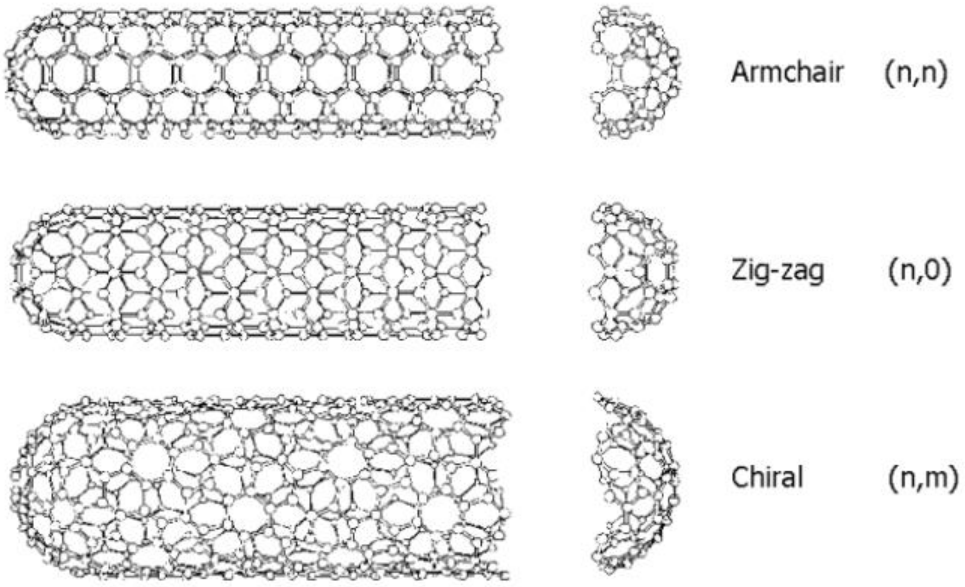
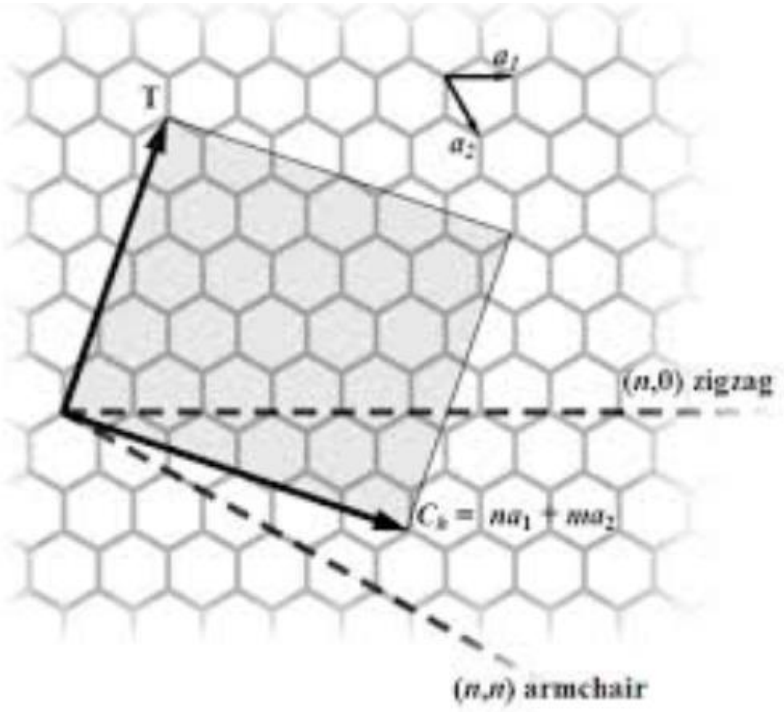
**17. Discuss the classification of single walled carbon nanotube with diagram.**




*Single Walled Carbon Nanotube Structural Models*

Single walled carbon nanotubes have three types of structures, Zigzag, Armchair, and Chiral. It's possible to recognize zigzag, armchair, and chiral nanotubes just by following the pattern across the diameter of the tubes, and analyzing their cross-sectional structure as shown below.




