like molecular self-assembly or the DNA scaffolding method, start with molecules or nanoparticles and build up to nanostructures. The majority of top-down techniques are subtractive techniques that either call for numerous steps or are difficult to build three-dimensional nanostructures. Most of what they can do is only in two dimensions. Bottom-up techniques can create nanostructures additively by assembling nanoscale building components since they are inherently additive in nature [80]. The need for three-dimensional (3D) nanoscale manufacturing techniques that can be used to fabricate a variety of devices, including integrated circuits, data storage and memory devices, optical devices, sensors, and analytical devices, to name a few, is growing as a result of recent advances in nanotechnology. The development of mechanical nanomanufacturing has been attempted methodologies for production of 3D nanoscale components and apparatus as a substitute for photo-lithographic and other nanomanufacturing techniques, driven by the agility of the mechanical manufacturing techniques utilized in the macro- and micro-scales [81]. Advanced manufacturing tools are becoming increasingly necessary for nanomanufactured objects with higher complexity in function, materials, scales, and their integration. Applications including molecular reading and sorting, customized healthcare and drug delivery, ultra-dense memory, and nanoscale electronics are what fuel this industry. The tip-based nanomanufacturing (TBN) platform, which enables a wide range of manufacturing activities at the nanoscale with in-situ metrology and visualization, is a powerful tool for these kinds of applications [82].

Table 3. Perspective adjustments for macroscale technologies in comparison to nanotechnology [80]

	Macro Scale Technologies	Nano Scale Technologies
1	Classical continuums physics	Quantum physics
2	Solid state properties	Binding properties
3	Bulk properties dominating	Surface properties dominating
4	Conventional materials/mixtures	New compounds and mixtures
5	Classical top-down-approach	Combination with self-organization
6	Statistical ensembles	Individual particles
7	Sufficient high energy ranges	Energy range of tiny fluctuations
8	Moderate field strength	Extremely high field strength

Present-day nanomanufacturing technology, logic and memory chips are made using top-down lithography techniques since they need to be nearly flawless in order to work. Costly metrology is required to ensure perfection. Regardless of the requisite Metrology is costly, and only accounts for a little portion in the overall cost of production for premium logic, which per square meter, is sold for several hundred thousand dollars. Modern lithography technologies provide a level of stability and control that allows for most of this metrology to be online and statistical. The items produced by many of the revolutionary forms of nanomanufacturing currently under development, however, will only be a few dollars per square meter [83]. The necessary metrology must be cheaper proportionately to be cost-effective. Thankfully, many of these nanofabrication methods—including DNA origami, roll-2-roll nano-imprint, block copolymer self-assembly, colloidal self-assembly, and others—will not need to be as precise to encounter requirements. Considering the diversity of these self-assembling techniques, some degree of real-time online metrology will be necessary for these techniques to maintain process control. Future nanomanufacturing might call for "affordable" nanometer scale metrology that operates in real time and online, GHz rates, for example, are used in the manufacturing process [82, 83]. When some polymers are heated above their breakdown temperature in the absence of oxygen, they undergo a semi-solid phase. This phase is followed by the loss of heteroatoms and the development of a solid carbon substance. This material is composed of a three-dimensional graphenic structure and is commonly referred to as glittering or glass-like carbon. Pyrolysis refers to the process of thermally decomposing polymers or any organic substance. Iridescent carbon has exhibited its versatility in numerous extensive industrial applications and in small devices [84]. Exploration of the production and joining of these substances has been prompted by the potential use of nanocrystals in several areas like as catalysis, electronics, medicine, and related subjects. For most applications, it is necessary to have nanocrystal samples that have precise control over their size, shape, content, and structure, all within a limited range of variation [85]. Manufacturing is the primary sector that promotes economic and social development. Over the past three decades, there has been a push to promote manufacturing at the micro- and nano-scales in response to global trends in precision and the shrinking of devices. Industry, academia, and private and national scientific investment foundations all have a keen interest in discovering the most promising micro-nano manufacturing technologies (MNMT) [86]. Quantum dots (QDs) are semiconductor nanocrystals, such as CdSe, ZnS, InP, and organic/inorganic perovskite, that have been widely researched for their potential use in solution processed photovoltaics and light emitting diodes for the past two decades. 1 to 12 Despite detailed characterization of the synthesis (nucleation and growth) of II-VI and III-V QDs, a fundamental and comprehensive understanding of the next generation of QDs, such as organic/inorganic halide perovskite QDs, has not been established. Enhancing the process of adjusting the energy band gap in large-scale production would greatly benefit from a comprehensive analysis of the rate at which these chemical reactions occur, as well as continuous optimization during the manufacturing process to consider variations between batches as depicted in Figure 6 [87].

