Fabrication for Nanotechnology

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Introduction

There is much discussion what nanotechnology really is: anything produced in the nanometer scale, manipulating atoms or small particles. Seeing the wide variety of materials and fabrication technologies one could better speak of nanotechnologies. In general the fabrication technologies could be divided into four groups as pictured in the following figure.

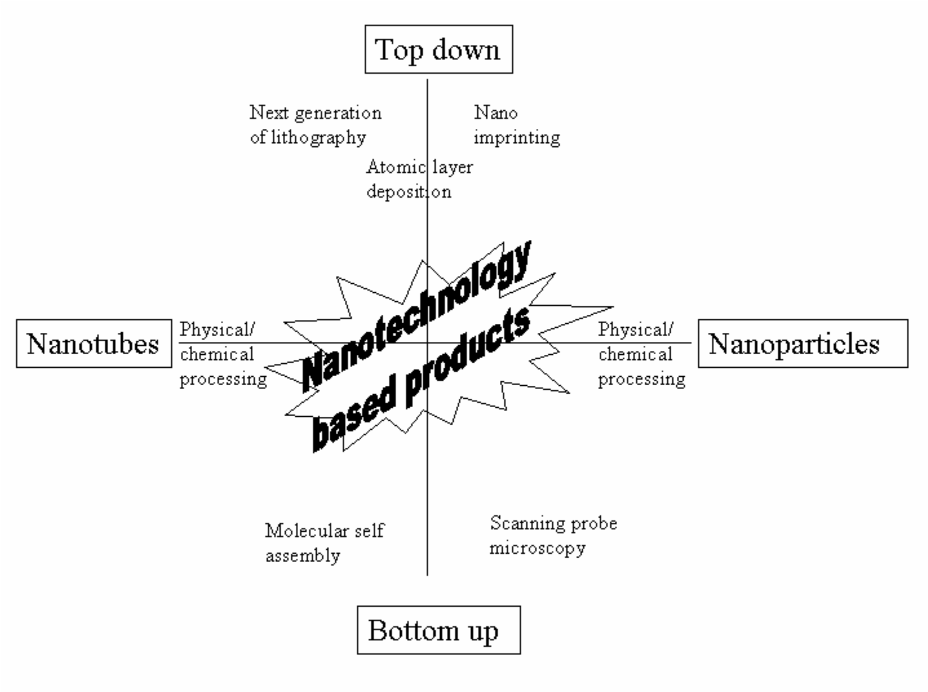

Figure 1: Nanotechnology fabrication methods

Top-down nanofabrication

The currently best developed area is the top-down nanofabrication with its base in the semiconductor industry. This industry is rapidly entering the sub nanometer area, and they need increasingly more accurate and therefore more expensive equipment. For semiconductor lithography nanoimprinting can offer a less complex process using more affordable equipment. The process uses a stamp instead of the more commonly used transparent mask. On a longer time frame, nanotubes are becoming of interest.
In the deposition area much attention is given to processes like Atomic Layer Deposition (ALD) and Molecular Layer Epitaxy, cyclic processes to make gap layers with high conformality and breakdown voltage. Basically the build up is layer by layer, whereby the layers can be varied according to need for specific layer properties.
Another deposition option is plasma deposition. The core is a DC magnetron which is used to sputter material into a liquid nitrogen cooled, high pressure aggregation/ drift region. The clusters (nanoparticles) formed in this region and are then channelled though apertures into the user's system and guided, as they have the properties of a beam, to a (cooled) substrate on which a layer is formed.

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Nanoparticle creation

The simplest process to create nanoparticles is the sol-gel process. Hereby mixing of ingredients dissolved in a liquid creates the initial particles. At a certain moment a surface active material is added to stop the growth. Hereafter the materials, still dispersed in liquid, can de transferred to the point of use.
Pyrogenic processing on the other hand is a process carried out in large expensive tools. It is used to create oxide particles by means of flame oxidation of metals, metalloids or their derivates in the gas phase.

