

Physics of Nanomaterials

Module III

Growth Techniques in Nanomaterials

Learning objectives

Introduction, top down and bottom up approaches, lithographic process and limitations, non-lithographic processes, plasma arc discharge, sputtering, evaporation, chemical vapor deposition, molecular beam epitaxy, sol-gel technique, electrodeposition.

1. Distinguish between Top-Down and Bottom Up approaches with examples?

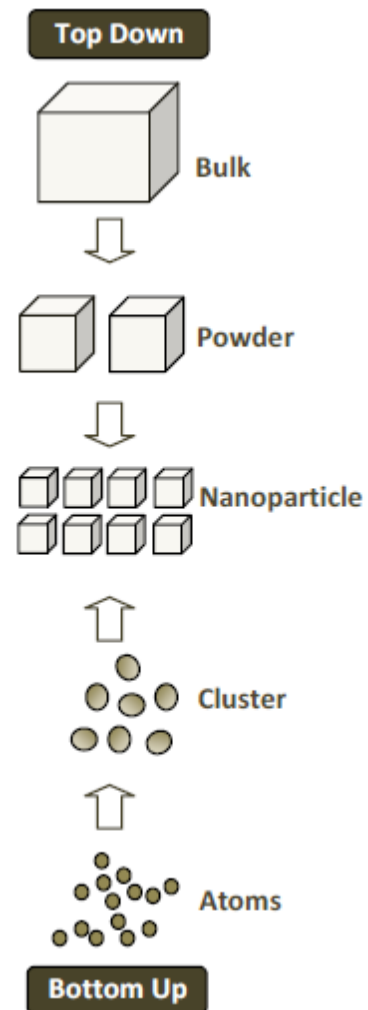
Role of Bottom-up and Top-Down approaches in Nano technology:

Top down approach refers to slicing or successive cutting of a bulk material to get nano sized particle.

1. Nanomaterial synthesis, ball-milling is an important top-down approach, where Macrocrystalline structures are broken down to nanocrystalline structures, but original integrity of the material is retained.
2. The crystallites are allowed to react with each other by the supply of kinetic energy during milling process to form the required nanostructured oxide.
3. Attrition or Milling is a typical top down method in making nano particles
4. This approach leads to the bulk production of nano material.
5. Introduces internal stress, in addition to surface defects and contamination
6. Lithography process

Bottom up approach refers to the build up of a material from the bottom: atom by atom, molecule by molecule or cluster by cluster.

1. The colloidal dispersion is a good example of bottom up
2. Bottom up approach also promises a better chance to obtain nano structures with less defects, more homogeneous chemical composition.
3. Assembling materials from the atoms/molecules up, and, therefore very important for nano-fabrication
4. Though the bottom up approach oftenly referred in nanotechnology, it is not a newer concept.
5. Examples of bottom-up technique are self-assembly of nanomaterials, sol-gel technology, electrodeposition, physical and chemical vapour deposition (PVD, CVD), epitaxial growth, laser ablation
6. Non lithography process



3. Distinguish between lithography and nonlithography process with examples OR

What is lithographic process? Explain Photolithographic and Electron beam lithography with limitations

Lithographic Process and Non Lithographic Process

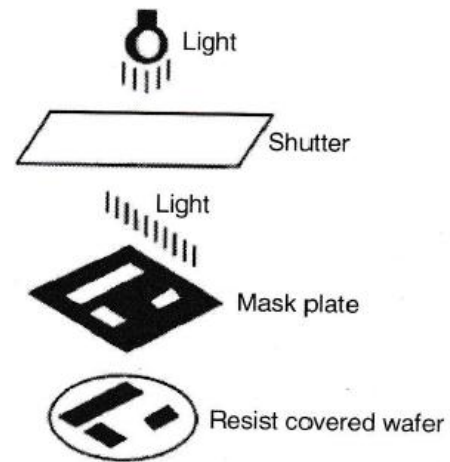
Lithographic Process: Is a printing method that uses chemical process to create an image.

Two types of lithographic process used in silicon industry

1. Photolithography
2. Electron beam (e-beam) lithography

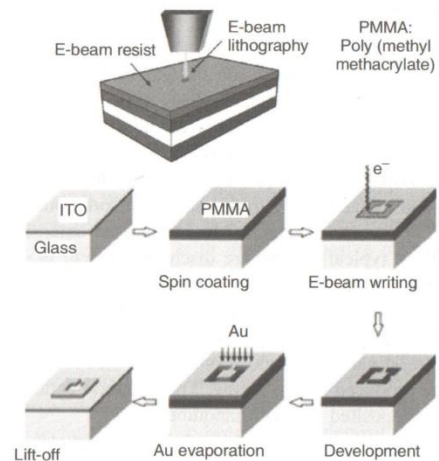
1. Photolithography:

1. Photolithographic process uses light to transfer a geometric pattern from a photomask to a light-sensitive chemical (photoresist) on the substrate (as shown in Figure).
2. Depending on the pattern on the photomask, various structures can be generated on the substrate, which is further used to develop different silicon-based photonic and electronic devices.
3. Current state-of-the-art photolithography tools use deep ultraviolet (DUV) light with wavelengths of 248 and 193 nm, which allow minimum feature sizes down to 50 nm.



