

Chemical Vapor Deposition (cont.)

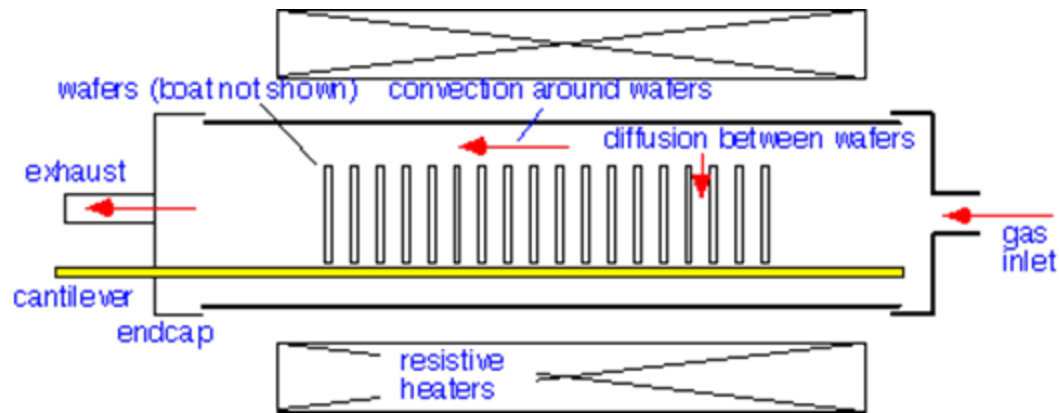
CVD Reactor Notes

- The kinetics of your reaction mostly determines the choice of the reactor type.
- Mass transport limited growth (high T):
 - Should be able to control gas flow and pressure to get uniform films
- Reaction rate limited growth (low T, low P):
 - Should be able to control the temperature profile for uniform films

CVD Reactor Types by Architecture

- Tube reactors
- Showerhead reactors
- High-density plasma reactors
- Linear injection reactors

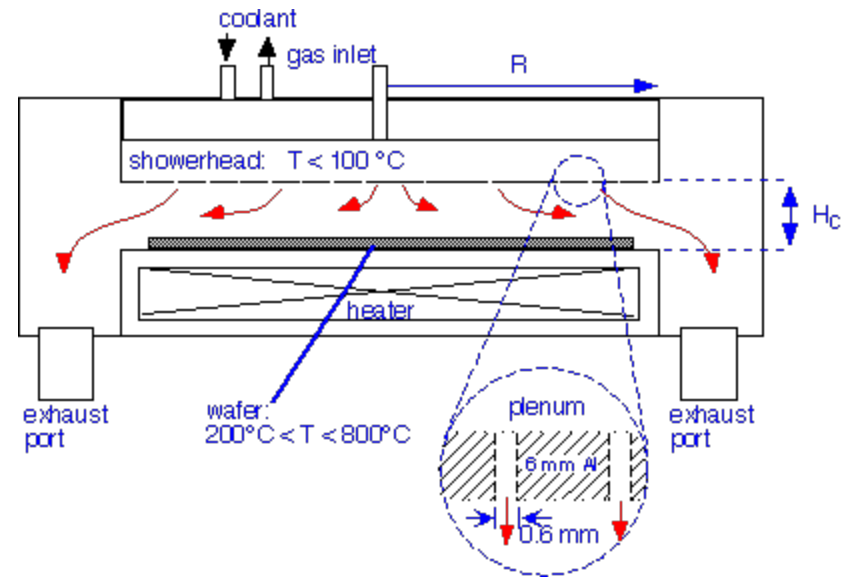
Tube Reactors



- Hot wall design (the reactor walls are heated).
- Can be horizontal or vertical.
- Batch processing of wafers
- Good radial uniformity of films
- Axial uniformity more suspect
- Need to slow down deposition rates for axial uniformity.

Showerhead Reactors

- Cold wall design (only substrate is heated)
- Better suited for plasma enhanced processing.
- Generally a single wafer design.
- Good heater design is needed for radial uniformity.