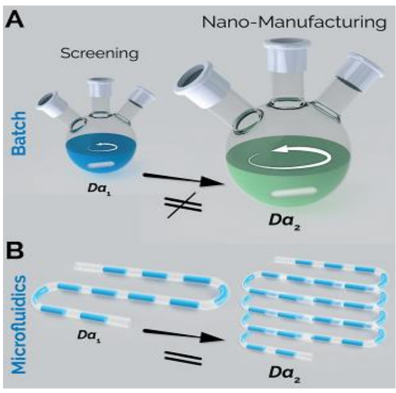

Figure 6. A case of nano-manufacturing in batch and microfluidics [87]

As illustrated in Figure 6, the limitations in mixing and mass transfer between (A) batch systems and (B) multi-phase microfluidic methods for colloidal semiconductor nanocrystal screening and large-scale production [87]. The successful production of micro and nanoscale manufacturing, along with various emerging applications, relies significantly on fabrication technologies capable of reliably creating features and structures with precise dimensions at the micro- and nanoscale level. Optical lithography-based micro/nanofabrication techniques are frequently employed in the semiconductor industry and micro/nanotechnology research. Contemporary lithography methods can produce features with critical dimensions significantly smaller than 50 nm by exposing a thin layer of photoresist on the substrate's surface using a photomask. Optical lithography methods are generally limited to producing two-dimensional features on a flat substrate utilizing a small range of functional materials, despite their high resolution capabilities and fast manufacturing speed. Furthermore, these processes depend on technologies that need significant investment. Micro/nano scale material removal methods have garnered significant attention due to their immense potential in micro/nano production. Illustrations encompass laser micromachining and micro/nano machining [88].

In summary, nanomanufacturing which is the production of materials and devices at the nanoscale, has significant implications across various fields as earlier mentioned, including robotics, ultrasound, agriculture, and medicine. Here are the key significances in each area:

Robotics

1. Enhanced Material Properties:

Nanomaterials can provide superior strength, flexibility, and durability, leading to the creation of more efficient and resilient robotic components.

2. Miniaturization:

Nanomanufacturing enables the production of extremely small, yet powerful, robotic systems and components. This is crucial for applications like nanorobots, which can operate at a cellular or molecular level.

3. Increased Sensitivity and Precision:

Nanoscale sensors and actuators improve the precision and responsiveness of robots, allowing for more delicate and accurate tasks, especially in fields like medical robotics and precision manufacturing.

Ultrasound

1. Improved Imaging Resolution:

Nanoscale materials and techniques can enhance the resolution of ultrasound imaging, providing more detailed and accurate images for medical diagnostics.

2. Targeted Drug Delivery:

Nanoparticles can be engineered to respond to ultrasound waves, allowing for the targeted delivery of drugs to specific tissues or organs, minimizing side effects and improving treatment efficacy.

3. Enhanced Contrast Agents:

Nanotechnology can be used to create advanced contrast agents that improve the clarity and detail of ultrasound images, aiding in better diagnosis and monitoring of diseases.

Agriculture

1. Precision Farming:

Nanosensors and devices can monitor soil conditions, crop health, and environmental factors at a very detailed level, enabling precise management of agricultural inputs like water, fertilizers, and pesticides.

2. Improved Pest and Disease Control:

Nanopesticides and nanoherbicides offer targeted action against pests and weeds with minimal environmental impact, enhancing crop protection while reducing chemical usage.

3. Enhanced Plant Growth:

Nanofertilizers can provide nutrients more efficiently and in a controlled manner, promoting better plant growth and higher yields while minimizing nutrient runoff and environmental pollution.

Medicine

1. Advanced Diagnostics:

Nanoscale biosensors and diagnostic tools can detect diseases at very early stages with high accuracy, improving early intervention and treatment outcomes.

2. Targeted Therapy:

Nanoparticles can be used to deliver drugs directly to diseased cells, such as in cancer treatment, reducing side effects and improving the effectiveness of therapies.

3. Regenerative Medicine:

Nanomaterials are used in the development of scaffolds and implants that support tissue regeneration and healing, offering new solutions for treating injuries and degenerative diseases.

4. Minimally Invasive Procedures:

Nanodevices enable minimally invasive surgical procedures, reducing recovery times, minimizing scarring, and improving patient outcomes.

3. FUTURE SCOPE

Nanotechnology may be used in the future for a range of requests, including: A new chip may be introduced in the healthcare industry to measure the patient's blood pressure in place of the conventional sphygmomanometer. For tasks in businesses where human involvement is impossible, a tiny, sturdy robot can be introduced. Nanoflies can be utilized as spies in the defense zone to report on adversaries engaged in combat.

In the future, nanotechnology may facilitate the ability of objects to extract energy from their surroundings. Emerging nano-materials and concepts are presently under development, exhibiting promise in generating energy using motion, light, temperature fluctuations, glucose, and other sources, while achieving high conversion efficiency.

4. CONCLUSIONS

In conclusion, nanomanufacturing greatly improves the capabilities and efficiency of technologies in the disciplines of robotics, ultrasonography, agriculture, and medicine. This, in turn, leads to innovations that improve performance, precision, and outcomes across all of these fields.

Future applications of nanomanufacturing, cutting-edge technology for producing small nanoscale items with more uses than currently exist have a variety of potential for nanomanufacturing. In the area of MEMS technology, there will be further developments. Nanotechnology is one of the potent tools for viewing, controlling, and modeling matter at the atomic scale. Advances in science and technology in the final few decades of the 20th century have opened new opportunities for utilising advanced technologies. It introduces the possibilities for innovation in anything from commonly used devices to extremely exclusive fields like aerospace and military. If technology keeps developing and competition almost ensures that advancement will continue, nanotechnology appears to be where the world is headed. It widens the scope of opportunities for science and technology.

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