2. Electron beam (e-beam) lithography:

1. Electron beam lithography is the process of using a beam of electrons to generate patterns on a surface (cf. Figure).
2. Primary advantage of this technique is that it is fine-tuned to beat the diffraction limit of light and make features in the sub-micrometer regime.



2 Schematic diagram of electron-beam lithographic process.

Limitations:

1. Due to very slow speed, this form of lithography has yet to become a standard technique in the industry but found wide usage in research, although this form of lithography has found wide usage in mask-making (for masks used in photolithography) and low-volume production of semiconductor components.

2. Such systems have produced line widths of ~20 nm.
3. But these techniques seem to be approaching their limits for fabricating one-dimensional (1D) and 0D nanostructures of very small size.
4. Therefore, alternative non lithographic approaches to nanostructure fabrication are the need of the hour.

3.what is non-lithographic process? Distinguish between Vacuum-based deposition process and Solution-based deposition process with examples?

Non Lithographic Process

Non Lithographic Process: Nonlithographic techniques are based on natural self-organization processes. In general, these techniques can be broadly divided into two groups:

1. Vacuum-based deposition process
2. Solution-based deposition process.

1. Vacuum-based deposition process:

1. Deposition takes place under high vacuum (10^{-8} to 10^{-11} mbar).
2. Therefore, the process is very clean; probability of deposition of foreign and undesired materials is very low.
3. Hence these types of techniques are highly favorable for efficient device fabrication.
4. But the vacuum-based systems require costly and complicated equipment, with leak-proof accessories, vacuum pumps, gauges, etc.
5. Examples of these types of techniques are plasma arc, evaporation. sputtering, chemical vapour deposition(CVD), Molecular beam epitaxy (MBE) etc.,

2. Solution-based deposition process:

1. Deposition takes place based on chemical reactions in liquid.
2. Simple and cost effective and large range of materials can be synthesized by these methods
3. They are not very clean processes; due to the chemical reactions with different constituent materials in solution, undesired molecules, ions, etc, remain within the synthesized material, and, thus affect the desired property of it.
4. Also these techniques are not compatible the modern solid state device technology, which is the primary manufacturing process electronic and photonic devices.
5. Examples of solution-based techniques are wet-chemical syntheses such as sol-gel dip-coating, spin coating, spray pyrolyses, electrodeposition process self-assembly of nanopores, field-assisted nanowire growth through porous matrix in solution vapour-liquid-solid method, chemical bath deposition, etc.

Unlike lithographic technique of top-down approach, which is extensively used in silicon industry, this bottom-up nonlithographic approach of nanomaterial synthesis is not completely proven in manufacturing yet, but has great potential to become important alternative to lithographic process.

4.Explain principle and construction of Plasma Arc Discharge

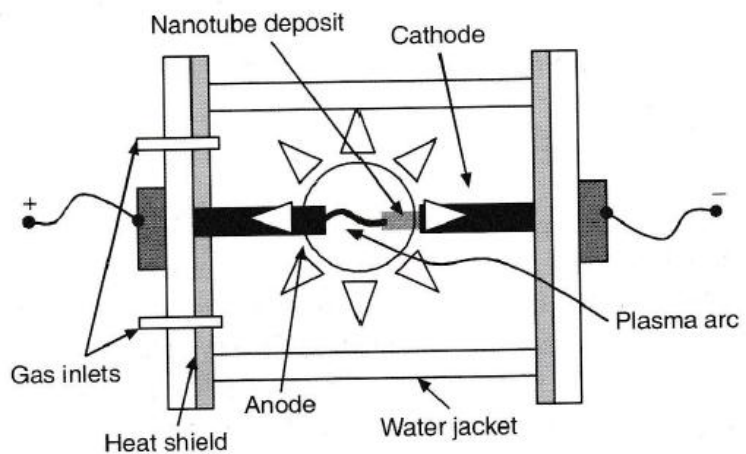
Plasma Arc Discharge

Principle:

An ionized gas system is considered as plasma. When a gas is made conducting by provide a high potential difference via electrodes inside the gas-system, so that the gas yields up electrons and thus ionizes plasma is achieved. In general, plasma consists of electrons, ions, well as neutral particles. Due to high conductivity of the plasma, an arc is generated (due current conduction through plasma) between the two closely spaced electrodes in vacuum or low-pressure inert gas atmosphere, which produces heat inside the system. This heat produced can be used to vaporize and ionize the electrodes and even some other materials present inside the discharge chamber.