A slightly more exotic process is called Controlled Detonation Synthesis and is used to create Nanoceramics and cubic carbon nanoparticles (Nanodiamonds). It involves the atomization of an explosion precursor material, immersed in specific gas medium. During the fly from the middle of reactor to the reactor walls atoms are clusterized and form nanoparticles.

Milling is a more traditional process. It can produce bulk metal powders of conventional, 10 – 1000 micron sizes, but with a nano-sized grain structure. A new variation of this process uses a mix of mechanical downsizing and chemical reactions. The chemical reactions are mechanically activated during milling, forming nanoparticles via a bottom up process. A ball mill acts as a low temperature chemical reactor. The particles are kept apart by salt matrix, which is removed through simple washing steps.

Nanotubes/fullerene production

The main challenges in nanotube fabrication are cost and purity. General a mix is created of several kinds of nanotubes. Depending on the process the balance between them can be shifted. Two broad ranges of processes can be distinguished: medium and high temperature processes.

The medium temperature category includes most of the catalytic processes like conventional Chemical Vapor Deposition (CVD), Plasma Enhanced CVD (PECVD), Hot Filament CVD and High Pressure Carbon Oxide CVD (HiPCo). The carbon source is a tightly controlled flow of a hydrocarbon gas (methane, carbon monoxide or acetylene). Metal catalyst such as Ni, Fe or Co are used to control the yield. Differences can appear in the methods used to decompose the gas. These methods are called "medium temperature" as the decomposition temperature is generally below 900°C. Medium temperature processes are particularly suitable for the synthesis of Multi Wall carbon nanotubes (MWNT).

The high temperature processes include laser ablation and electric arc discharge. In these methods, a composite target – made of graphite and a catalyst - is vaporized at high temperature (>1500°C). The carbon and the catalyst atomized, create a plume. In this zone carbon atoms combine to form carbon nanotubes. Like the medium temperature processes, the carbon nanotubes obtained are always contaminated with impurities such as amorphous carbon, residual metal catalyst and graphite nanoparticles. However, these methods provide very high structural quality material, monotype products (i.e. 100% of SWNT or MWNT) and they offer a strict control over the CNT diameter.

During the arc discharge process an arc is being created between a graphite cathode and a graphite anode. In the vapour phase carbon cluster are being created. These clusters are then cooled down and they condense on the surface of the graphite cathode. This deposit contains carbon nanotubes and impurities. By adding a catalyst (Co, Ni, Fe and Y powder), Single Wall NT are synthesized on the cathode.

Bottom up nanofabrication

The last part of the nanofabrication technologies is the bottom up fabrication involving the handling of individual atoms and molecules. The best known instrument here is the scanning probe microscope

(SPM). Advanced SPMs can be used to manipulate individual atoms. This is a rather slow fabrication technology of limited scope and efforts to create multiple probe systems meet high technological barriers. Nanoscribing is proposed as an alternative. Here a SW package transforms an AFM tool into a nano dispense unit. The achieved resolution is less then 10 nm. Probably the most promising area for this technology will be for the deposition of bioactive materials, which can not be deposited or structured via the harsh conditions of thin film processing. (I.e. writing of proteins patterns on gold surfaces)

Molecular self assembly can be achieved by using the ordered organization power of matter to produce homogenous monolayers with a high level of uniformity and reproducibility. It involves the dipping of a substrate into alternate aqueous solutions containing anionic and cationic materials, thereby creating subsequent layers on the substrate.

Far more futuristic is the idea to use molecules to create other molecules (nanofactories/molecular electronics).

Summary

Although many processes are discussed in this article the identified mainstream nanotechnologies are:

- arc combusting for nanotubes
- CVD for special nanotubes
- Molecular self assembly for monolayers
- Sol- gel process for nanolayers
- ALD for semiconductor isolating layers
- Nanoimprinting for thin film production
- Plasma processing for coatings and metal particles

The ultimate nanotechnology, the manipulation of atoms and molecules, has only been demonstrated yet in research environments.