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Nano Manufacturing: An Introduction

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ABSTRACT

Nanotechnology involves the manipulation of matter in atomic and molecular scale. It is emerging as a principal discipline that is integrating chemistry and materials science. It holds the promise of being a main driver of technology with significant impact for all aspects of society. Nano manufacturing is manufacturing at the nanoscale. It is an interdisciplinary field covering physics, chemistry, biology, materials science, and engineering. This paper provides an introduction to nano manufacturing.

KEYWORDS: *nanotechnology, manufacturing, nanomaterials, nano manufacturing, nanofabrication, nanotechnology in manufacturing*

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INTRODUCTION

The nanoworld is a mysterious place because materials behave differently at the atomic or nano scale. The discovery of higher resolution microscopes in the 1980s enabled having insight into nanoscale material structures and their properties. Nanotechnology (science on the scale of single atoms and molecules) has been identified as the "fourth industrial revolution" to disrupt the modern world. It is so described because of the special properties of materials at the nanoscale. It has permeated all sectors of our economy due to the unique properties of materials at the nanoscale. It is transforming the world of materials and its influence will be broad. It will not only initiate the next industrial revolution, it will offer technological solutions.

Nanotechnology refers to the science of nanomaterials. It is the measuring, modeling, and manipulating of matter at atomic scale or in the dimension of 1 to 100 nanometers (nm). (A nanometer is 1 billionth of a meter). It offers the opportunity to produce new structures, materials, and devices with unique properties such as conductivity, strength, and chemical reactivity. Electrical and mechanical properties can change at the nanoscale. For example, at the nanoscale, gold becomes an active catalyst, helping to turn chemicals X and Y into product Z. Most nanomaterials are made by chemical processes, which may or may not generate pollutants or waste materials [1]. Widespread commercialization of nanotechnologies has been restricted by lack of means to produce these technologies at scale. Therefore, the next major step facing nanotechnologists is figuring out how to move from laboratory discoveries to commercial products, i.e. how to manufacture devices with nanoscale features in a cost effective manner.

Manufacturing is the major industry for promoting economic and social development. It is a dynamic, ever-evolving industry, with newer and better technologies being developed on a regular basis. Nano manufacturing is the manufacturing processes of objects or material with dimensions between one and one hundred nanometers. It is the scaled-up, cost effective manufacturing of nanoscale materials, structures, devices and systems. It focusses on developing scalable, high yield processes for the production of materials, structures, devices, and systems at the nanoscale. The terms "nanofabrication" and "nanomanufacturing" are often used interchangeably.

OVERVIEW OF NANOTECHNOLOGY

Techniques are now available which make it possible to manipulate materials on the atomic or molecular scale to produce objects which are no more than a few nanometres in diameter. The processes used to make and manipulate such materials are known as *nanotechnology*, the materials or objects themselves are called *nanomaterials*, and the study and discovery of these materials is known as *nanoscience*.

Richard Feymann, the Nobel Prize-winning physicist, introduced the world to nanotechnology in 1959. The term "nanotechnology" was coined in 1974 by Norio Tanigutchi, a professor at Tokyo Science University. Nanotechnology involves the manipulation of atoms and molecules at the

nanoscale so that materials have new unique properties. Nanotechnology is a multi-disciplinary field that includes biology, chemistry, physics, material science, and engineering. It is the science of small things—at the atomic level or nanoscale level [2]. Nanotechnology also includes domains like nanoscience, nanomaterials, nanomedicine, nanomeasurement, nanomanipulation, nanoelectronics, and nanorobotics.

Nanotechnology is the science of small things—at the atomic level or nanoscale level. It has the idea that the technology of the future will be built on atoms. It has impact on every area of science and technology. Nanotechnology involves imaging, measuring, modeling, and manipulating matter at the nano scale. At this level, the physical, chemical, and biological properties of materials fundamentally differ from the properties of individual atoms and molecules or bulk matter [3].

Nanotechnology covers a wide variety of disciplines like physics, chemistry, biology, biotechnology, information technology, engineering, and their potential applications.

Some of the sectors covered by nanotechnology are shown in Figure 1 [4]. Nanotechnology holds great potential for pollution prevention and sustainability.