Construction:

1. Plasma arc method has been used extensively in the deposition carbon nanotube. A typical plasma arc discharge system is shown in figure,
2. It consists of two electrodes inside a discharge chamber in vacuum or at low-pressure inert atmosphere.
3. An electric arc passes from one electrode (anode) to the other (cathode), due which the anode vaporizes and gets deposited to the other electrode as well as on the inside the chamber wall.
4. For carbon nanotube deposition, carbon electrodes are used, through which atomic carbon cations are produced due to arcing.
5. These carbon cations move to the cathode pick up electrons and get deposited to form nanotubes.
6. The electrodes can be made of other materials but they must be able to conduct electricity.
7. Boron and silicon nitride nanotubes are formed by this method using elemental boron and silicon electrodes, respectively, in an activated nitrogen atmosphere.
8. An interesting variation is to make the electrodes from a mixture of conducting and nonconducting materials.
9. During heating, the non-conducting material is vaporized and ionized so that it also becomes part of the plasma arc and is transported and deposited on the cathode.
10. Another interesting variation on plasma arcing is flame ionization. In this process, a material is sprayed into a flame and ions are produced, which can be collected and deposited in nanocrystalline form.



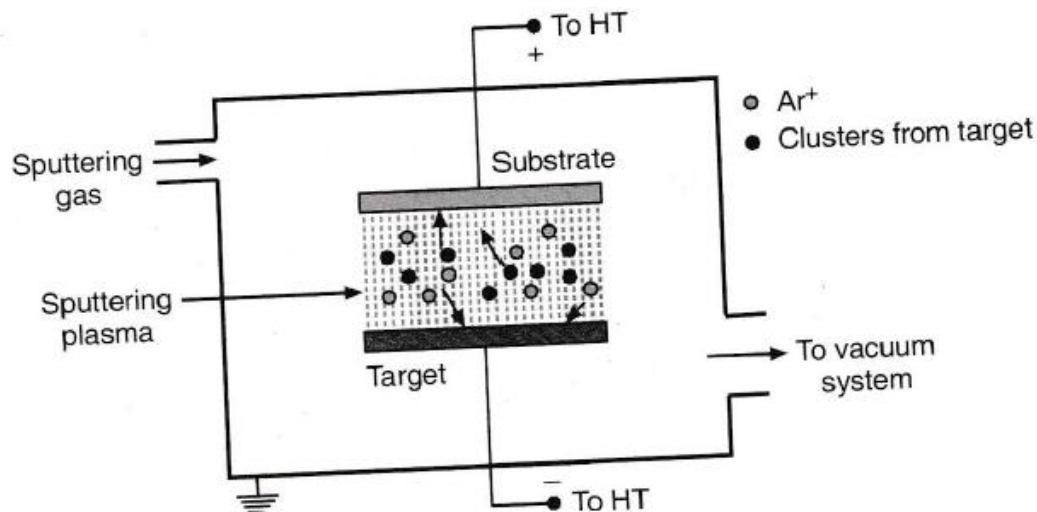
5. What is sputtering? Explain principle and construction of sputtering?

Sputtering

Principle:

Sputtering is a physical vapour deposition (PVD) process whereby atoms in a solid target material are ejected into the gas phase due to bombardment of the material by energetic ions (see figure).

1. It is commonly used for thin-film deposition. Standard physical sputtering is driven by momentum exchange between the ions and atoms in the material, due to collisions.
2. In sputtering, a glow-discharge (plasma) of non-reactive ions (e.g. Ar) is created by a potential difference inside a vacuum chamber, which fall on the target (the material to be deposited) and break loose cluster of atoms and then are collected on the surface to be coated.



3. Sputtering is one of the most versatile techniques used for the deposition of device-quality films.
4. Compared with other deposition techniques, the sputtering process produces films with high purity and better controlled composition, provides films with greater adhesive strength and homogeneity and permits better control of film thickness.
5. Initially, sputtering was used to deposit thin metal films, but later, compound materials are also deposited by this method.
6. But in these cases, target stoichiometry is a critical parameter to deposit the compound material as the sputtering rates of different elements of the compound are different.
7. Therefore, to get proper film composition, target composition has to be chosen properly.
8. Also, unlike normal physical sputtering, where the target material has same chemical composition as that of the deposited film, reactive sputtering technique has also been used to deposit oxide, nitride and carbide thin

