Assignment 1 Task 2: Chemical engineering at nanoscale: Nanofabrication

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# Abstract

Nanostructures is defined as materials measure in nanometre scale. Nanotechnology is categorised into characterisation, creation and use of nanostructures. Unique properties of nanostructure aid in constructing widely used well-known products. In this research, we discuss two fabrication methods for nanostructures, top-down and bottom-up. There are a few techniques used for each of the fabrication methods. The specific process of techniques being discussed are electron-beam lithography, thermal imprint lithography, atomic layer decomposition and molecular self-assembly. Lithography has been around for many decades, it is an active area of research and development. There are advantages and disadvantages towards these techniques, fabrication of perfect Nano-scale structures is a constantly faced obstacle in this field of study.

# Introduction

Nanostructures are materials of size between microscopic and molecular structures. Generally, it can be classified into 4 different attributes [1], dimensionality, morphology, composition and agglomeration state. Based on the first attribute, nanostructures can be categorized into four dimensions [2], zero; one; two and three, typically ranges from [3] 0.1 to 100nm. [4] Morphology, study the form of nanostructured materials, including shape, size and structure, for example, nanowires; nanopillars and nanorods. Nanomaterials can be make-up of a single material or composite such as alloy. Agglomeration rate of the nanostructures depends on the chemistry and electrostatic properties of nanoparticles. Commonly, nanoparticles tend to agglomerate due to their surface energy. Reference to the size, nanostructures consist of unique properties. [5] These unique properties contain large surface area, change in electronic state, and ability of forming unusual lattice structures. Taking into account of the [6] surface to volume ratio, nanostructured materials tend to have big ratio because size is inversely proportional to the ratio. The well-known nanostructures are carbon nanotubes and graphene. Carbon nanotubes are fullerenes with hexagonally arranged carbon atoms, it can be made relatively long. When a voltage is applied, electrons in nanotubes are delocalized and are able to move along the cylinder, hence it has high electrical conductivity. [7]

It is commonly used in tiny electrical circuits as wires and as electrodes in paper-thin batteries. Another frequently used of carbon nanotubes are in clothing and sports equipment for added strength, due to very high tensile strength between the individual particles in fullerenes.

Moving on to graphene, it is a single isolated layer of graphite, composed of hexagonally arranged carbon atoms. The properties of graphene are similar to nanotubes. Graphene is extremely strong and have a high strength to weight ratio. It can also conduct electricity and heat fast. Applications of graphene include use in tiny electrical circuits and for tiny transistors, touch screens, solar cells and other energy storage devices. The aim of the report is to gain knowledge on application of nanostructures and the process of nanofabrication.

# Discussion

There are multiple variety of approach toward the synthesis of nanomaterials and fabrication of nanostructures. [8] Top-down and bottom-up are two basic strategy being used in fabrication.

## Nanofabrication

Top-down refers to breaking of bulk substrate by using a milling process, reducing the size to nanoscale. Grinding of bulk materials are also involved then followed by the addition of colloidal protecting agents to steady the nanosized particles. This approach is usually applied to production of metallic and ceramic nanomaterials. [9] However, top-down method is not recommended for mass production as the production rate is slow. The other drawbacks consist of surface imperfections and contamination. Photolithography, electron-beam lithography, soft lithography, thermal imprint lithography and nanosphere lithography are some of the methods used for top-down production.

Moving on to the next approach, Bottom-up begin with atoms which have the ability to self-assemble and self-regulating manner, then building into nanomaterials. Bottom-up produced better products compared to top-down as the nanostructures contain less defects. Methods of bottom-up process include molecular self-assembly, atomic layer deposition, inert gas condensation, vapour condensation and molecular beam epitaxy.

## Techniques

### Top-down

A basic top-down process, electron-beam lithography (EBL), which uses electron to make a pattern. Electron-beam lithography is similar to photolithography, except that EBL uses electron beam resist and doesn’t required light. [10] First, a substrate such as silicon wafer is selected. It is then coated with a thin layer of polymer followed by another thin layer of resist. Both layers are coated through the process of spin coating. When polymer is exposed to a beam of electrons, it undergoes chemical reaction. In an electron-beam lithography equipment, it consists of electron source, electromagnetic lens system and beam deflectors. An electromagnetic lens system is used because it focuses the beam of electrons into a small spot size approximately five nanometres in diameter. The direction of beam is electronically deflect by the beam deflectors, hence beam is allowed to be steered into different spot on the substrate. After exposing in electron beam, the substrate is removed from the EBL instrument and undergoes development process, it is submerge in a solution known as developer, removing the exposed resist. The substrate is then engraved using the developed resist layer as binary mask.

Moving on to the next top-down method, thermal imprint lithography, this method does not require energetic beam. The process is similar to EBL. [11]A substrate such as silicon is spin coated by a resist such as poly(methylmethacrylate) and heated. Template is required to press into the resist at elevated temperature. Allow the template and substrate to cool before separation, the resulting product is a reverse tone image, which is able to replicate the features on the mold. This process is usually carried out in a vacuum to prevent trapping air in the template.

### Bottom-up

Atomic layer deposition, a technique that has been around for many years. In the reaction chamber, [12] gases enter one after the other. Chemisorption occurs when gases attach to the surface of the substrate forming a monolayer. When the surface is fully covered, the excess gas is pumped away and a second gas is transported to the substrate. This process can be repeated multiple times until the required thickness is reached. [13] By controlling the gas exposition time, substrate temperature, gas inflow pressure and removal time, this fabrication process is able to produce high quality thin films such as oxides, metal nitrides and sulphides.

Another approach is molecular self-assembly. Molecules assemble without any guidance, building into a nanostructure. They are joined by weak non-covalent bonds and form a stable chemical structure. There are two methods to the idea of self-assembly molecular. First method is to use a nanostructure as a starting point then submerge it in a pool of atoms. The submerged structure would grow asymmetrical shape, increasing the surface area hence more molecules are being attracted to it. The process continues until nanostructure is formed. The other method starts with components that gather themselves into the product. A micro sized computer chip is by far the only product which succeed in this approach [14].

# Conclusion

This research aimed to gain knowledge on nanofabrication and the use of nanostructure in benefiting our daily life. In short, nanofabrication is split into two approaches, top-down and bottom-up. Using the concept of these two approaches, there are different techniques can be applied to synthesize. Properties of nanostructures have achieved in improving our life. It is suggested that further studies in this field are towards the other techniques of nanofabrication, in order to find out the best approach to fabricate the perfect nanoscale structures.

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