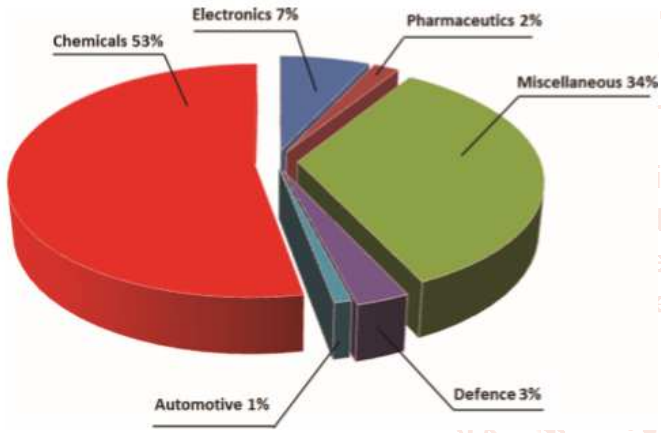

Figure 1 some sectors covered by nanotechnology [4].

Many view the United States as the world's premier nanotechnology research and development (R&D) nation. Some nanotechnology companies in US include [5]:

- 10 Angstroms
- 3D Systems
- 3DIcon
- 3DM
- 4Wave
- A & A Company
- Abeam Technologies
- Accelergy
- Accium
- ACS Material
- Aculon
- Adámas Nanotechnologies
- ADA Technologies
- Advance Reproductions
- Advanced Ceramic Materials
- Advanced Diamond Technologies
- Advanced Energy Industries
- Advanced Micro Devices (AMD)
- Advanced Nano-Coatings
- Advanced Optical Technologies
- American Elements
- Antibodies Incorporated
- Berkeley Advanced Biomaterials
- Carbon Solutions, Inc.
- Chemat Technology
- Cospheric Nano
- Green Millenium

FEATURES OF NANO MANUFACTURING

Nanotechnology has only come into wide use in manufacturing sector recently. A series of breakthroughs in materials and design has allowed manufacturers to work at scales smaller than a billionth of a meter. Some key features of nanomanufacturing are discussed as follows [6,7].

1. Top Down or Bottom Up: There are two basic approaches to nanomanufacturing: top-down and bottom-up**.** Top-down nanomanufacturing reduces large pieces of materials all the way down to the nanoscale. A manufacturer will start with larger materials and use chemical and physical processes to break them down into nanoscopic elements. This approach requires larger amounts of materials and can lead to waste due to the need for discarding material. The bottom-up approach to fabrication creates products by building them up from atomic- and molecular-scale components, which can be time-consuming. For example, carbon nanotubes are manufactured with a bottom-up approach. The top-down method is the more common approach, while the bottom-up method is still in the experimental stage of development. These two approaches are compared in Figure 2 [8].

Figure 2 Comparing bottom-up and top-down nanomanufacturing approaches [8]

Various processes have been developed under the categories of bottom-up and top-down nanomanufacturing. Some of the more common procedures include the following [8].

- Chemical vapor deposition (CVD): This process is used to make materials from a series of chemical reactions. CDV is often employed in the semiconductor industry, where it is used to create film strips with silicone, carbon, and filaments.
- Molecular-beam epitaxy (MBE): A process used to deposit thin films.
- Atomic layer epitaxy (ALE): A process where layers comprised of single-atom thickness are deposited onto surfaces.
- Dip-pen nanolithography (DPN): In a process that resembles the functions of an ink pen, DPN involves the use of a chemically saturated microscopic tip, which is used to write on surfaces. A lithograph that heats above 100°C is capable of fabricating metal electrodes far more effectively than a conventional electron beam.
- Nanoimprint lithography (NIL): A nanoscale stamping process where features are imprinted onto a surface.
- Roll-to-roll processing: A process where ultrathin strips of metal and plastic are imprinted with nanoscale devices at a rapid frequency.

- Self-assembly: A set of processes where different elements are brought together without intervention to form a structure.

2. Nanomaterials in Manufacturing: A nanomaterial (NM) (or nano-sized material) is the material with any external dimension in the nanoscale. Nanomaterials are basically chemical substances or materials that are manufactured and used at a very small scale.

For example, miniaturization enables microprocessors developed using these parts, to operate faster. However, there are a number of technical challenges to achieving these advancements, such as the lack of ultrafine precursors to make these parts, inadequate dissipation of huge amounts of heat generated by these microprocessors, and poor reliability. Nanomaterials help overcome these barriers by offering manufacturers materials with better thermal conductivity, nanocrystalline starting materials, ultra-high-purity materials, and longer-lasting, durable interconnections. The use of nanoparticles in the manufacturing industry will continues to grow.