6. What is evaporation? Explain the principle and construction of Thermal evaporation.

Evaporation

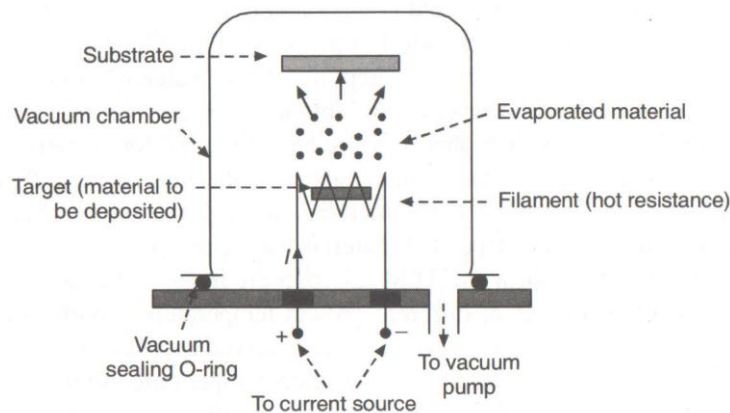
Evaporative deposition of thin films is a process where the material to be deposited is heated to a high vapour pressure in vacuum. The heating of the material can be done either by electrically

resistive heating (Joule heating) or electron bombardment. The former is called thermal evaporation and the latter is called electron-beam (e-beam) Evaporation.

Thermal evaporation

1. Thermal evaporation uses a filament of high current ($\sim 10\text{--}100\text{ A}$, depending on the filament and the material to be deposited) passing through it, producing sufficient amount of thermal energy, which heats up the material to be deposited.
2. When the substance is heated adequately it begins to evaporate and travel through the chamber and deposit on the substrate to be coated. The higher the vacuum, the more efficiently material will be deposited to the substrate.
3. In a higher vacuum there are less number molecules in the chamber, which will increase the 'mean free path' and, a longer mean free path will allow the evaporated molecules to travel further before striking an unwanted molecule in the chamber. The rate of deposition can be controlled by the current being passed through the filament.

Construction: A schematic diagram of a thermal evaporation system is shown in figure



Schematic diagram of a thermal evaporation system.

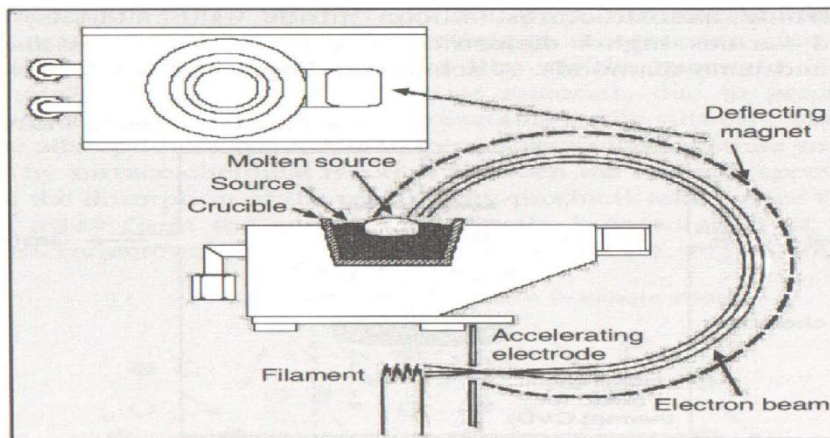
1. There are different types of evaporation sources. The simplest are the metal boat, made up from refractory metals like W, Mo, Ta, etc. and heat-shielded crucible made up of alumina or ceramic materials.
2. The metal boat is heated up by passing high current ($10\text{--}100\text{ A}$) through it. The amount of heat generated is I^2R (Joule heating), where R is the parallel resistance of source evaporant combination at the evaporation temperature, T .
3. In general, T is not uniform because of heat conduction down the current contacts. Therefore, if evaporation rate control is important (and this is significant for nanomaterial synthesis), continuous flux monitoring is necessary.
4. Preferably, with feedback control of the current source. To prevent the evaporant to spread away from the hot zone of the boat, a narrower zone is always provided at each end.

5. The resulting higher R increases heating enough in those regions so that evaporation rate exceeds spreading rate.
6. Alloying of the evaporant with the boat metal may result in the embrittlement or melting.
7. If there are no metals suitable for contact with the desired evaporant, ceramic-coated boats or ceramic crucibles can be used. In this case, the ceramic crucible is placed inside a heating coil and the crucible along with the evaporant is heated up with the current passing through the coil.
8. Transport of the evaporated material from the source to the substrate is another important factor in the vacuum evaporation process, which determines the uniformity of the film deposited on the substrate.
9. In high vacuum, the evaporant molecule, during its travel from the source to the substrate, is assumed to have very less probability to collide with background molecules along its way.

7. What is evaporation? Explain the principle and construction of E-beam evaporation

E-beam evaporation

1. This technique is based on the heat produced by high energy electron beam bombardment on the material to be deposited.
2. The electron beam is generated by an electron gun, which uses the thermionic emission of electrons produced by an incandescent filament (cathode).