CVD Reactor Types by Process

- APCVD – Atmospheric Pressure CVD
- LPCVD – Low Pressure CVD
- PECVD – Plasma Enhanced CVD
- PHCVD – Photon (Laser) Induced CVD
- MOCVD – Metalorganic CVD

APCVD

- Chamber is at room pressure
- In order to improve diffusion for better film quality, we need high temperatures.
- The process is limited by mass transport.
- The high pressure is needed to slow the deposition rate for even better diffusion.
- Still, since we are at high pressure, there are many impurities around and the film quality is not great.
- Step coverage is not very good.
- Not suitable for high quality Silicon deposition, better for dielectric films.

APCVD Reactors

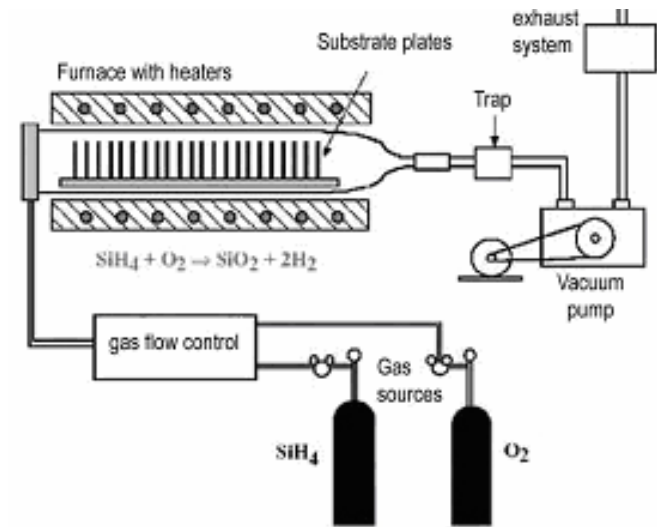
- Belt Reactors
 - Continuous in-line deposition
- Bell Reactors
 - For Silicon epitaxial layers
- Tube Furnace
 - Need to tilt samples for them to see a uniform gas concentration.

LPCVD

- Gas pressures around 1mTorr - 1 Torr
- Higher gas concentrations
- Higher diffusivity of gas to the substrate
- Often reaction rate limited growth
- Due to lower pressures, there are fewer defects.
- Better step coverage, better film uniformity.

LPCVD Reactors

- Can be “hot wall” or “cold wall” reactors
- Hot wall reactors have a more uniform temperature distribution but the surface of the reactor walls can also get coated. This limits the reactor to one species. Used more for polycrystalline films.
- In cold wall reactors, the reaction rate is reduced but film quality can be better controlled. Better for epitaxial films.



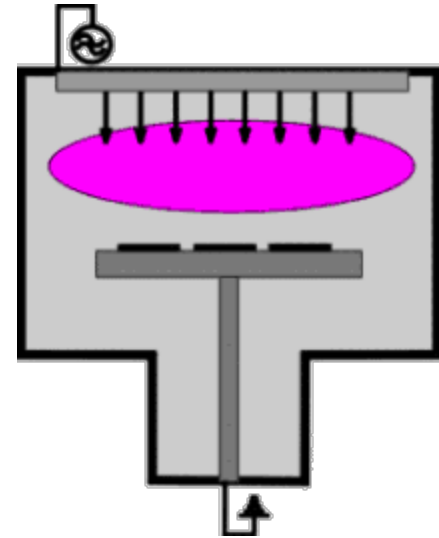
Hot wall reactor

LPCVD Summary

- Fewer defects
- No need for a carrier gas (not transport limited)
- Slow growth rate
- Good conformation (step coverage)
- High temperature dependence

