Epitaxial Deposition Technique

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Common deposition techniques

- **Chemical vapor deposition (PVD),**
  - Vapor Phase Epitaxy (VPE)
- **Physical vapor deposition (CVD),**
  - Evaporation, and
  - Sputtering

Chemical vapour deposition creates thin films using chemical reactions.

Physical vapour deposition uses physical reactions to change a liquid source material to a gas. The material then returns to its solid state as a thin layer on the surface of the substrate.

Aadvantages of the CVD

Chemical vapour deposition provides a versatile process for coating the surface of a substrate.

Aadvantages of the CVD method:

- *High purity:* CVD uses gas coating materials, avoiding the impurities of liquid coating processes.
- *Uniform coating*: CVD is a conformal deposition process, which means it uniformly coats a substrate regardless of the shape to produce an even coating.
- *Application variety*: CVDis being used to create thin layers on many materials regardless of rigidity, flexibility, or density, from electronics manufacturing to producing crisp bags. For synthesis of large graphene sheets, carbon nanotube arrays, and other essential coated manufacturing materials.
- *Cost:* CVD systems cost less than PVD systems.

Aadvantages of the PVD

- ***Environmental friendliness*:** Unlike CVD, PVD does not produce hazardous byproducts and does not use hazardous gases in its processes. Instead of using a reactive gas, PVD uses high-power electricity or lasers to gasify the coating material.
- ***Diversity:*** Using the PVD method, it is possible to deposit almost any type of inorganic material and some organic materials on a diverse and wide group of surfaces and substrates
- ***Variety:*** Provide a variety of techniques for deposition of a specific material

Disadvantages of PVD:

Some PVD methods and techniques require high attention and accuracy of the user due to the high vacuum and high temperature of the coating environment.

Features of a Device Layers

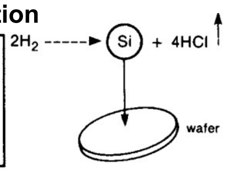
General criteria that all films must meet for semiconductor use include:

- Thickness/uniformity
- Surface flatness/roughness
- Composition/grain size
- Stress free
- Purity
- Integrity

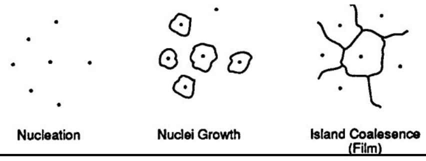
Chemical Vapor Deposition (CVD)

CVD involves four categories of chemical reaction i.e., **pyrolysis, reduction, oxidation, and nitridation**

Pyrolysis	$SiH_4 \rightarrow Si + 2H_2$
Reduction	$SiCl_4 + 2H_2 \rightarrow SI + 4HCL$
Oxidation	$SiH_4 + O_2 \rightarrow SiO_2 + 2H_2$
Nitridation	$3SiH_2Cl_2 + 4NH_3 \rightarrow Si_3N_4 + pH + 6H_2$



Epitaxy starts with Nucleation of first few atoms or molecules on the surface and form islands that grow into larger islands. Then the islands spread, finally coalescing into a continuous film.



CVD System

CVD system has the following basic parts

1. *source cabinet,*
2. *reaction chamber,*
3. *energy source,*
4. *wafer holder (boat), &*
5. *loading and unloading mechanisms.*

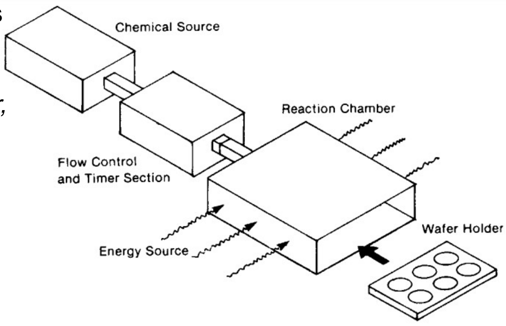


Figure 12.9 Basic CVD subsystems.