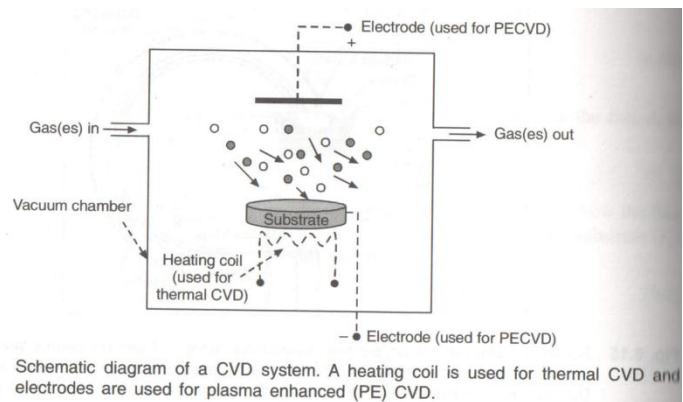
3. Emitted electrons are accelerated towards an anode by a high difference of potential (kV).
4. The material itself or the crucible or a near perforated disc can act as the anode.
5. A magnetic field is often applied to bend the electron trajectory, allowing the electron gun to be positioned below the evaporation line (as shown in figure).
6. The energetic impact of the electron beam raises the temperature of the evaporant, creating a hot zone on the material or a heated 'oven' in the case of a crucible.
7. At a sufficiently elevated temperature, the material will begin to evaporate.
8. As electrons can be localized, it is possible to obtain a much localized heating on the material to evaporate, with a high density of evaporation power (several kW). This allows controlling the evaporation rate from low to very high values, and best of all, the chance of depositing materials with high melting point (W, Ta, C, etc.).
9. Cooling the crucible avoids contamination problems from heating and degasification.

9. What is Chemical Vapour Deposition (CVD)? Explain the principle and construction of Chemical Vapour Deposition (CVD). OR

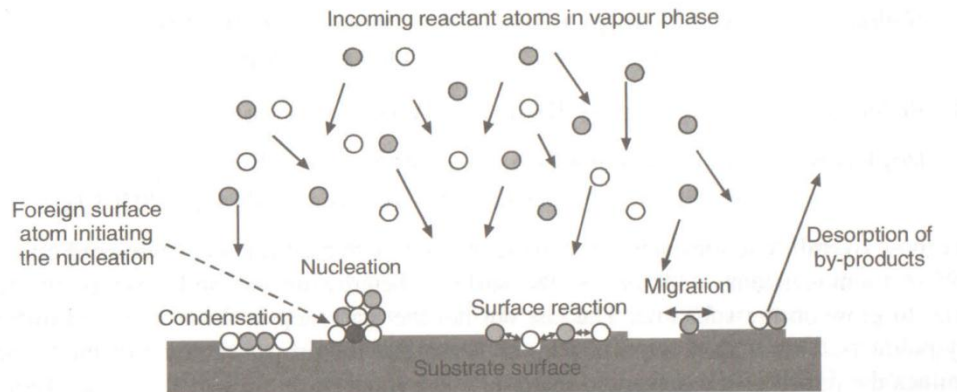
Mention types of CVD? Give construction and working of Chemical Vapour Deposition (CVD)

Chemical Vapour Deposition (CVD)

1. Chemical vapour deposition (CVD) is a chemical process used to produce high-purity, high performance solid materials.
2. The process is often used in the semiconductor industry to produce thin films.
3. It is a technique for synthesizing materials in which chemical components in a vapour phase react to form a solid film at some surface (substrate).
4. The occurrence of chemical reaction is central to this means of thin film growth, as is the requirement that the materials must start out in the vapour phase.
5. Ability to control the components and physical conditions of the gas phase, the solid surface and the envelope that surrounds them determine the capacity to control the properties of the thin film deposited by the CVD process.
6. Micro and nano fabrication process widely used CVD to deposit materials in various forms, including: monocrystalline, polycrystalline, amorphous, and epitaxial. These materials include: silicon, carbon fiber, carbon nanofiber/nano rods/nano filaments/nano tubes, SiO_2 , silicon-germanium etc.,
7. CVD process also used to produce synthetic diamonds and nano diamonds
8. In general, the CVD process can be divided into two steps, one is transport of gas phase materials to the reaction zone and the reaction of materials and the other is the deposition of the film on the substrate.
9. The transport process involves the gas supply, convection of gas-phase materials due to pressure gradient and/or buoyancy of hot gases and diffusion of gaseous reactants to the substrate surface. The deposition process involves the adsorption of the reactant species on to the substrate surface sites by surface migration followed by surface chemical reaction between the reactant species, usually catalyzed by the surface, then the desorption of the reaction by-products takes place followed by diffusion of the by-products away from the surface and finally incorporation of the condensed solid products into the macro/nano-structure of the growing film.



10. Convection in a CVD chamber refers to the flow of the gaseous fluid as it moves through the reactor after being injected from the gas supply. Two types of convection generally take place inside the chamber, one is the forced convection due to pressure gradient across the chamber and the other is the free convection due to buoyancy of the hot gases.



Schematic diagram of various processes involved in CVD.