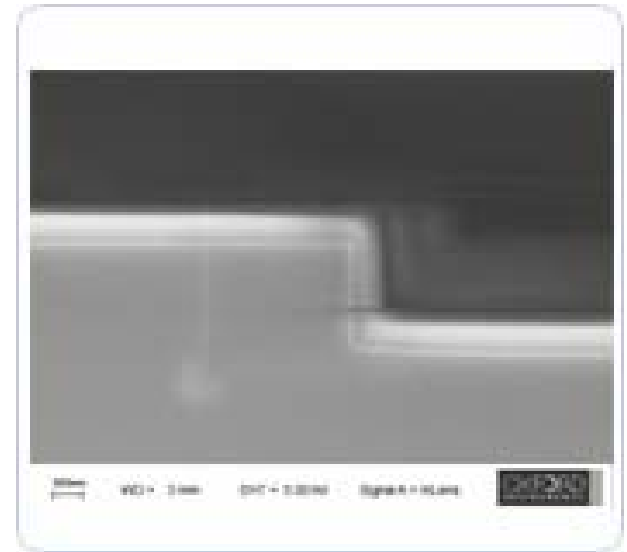
PECVD

- Create a plasma (RF or DC) in the vicinity of the substrate.
- As in sputtering, the energetic ions impart their energy and momentum on the reactant gas molecules and atoms.
- The energy transfer breaks up the molecules and aids the chemical reactions.



PECVD

- The “helping hand” of the plasma allows for lower temperatures and pressures and improves film quality.
- The imparted momentum allows for better step coverage.
- The lower temperatures are especially useful when depositing metal contact layers (eg. Al) between dielectric (insulating) layers (eg. SiO_2)..
- The higher temperatures of plain LPCVD would melt the metal and the alternate layers would interact.



Step coverage in PECVD

PECVD

- Compared to sputtering, the pressures are higher, meaning the ions are less energetic when they hit the substrate (more collisions to lose energy).
- This reduces the sputtering effects on the substrate.
- For insulating films, again, RF plasma can be used to minimize coating.

PHCVD

- Use a laser to enhance surface reactions
- Two main processes are involved:
 - pyrolytic
 - heats substrate to enhance reactions
 - photolytic
 - gas phase dissociation of molecules to enhance reactivity
 - typically use UV radiation

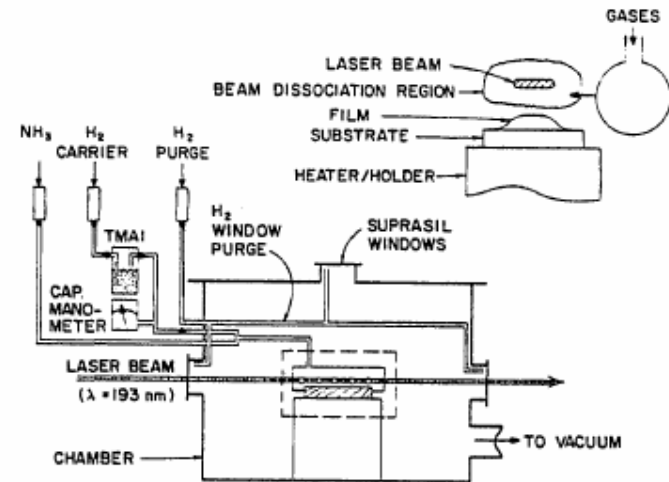
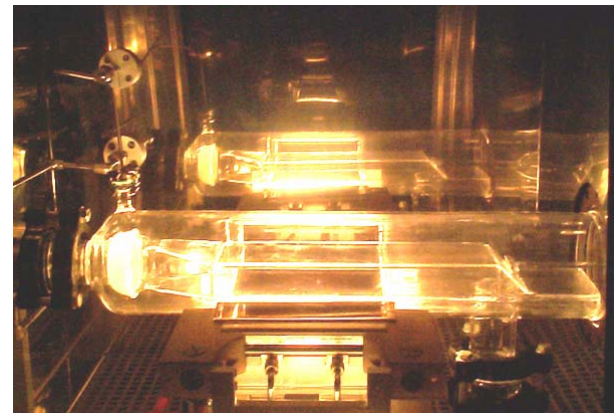
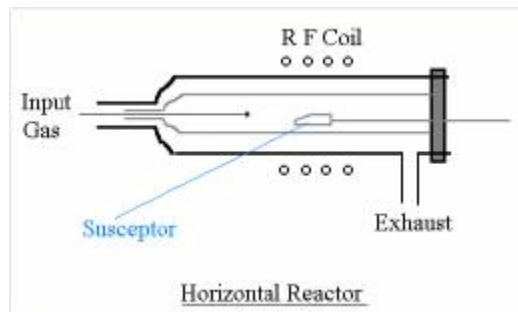


Fig. 1. Schematic diagram of the L-CVD deposition apparatus.