In some cases, the CVD system is a tube furnace

CVD Process Steps

- Cleaning
- Chemical vapor deposition
  - First, the wafers are loaded into the chamber, usually with an inert atmosphere.
  - The wafers are brought to temperature. Chemical vapors are introduced for as long as required to deposit the film.
  - The chemical source vapors are flushed out and the wafers removed.
- Evaluation
  - for thickness, step coverage, purity, cleanliness, and composition.

CVD Types

- Atmospheric-pressure chemical vapor deposition (APCVD)
- Low-pressure chemical vapor deposition (LPCVD)

Another differentiation is **cold wall** versus **hot wall**

Cold-wall directly heats the **Wafer/Wafer-holder**

Hot-wall heats the wafers, the wafer holder, and the **chamber walls**

A specialty CVD used to deposit compound films, such as GaAs, is **vapor phase epitaxy (VPE)**.

A newer technique used to deposit ***metals*** is a **metalorganic (MOCVD)** source in a VPE system.

APCVD

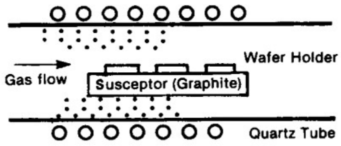


Figure 12.11 Cold-wall induction APCVD with horizontal susceptor.

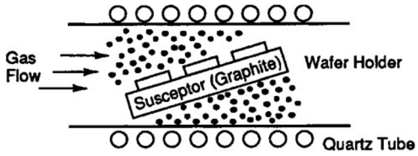


Figure 12.12 Cold-wall induction APCVD with tilted susceptor.

LPCVD System

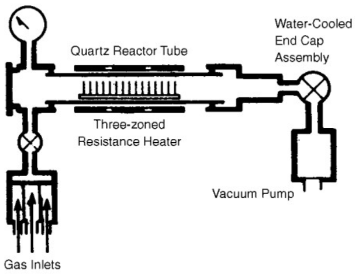


Figure 12.18 Horizontal hot-wall LPCVD system.

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Vapor Phase Epitaxy (VPE)

VPE has the ability to deposit compound materials, such as gallium arsenide (GaAs).

A VPE system is a combination of a standard liquid source tube furnace and a two-zone diffusion furnace

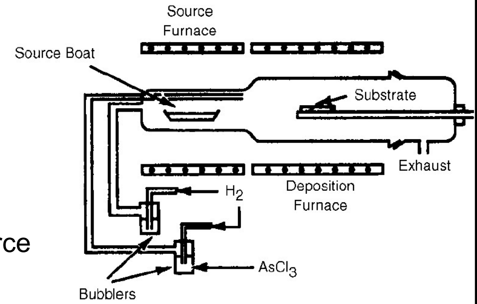


Figure 12.22 Diagram of gallium arsenide VPE deposition system.

GaAs deposition

The creation of the GaAs layer on the wafer in the main chamber proceeds in two stages.

- $AsCl_3$ bubbles reacts with solid gallium that is sitting in a boat. The $AsCl_3$ reacts with the hydrogen in the first section to form arsenic by the reaction

$$4AsCl_3 + 6H_2 \rightarrow 12HCl \rightarrow As_4$$

- The arsenic deposits on the gallium, forming a crust. The hydrogen passing over the crust reacts in the first section to form three gases that pass into the wafer section. $\frac{\text{GaAs}}{\text{(solid)}} + \frac{\text{HCl}}{\text{(gases)}} \leftrightarrow \frac{\text{GaCl}}{\text{(gas)}} + \frac{1/2\text{H}_2}{\text{(gas)}} + \frac{1/4\text{As}_4}{\text{(gas)}}$

This section is at a somewhat lower temperature, and the reaction proceeds in reverse, depositing GaAs on the wafers.