11. Another important process involved is the viscous friction experienced by the gas molecules, when they come very close to the substrate surface. Due to this the flow velocity slows down and the remaining transport of reactant to the surface occurs only by diffusion through the relatively stationary boundary layer of fluid.
12. The gas-transport flow pattern is an important aspect to determine how far from the deposition surface, the transition from convection to diffusion is occurring and which of these two transport processes is limiting the reactant arrival rate at the substrate surface.
13. Once the transition from convection to the diffusion takes place, the source gas molecules are adsorbed to the surface followed by the surface reaction to produce the required material.

Types of CVD process

A number of forms of CVD are in wide use and are frequently referenced in the literature. These processes differ in the means by which chemical reactions are initiated (e.g., activation process) and process conditions.

According to the classification of operating pressure, CVD can be categorized as:

- 1. Atmospheric pressure CVD (APCVD):** In this case, CVD process takes place at atmospheric pressure.
- 2. Low-pressure CVD (LPCVD):** Here, CVD occurs at subatmospheric pressures. Reduced pressures tend to reduce unwanted gas-phase reactions and improve film uniformity across the wafer. Most modern CVD processes are either LPCVD or UHVCVD.
- 3. Ultrahigh vacuum CVD (UHVCVD):** In this case, the CVD process takes place at " very low pressure, typically below 10^{-6} Pa ($\sim 10^{-8}$ H torr).

According to the physical characteristics of vapour used during CVD, it can be classified as:

1. **Aerosol assisted CVD (AACVD):** Here, the precursors are transported to the substrate by means of a liquid/gas aerosol, which can be generated ultrasonically. This technique is suitable for use with volatile precursors.
2. **Direct liquid injection CVD (DLICVD):** In this CVD process, the precursors are in liquid form (liquid or solid dissolved in a convenient solvent). Liquid solutions are injected in a vaporization chamber towards injectors and then the vapours are transported to the substrate as in the case of classical CVD process. This technique is suitable for use on liquid or solid precursors. High growth rates can be reached using this technique.
3. **Metalorganic CVD (MOCVD):** This CVD process is based on metalorganic precursors (gases) to deposit thin films. This is a very important process, in the sense that, use of organometallic compounds opens up the deposition of a wide variety of materials, which cannot be deposited by inorganic gases and precursors. Also the carbon containing by-products can easily be removed by heating to get high purity films.

CVD process can also be categorized according to the source of energy supplied for the chemical reaction enhancement inside the CVD chamber. They are as follows:

1. **Plasma-enhanced CVD (PECVD):** In this CVD process a plasma is created to enhance chemical reaction rates of the precursors. The plasma is generally created by RF frequency or DC discharge between two electrodes where the in-between space is filled with the reacting gases. When an RF source is used for generation of plasma, the process is called RF-PECVD, whereas for DC field, it is called DC-PECVD. Sometimes a magnet is used to concentrate the plasma near the substrate to enhance the reaction and growth.
2. **Hot filament CVD (HFCVD):** It is also known as Catalytic CVD (Cat-CVD) or hot wire CVD (HWCVD). Here a hot filament is used to supply the required energy to chemically decompose the source gases. Nano-diamond, CNT and many other nanomaterials are deposited by this process.
3. **Rapid thermal CVD (RTCVD):** In this CVD process, heating-lamps or other methods are used to rapidly heat the substrate surface so that the heating only takes place at the substrate rather than at the gas or chamber walls, which helps reducing the unwanted gas-phase reactions that can lead to particle formation.

10. What is Molecular beam epitaxy? Give construction and working of Molecular beam epitaxy.

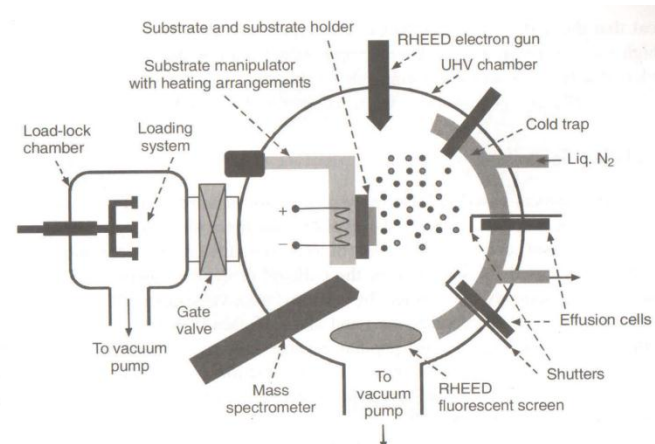
Molecular beam epitaxy (MBE)

1. Epitaxy is a process of an ordered crystalline growth of materials on a crystalline substrate. It is a kind of interface between a thin film and substrate. Generally epitaxy grown films are fabricated from gaseous or liquid precursors. The deposited film grows with identical lattice structure and orientation of the substrate on which it grows.
2. MBE is a technique for the epitaxial growth of materials by means of the chemical interaction of one of the several molecular or atomic beams of different intensities and compositions that occur on the surface of a heated single crystalline substrate. It is an Ultra-High Vacuum (UHV)-based technique for producing high quality epitaxial structures with monolayer (ML) control.