3. Nanomanufacturing Methods: Specialized equipment and techniques are necessary to manipulate matter at the nanoscale. There are many methods for this, including self-assembly, photolithography and dip-pen lithography. Self-assembly means that a group of nanocomponents have to come together to form an organized structure. This self-assembly would occur from the bottom-up. Photolithography is like the negative obtained with film, as it uses light exposure to project images. Dip-pen lithography relies on the tip of an atomic force microscope to be imbued with chemicals and used to create patterns.

Figure 3 shows a nano manufacturing facility [9].

APPLICATIONS

Nano manufacturing is revolutionizing many manufacturing sectors, including information technology, defense, medicine, transportation, energy, environmental science, telecommunications, and electronics. Common applications of nano manufacturing include [10,11]:

- **Automotive and Aerospace:** The manufacturing industry will see a huge development in sectors like automotive and aerospace. Nanotechnology is used in car manufacturing. Tire manufacturers are increasingly using polymer nanocomposites to increase their durability and wear resistance of tires. Since nanotechnology creates smaller and lighter crafts, less fuel will be needed to pilot aircraft.
- **Healthcare:** Nanotechnologies have enabled engineers and clinicians to collaborate in solving complex problems which require advanced nano manufacturing capabilities to develop medical applications. Introducing these technologies and disseminating these results to healthcare engineering will greatly benefit the majority of population in the developing countries in receiving appropriate and affordable medical care to achieve improvements in their quality of life.
- **Nanomaterials:** Popular nanomaterials, like carbon nanotubes, are already widely fabricated and applied in the manufacture of a variety of goods, including sailboat hulls, bicycle frames and spaceship components. Nanotechnology can also be used to create more effective and stable lubricants, which are useful in a variety of industrial applications.
- **Electronics:** In electronics, nanotechnology enables the manufacture of tiny electronics and electric devices, like nanoscale transistors made out of carbon nanotubes. In electronics, design at the nanoscale is creating highly flexible devices and circuit boards.
- **Nanomachines:** Nanotechnology has shown serious in nanomachines or nanites — mechanical or robotic devices that operate at the nanoscale. Nanoscale robots (called nanomachines or nanites) may soon revolutionize medical device construction. Nanomachines are, for the most part, future-tech and not widely used in manufacturing right now.

BENEFITS AND CHALLENGES

Nanotechnology is regarded as the driving force behind a new industrial revolution. Nano manufacturing will improve efficiency in a number of operations, from design to packaging, through to transportation of goods. Many manufacturers are using nanotechnology to make products with improved capabilities or to reduce their manufacturing cost.

Nanomanufacturing is currently very much in its infancy. Concerns about the health effects of nanoparticles and nanofibers imply that calls for the tighter regulation of nanotechnology are growing. Some other challenges of nano manufacturing include [12]:

- Developing production techniques that are economic and produce viable yield
- Controlling the precision of the assembly of nanostructures
- Testing reliability and establishing methods for defect control. Currently, defect control in the semiconductor industry is non-selective and takes 20-25% of the total manufacturing time. Removal of defects for nano-scale system is projected to take up much more time because it requires selective and careful removal of impurities
- Maintaining nano-scale properties and quality of nano-system during high-rate and high volume production as well as during the lifetime of the product after production
- Assessing the environmental, ethical, and social impacts
- Nano manufacturing is dominated by lithography tools that are too expensive for small- and medium-sized enterprises (SMEs) to invest in.

CONCLUSION

Nano manufacturing is a relatively new branch of manufacturing that focuses on developing scalable, high yield processes for the production of materials, structures, devices and systems at the nanoscale.

The National Nanomanufacturing Network (NNN) is an alliance of academic, government, and industry partners who are committed to advance nanomanufacturing in the US. The National Nanotechnology Initiative (NNI), a US government nanotechnology R&D initiative was established in 2000. Government agencies around the world are investing heavily in nanomanufacturing research and development. They provide researchers with the facilities, equipment, and trained workers to develop nanotechnology applications and associated manufacturing processes. More information about nano manufacturing can be found in the books in [13-20] and the related journals:

- Nanotechnology
- Nanoscale.
- Journal of Nanoscience and Nanotechnology,
- Journal of Micro and Nano-Manufacturing
- Journal of Nanoengineering and Nanomanufacturing

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