*SWCNTs chiral structure*

**18. Elaborate the synthesis of carbon nanotube by CVD method. Discuss special features and applications of it.**

**Chemical Vapour Deposition (CVD)**

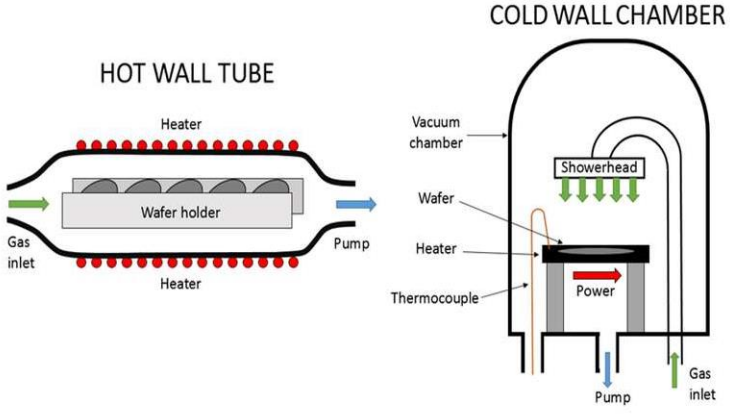
Chemical vapour deposition (CVD) is a process where one or more gaseous adsorption species react or decompose on a hot surface to form stable solid products. The main steps that occur in the CVD process can be summarized as follows:

1. Transport of reacting gaseous species to the surface
2. Adsorption of the species on the surface
3. Heterogeneous surface reaction catalysed by the surface
4. Surface diffusion of the species to growth sites
5. Nucleation and growth of the film
6. Desorption of gaseous reaction products and transportation of reaction products away from the surface.

Thin films and coatings formation can be done using CVD technique. Depending on the activation sources for the chemical reactions, the deposition process can be categorized into thermally activated, laser-assisted and plasma-assisted CVD.

CVD reactors are of generally two types

1. **Hot-wall CVD** – This type of CVD reactors are usually tubular in form, and heating is accomplished by surrounding the reactor with resistance elements.
2. **Cold-wall CVD** – In this type of CVD, substrates are directly heated inductively by graphite susceptors, while chamber walls are air/water cooled.



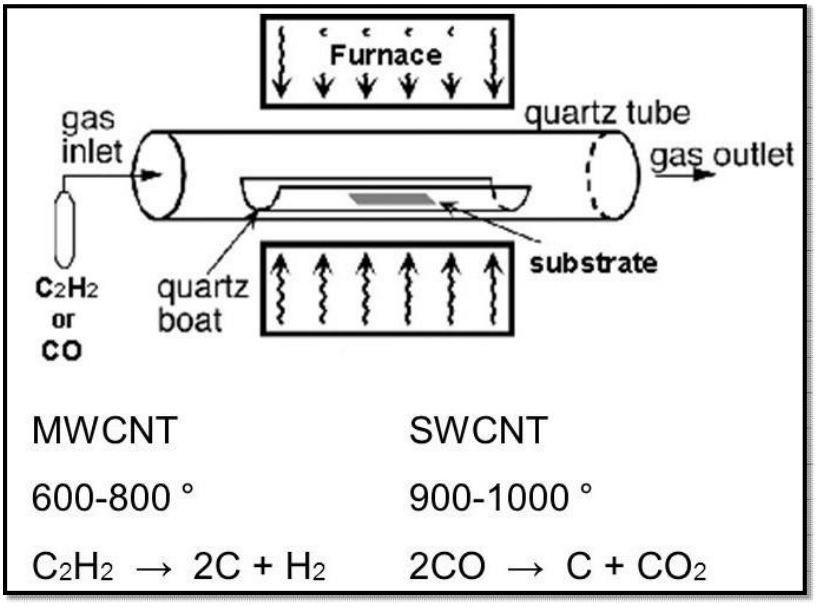
## Hot wall &Cold wall CVD

| | |
|---|---|
| ☐ **Deposition can take place even on reactor walls** | **No deposition on reactor walls** |
| ☐ **Reaction in gas phase is possible** | **This can be suppressed** |
| ☐ **Not feasible** | **Coupling of plasma with chemical reaction is possible** |

Advantages:

- ☐ Capability to produce highly pure and dense films or fine particles at reasonably high deposition rates, and the capability of coating complex-shaped components uniformly due to its non–line-of-sight nature.
- ☐ A variety of metallic, ceramic and semiconducting thin films are being deposited by CVD.