3. Molecular-Beam Epitaxy (MBE), where a source material is heated to produce an evaporated beam of particles which travel through a very high vacuum to the substrate, where they condense to grow layers.

Construction:

1. A schematic representation of a MBE apparatus is shown in figure. The source materials are placed in the evaporation cells which are composed of crucibles, resistive heaters and thermal screens. The shape and dimensions of the crucibles are such that they fulfill the requirement of angular distribution of atoms and molecules in a beam.
2. The angular distribution of the beam and the distances between the sources and the substrate determine the homogeneity of the parameters of epilayers and heterostructures grown by this technique. A manipulator connected to the substrate holder is used to enable the required position of the substrate relative to the effusion cells to get the desired structures.
3. Also substrate rotation and heating arrangements are provided to the system to heat the substrate to the necessary temperature and rotate the substrate to get homogeneous films.
4. The whole MBE chamber is pumped down to ultra-high vacuum (10^{-11} mbar) and the operation is also oil-free. Ultra-high vacuum condition used to ensure the molecular beam condition, where the free path of the particle is larger than the geometrical size of the chamber.
5. Oil-free condition is needed to ensure that the substrate is atomically clean before the film growth. Also the system is equipped with cryogenic system which ensures the screening of stray fluxes of atoms and molecules from the walls of the chamber to the substrate.
6. The MBE system is also equipped with a reflection high-energy electron diffraction (RHEED) system and mass spectrometers for monitoring the beams and their molecular composition and the residual atmosphere. The chamber also contains ionization gauges for monitoring fluxes.
7. Since its introduction in the 1970s as a tool for growing high-purity semiconductor films, MBE has evolved into one of the most widely used techniques for producing epitaxial layers of metals, insulators and superconductors as well, both at the research and the industrial production level.
8. The principle underlying MBE growth is relatively simple: it consists essentially of atoms or clusters of atoms, which are produced by heating up a solid source. They then migrate in an UHV environment and impinge on a hot substrate surface, where they can diffuse and eventually incorporate into the growing film.
9. Despite the conceptual simplicity, a great technological effort is required to produce systems that yield the desired quality in terms of material purity, uniformity and interface control.
10. The choice of MBE and other growth techniques depends on the desired structure and needs.
11. For example, in the case of mass production, MBE suffers from a lower yield, compared to other techniques such as Liquid Phase Epitaxy (LPE) and Metalorganic Vapour Phase Deposition



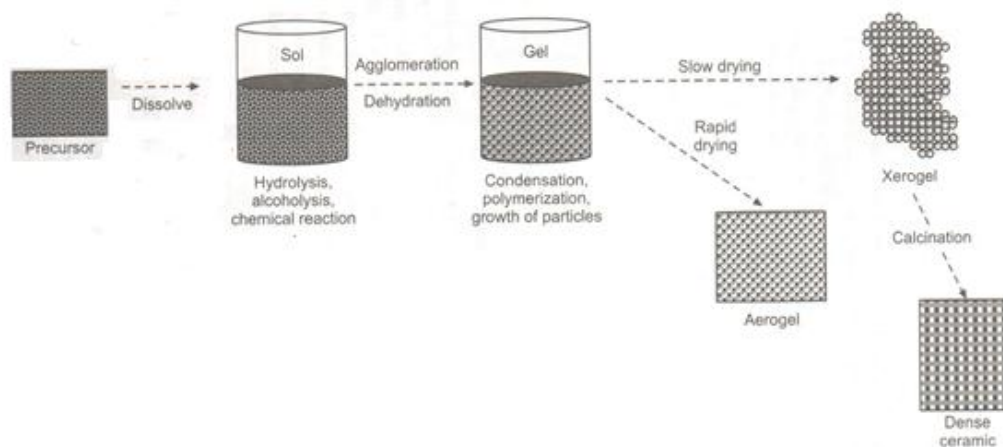
(MOCVD), due to a lower growth rate and wafer capability (currently, GaAs based MBE production systems are capable of up to 4 x 6" diameter wafers. compared to 5 x 10" of MOCVD).

12. MBE, instead, is the proper technique when some particular requirements are needed, such as abruptness and control of interfaces and doping.
13. Finally, the UHV environment allows the use of electron diffraction, which provides fundamental information on the growth mechanisms.
14. In MBE, the constituent elements of a semiconductor in the form of 'molecular beams' are deposited onto a heated crystalline substrate to form thin epitaxial layers.

10.Explain sol-gel process?

