CHAPTER 6.5
NANOTECHNOLOGIES

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INTRODUCTION

As integrated circuit technology and microtechnology progress and expand into all phases of human activities with micron-size devices and systems, we find that materials, devices, and even systems at the nanometer scale are interesting for study and may have great potential for new science, engineering, and industries. The national nanotechnology initiative of National Science Foundation, U.S.A., states "Nanotechnology is concerned with materials and systems whose structures and components exhibit novel and significantly improved physical, chemical, and biological properties, phenomena, and processes because of their small nanoscale size. Structural features in the range of about 10-9 to 10-7 m (1 to 100 nm) determine important changes as compared to the behavior of isolated molecules (1 nm) or of bulk materials."

The research and technology on nanoscale materials and some atomic scale biochemical films existed long before the organized initiative. However, only with the recent advances in sciences and technology, it is possible to perform atomic or molecular manipulation and to initiate organized efforts to study and develop all fronts of nanoscale natural world. The flourishing activities under the general topic of nanotechnology now include:

1. Materials with unique or modified properties
   a. Nanostructured metals, semiconductors, and superconductors
   b. Nanoparticles—clusters, crystals, and composites
   c. Hybrid materials—alloys, ceramics, and mono- or multilayer materials
   d. Supermolecular, dendrimers, polymers
   e. Nanotubes, nanorods, molecular wires
   f. Superlattice, quantum wires, and quantum dots
   g. Nanoporus systems

2. Science of nanomaterials—physical, chemical, and biological analysis; characterization and modeling of surfaces; nanomaterials and nanostructures aimed at understanding of them

3. Nanofabrication and processing—chemical vapor deposition (CVD) and other controlled deposition methods, molecular beam epitaxy growth, surface treatment, and programmable self-assembly techniques

4. Nanomanipulation and instrumentation—Nanoprobes, atomic force microscope (ATM), scanning tunnel current microscope, scanning electrochemical microscope, nanoactuators and controllers, and many other instruments

5. Nanoelectronics, nano-optics, and nanomagnetism—device characteristics and potential application

6. Application to electronics, information technology, robotics, fluidics, communication, and energy research

7. Nanobiotechnology and application in medicine and pharmacology

8. Others

The MEMS has served as a pathway for nanotechnology by providing instruments and tools for nanoresearch such as:

1. Microprobe devices, nanometer actuators, and controllers make these tools available for many researchers
2. Microfluidic systems for biomedical studies and self-assembly instruments with fast, multiple unit parallel process capability
3. Microsensors and actuator for nanofabrication and processes
4. Models and methods to understand nanoscale materials, devices, and properties

From engineering aspect of nanotechnology there are two parallel approaches. One is the bottom-up approach. This is to build materials and devices from atoms or molecules up, starting from the modification of the atomic or molecular structures or composition of material to alter their property. This includes research on self-assembly techniques, nanomaterials, composites, nanotubes, quantum dots … as well as biochemical and medical related activities. Using these modified materials and nanoassembly techniques applications in biochemical and medicine can be developed. The other is the top-down approach. That is to shrink the microdevices and systems to nanoscale such as the nanotransistors/switches, and 90 nm and smaller integrated circuits, nanoscale sensors and actuators, and thin film and thick film systems. Both approaches are being pursued with great enthusiasm and efforts. The choice depends on which one is more suited for which research activity.

The field of nanotechnology is so broad and is advancing with tremendous speed over many wide fronts; it is not possible for this section to cover it at any depth. Hopefully these few pages will call attention to this field and that the references, particularly the journals and Internet addresses, will serve as beginning steps to understand the scope and potential of this field.

CARBON NANOTUBES

The carbon nanostructures are the most well-known nanostructures, since the discovery of C_{60} in 1985 by Buckminster Fuller. Among all types of carbon nanostructures the carbon nanotubes may be the most studied material. A brief discussion of carbon nanotubes and applications from the electrical engineer's viewpoint is given here as an introduction to the vast world of nanomaterials and nanotechnology.

There are two main types of carbon nanotubes (CNT)—the single-walled nanotubes (SWNTs) and the multi-walled nanotubes (MWNTs). They can be thought of as single or multiple layers of graphite sheets seamlessly wrapped into cylindrical tubes. Depending on the manner the graphite sheet is rolled from the tube, a pair of integers (n, m) is used to denote the nanotube type that defines the direction of rolling and the diameter of the tube. There are three types of CNT: the armchair ($n = m$), zigzag (n or $m = 0$), and chiral (any other n and m). Armchair SWNTs are metals, those $n - m = 3k$ [k is an integer] are semiconductors with small band gap.

Carbon nanotubes can be produced, in small quantity, by several methods, such as laser ablation of carbon, carbon arc discharge, and chemical vapor deposition of hydrocarbon vapor over a dispersed Fe or other catalysts. One method used decomposition of CH_4 or CO over Al_2O_3 supported Mo or Fe:Mo (9:1), at 700 to 850°C.