Appl. Opt., v25, pp 1311-1317, 1986

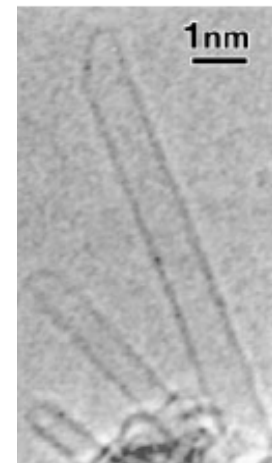
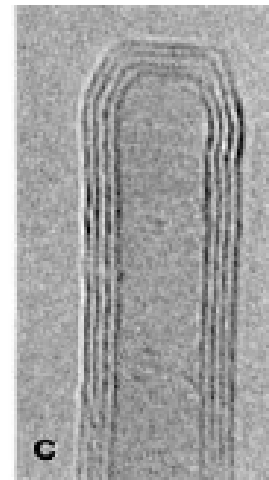
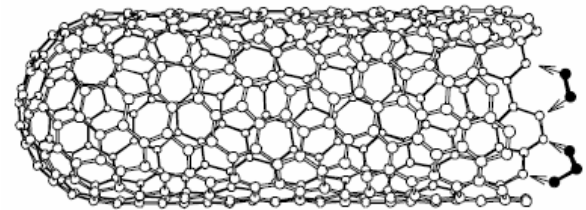
MOCVD

- Use organometallic source gasses.
- eg: $(\text{CH}_3)_3\text{Ga}$ tri-methyl Gallium
- Reactants are volatile at relatively low temperatures.
- Can grow high quality epitaxial films at nanometer scale.
- Both the reactants and the byproducts can be hazardous.



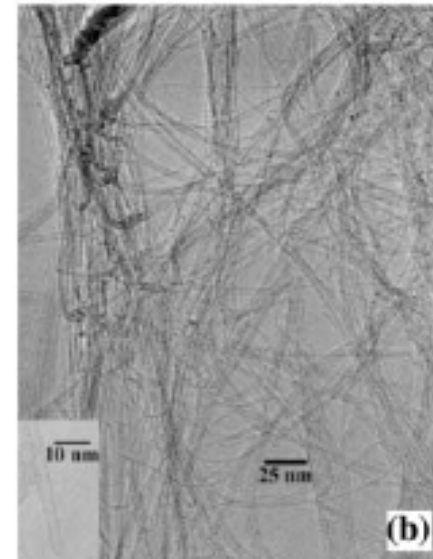
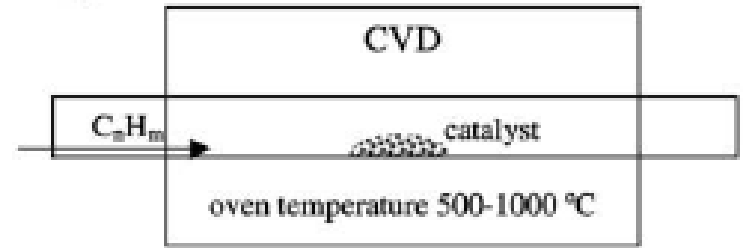
Carbon Nanotubes

- Carbon nanotubes are tubular structures of carbon, typically several nanometers in diameter and hundreds to thousands of nanometers in length.
- They can be single or multiwalled.
- Can have a wide range of electrical, mechanical and optical properties.



CVD Growth of Carbon Nanotubes

- A hydrocarbon gas is passed over a catalyst in a high temperature oven.
- The catalyst (often transition-metal nanoparticles on alumina) allows the dissociation of the hydrocarbon.
- The carbon then dissolves and saturates the nanoparticles.
- Upon precipitation from the catalyst, carbon atoms form nanotubes (energetically favored over graphite sheet formation).
- The chamber is cooled to room temperature and the tubes are collected.
- The choice of the hydrocarbon, the catalyst and the temperature determine the nature of the nanotubes.



CNT Growth Details

- MWCNT
 - Ethylene or acetylene as the hydrocarbon
 - Temperature: 550 °C – 700 °C
 - Nickel or Cobalt nanoparticles as catalyst
- SWCNT
 - Methane as the hydrocarbon
 - Temperature: 850 °C – 1000 °C
 - Nickel, Cobalt or Iron nanoparticles as catalyst