**Synthesis of Carbon nanotubes (CNT) by CVD technique**




During CVD, a substrate is prepared with a layer of metal catalyst particles, most commonly nickel, cobalt, iron or combination. The diameters of the nanotubes that are to be grown are related to the size of the metal particles. This can be controlled by patterned (or masked) deposition of the metal, annealing, or by plasma etching of a metal layer. The substrate is heated to

approximately 700 °C. To initiate the growth of nanotubes, two gases are bled into the reactor: a process gas (such as $NH_3$, $N_2$ or $H_2$) and a carbon-containing gas (such as acetylene, ethylene, ethanol or methane). Nanotubes grow at the sites of the metal catalyst; the carbon-containing gas is broken apart at the surface of the catalyst particle, and the carbon is transported to the edges of the particle, where it forms the nanotubes. The catalyst particles can stay at the tips of the growing nanotube during growth, or remain at the nanotube base, depending on the adhesion between the catalyst particle and the substrate. Thermal catalytic decomposition of hydrocarbon has become an active area of research and can be a promising route for the bulk production of CNTs.

CVD is the most widely used method for the production of carbon nanotubes. For this purpose, the metal nanoparticles are mixed with a catalyst support such as MgO or $Al_2O_3$ to increase the surface area for higher yield of the catalytic reaction of the carbon feedstock with the metal particles. One issue in this synthesis route is the removal of the catalyst support via an acid treatment, which sometimes could destroy the original structure of the carbon nanotubes. However, alternative catalyst supports that are soluble in water have proven effective for nanotube growth.

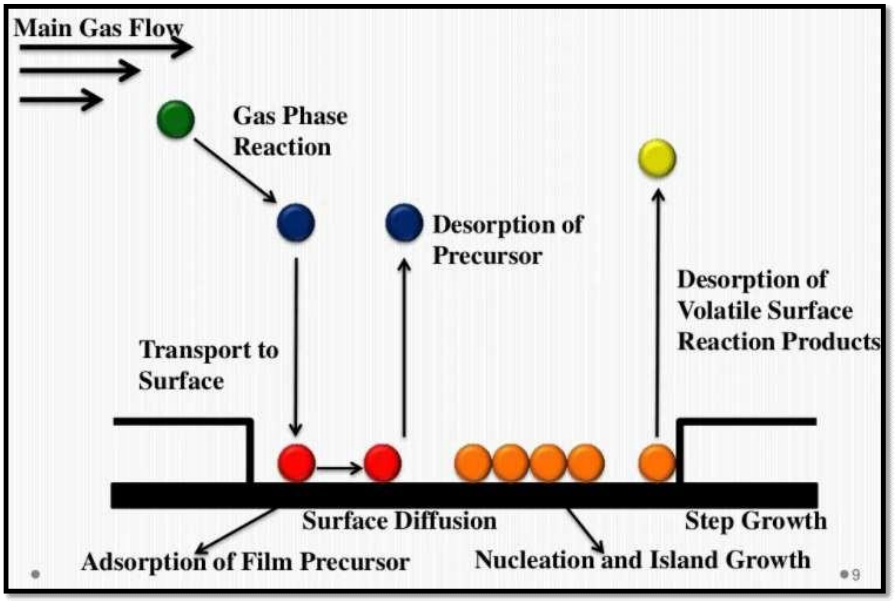



Figure: CVD – Nanomaterial growth mechanism

**Limitations:**

- Use of toxic, corrosive, flammable precursors
- High deposition temperature (> 600°C) unsuitable for structures already fabricated on surfaces

Mechanical instabilities in the deposited films may occur due to stress.