Sol-gel Process

1. Sol-gel is a wet-chemical-based self-assembly process for nanomaterial formation.
2. The sol-gel process, as the name implies, involves the evolution of networks through the formation of a colloidal suspension (sol) and gelation of the sol to form a network in a continuous liquid phase (gel).
3. The precursors used for synthesizing the colloids generally consist of metallic ions and ligands, which are elements surrounded by various reactive species. Metal alkoxides (e.g. aluminates, titanates, borates, cuprates, etc.) and alkoxysilanes (e.g. tetramethoxysilane, TMOS and tetraethoxysilane, TEOS) are most popular because they react readily with water.
4. In some cases, few alkoxides are immiscible in water; in that situation some homogenizing agents such as alcohols are used as mutual solvents to facilitate miscibility of these materials. In general, sol-gel formation occurs in four steps:
 - (a) Hydrolysis and alcoholysis
 - (b) Water and alcohol condensation and polymerization of monomers to form particle
 - (c) Growth of particles
 - (d) Agglomeration of particles followed by the formation of networks throughout the liquid medium resulting in thick gel.
5. In general, all the above-mentioned steps are dependent on several initial conditions such as pH value of the sol, temperature of the reaction, reagent concentrations, time of reaction, nature and concentration of catalyst (if needed), $[H_2O/M^+]$ molar ratio (M^+ : cation), aging temperature and time of the gel formation, etc. By controlling these parameters, it is possible to vary the structural, electrical and optical properties of the sol-gel derived inorganic network over a wide range.
6. Once the gel is formed, there are several ways to convert this gel (inorganic network) to the desired solid form.
7. Depending on the deposition and drying processes or conditions, this gel can be converted into various forms such as aerogel, xerogel, gelled spheres, nano-powders, thin film coatings, nanostructured layers, etc.
8. Figure describes the formation of various inorganic structures by sol-gel method. The first three steps of the figure describe the sol preparation and gel formation via four stages described earlier. Once the gel is formed, it can be converted into aerogel by rapidly drying the gel.



9. Also by slow drying process, the gel can be converted into xerogel, which, in turn, can be converted into dense ceramic material under calcination.
10. In a similar way, the sol can be converted into small gelled spheres by using various surfactants, which modify the surface tension of the dispersed particles in the sol and prevents them from agglomeration.
11. The gelled spheres can then be converted into powders by calcination.
12. For nanomaterial fabrication, proper use of surfactant is very important because it controls the level of agglomeration of the suspended particles in the sol.

11.Explain electrodeposition and give its construction.

Electrodeposition

Principle:

1. Electrodeposition is a liquid-based deposition process where an electrical current is passed through a polar liquid by applying an electric potential between two electrodes. Due to this electrical energy injection, the liquid breaks into ions and other charged compounds and, depending on the charge on the ions/compounds and the potential of the electrodes, these charged materials deposit on the electrodes. Thus, by suitable arrangements of preferred substrates on the electrodes, one can coat thin layers of films of some desired materials on the substrate.
2. This technique has been used for long time to make electroplated materials, which is an electrodeposition process to coat an electrically conductive object with a relatively thin layer of metal.
3. The primary application of electroplating is the deposition of a layer of a metal having some desired property (e.g., abrasion and wear resistance, corrosion protection, lubricity, etc.) onto a surface lacking that property.
4. Another application uses electroplating to build up thickness on undersized parts.
5. Electrodeposition is evolving as an important method in ceramic processing.
6. Two processes for forming ceramic films by cathodic electrodeposition are electrophoretic deposition (EPD), in which suspensions of ceramic particles are used, and electrolytic deposition (ELD) , which is based on the use of metal salts solutions.
7. Electrolytic deposition enables the formation of thin ceramic films and nanostructured powders; electrophoretic deposition is an important tool in preparing thick ceramic films and body shaping.

Construction

1. A schematic diagram of the electrodeposition apparatus is shown in figure, the material deposition in electrodeposition follows the Faraday's laws of electrolysis
2. By carefully controlling the number of charged particles transferred, the amount of deposited material can precisely be controlled.
3. If the surface is perfectly flat, then knowing the ionic radius of the material to be deposited, it is possible to calculate the number of atoms transferred and the thickness of the deposited layer. If the surface is rough (which is the practical case) then a coverage factor is included in the calculations, which is related to the root-mean square roughness or average roughness of the surface.
4. Electrodeposition process is especially very useful in nanofabrication process as in nanotechnology, the main aim is to place a single (or a few) layer(s) on a surface in a controlled way.
5. The current (I) and time (t) must be carefully measured and any other factor(s) involving in consuming current, such as impurities, must be known in great detail.
6. Another very important application of electrodeposition is the fabrication of self-assembled/-organized nano-porous materials, such as anodic aluminium oxide (AAO, also called porous alumina) and porous silicon (PS) and growth of nano-particles/rods/wires through the nano-pores of these porous matrixes. This process in general is termed as anodization, as the pores are formed in the anode of an electrodeposition cell. The dimensions of the pores depend on several factors such as the electrolyte (active liquid) used, the anodization current (voltage), anodization time, deposition temperature, etc.