Molecular Beam Epitaxy (MBE)

- MBE is an evaporation rather than a CVD process that offers deposition rate control at low deposition temperature, and produces controlled film stoichiometry

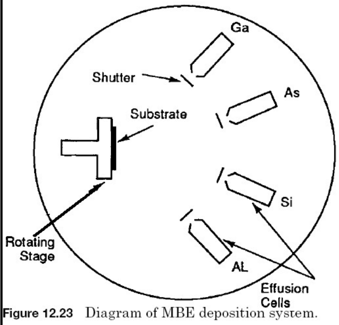


Figure 12.23 Diagram of MBE deposition system.

The system consists of a deposition chamber that is maintained at a low pressure to 10^{-10} torr. Within the chamber can be one or more cells (called *effusion cells*) that contain a very pure sample of the target material desired on the wafer.

Shutters on the cells allow exposure of the wafer to the source material(s). An electron beam is directed into the center of the target material, which it heats to the liquid state. In this state, atoms evaporate out of the material, exit the cell through an opening, and deposit on the wafers. If the material source is a gas, the technique is called *gas source MBE* or *GSMBE*.

Advantages & Disadvantages of MBE

- The primary advantage of MBE for silicon technology is the low temperature (400 to 800°C),
  - minimizes autodoping and outdiffusion.
- Ability to form multiple layers on the wafer surface during one process step (one pump down).
- The films produced are very controllable.
  - The incorporation of film growth and quality-analyzing instruments in the chamber produce uniform films

Disadvantage of MBE is the low film growth rate of 60 to 600 Å/min.12

Metalorganic CVD (MOCVD)

MOCVD is one of the latest options for CVD of compound materials. Whereas VPE refers to a compound material deposition system, MOCVD refers to the sources used in VPE systems

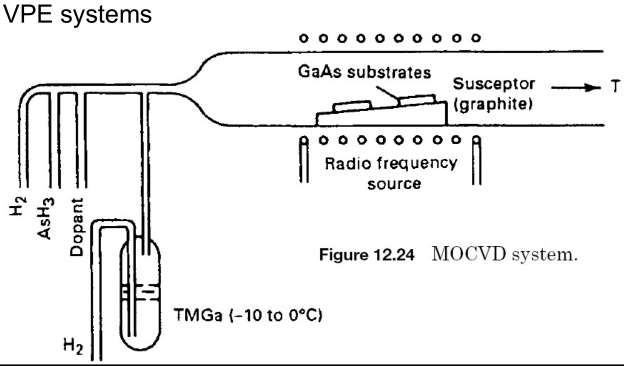


Figure 12.24 MOCVD system.

MOCVD process for GaAs

Two chemistries are used, halides & metalorganic.

– halide process. $\frac{GaAs}{(solid)} + \frac{HCl}{(gases)} \leftrightarrow \frac{GaCl}{(gas)} + \frac{1/2H_2}{(gas)} + \frac{1/4As_4}{(gas)}$

A group III halide (gallium) is formed in the hot zone, & the III–IV compound is deposited in the cold zone.

– metalorganic process $(CH_3)_3Ga + AsH_3 \rightarrow GaAs + 3CH_4$

Trimethylgallium is metered into the reaction chamber along with arsine to form gallium arsenide by the reaction

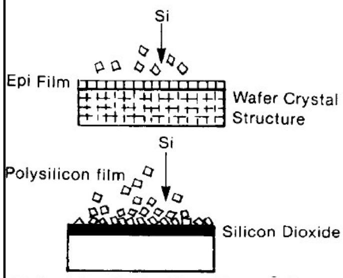
Deposited films

- Deposited films may be of
  - semiconductors,
  - dielectrics, and
  - conductors.

Semiconductor Deposition

There are several drawbacks to using bulk wafers for high-quality devices and circuits. Crystal quality, doping ranges, and doping control all limit bulk wafer use. These factors placed a limit on the fabrication of high-performance bipolar transistors. A solution was found by the development of a deposited silicon layer, called an ***epitaxial layer***.

Epitaxial Silicon



Epitaxial and polysilicon film growth

The depositing atoms arrive at the wafer surface orient themselves to the crystal arrangement of the wafer atoms.

If the wafer surface has a thin layer of silicon dioxide, an amorphous surface layer, or contamination, the depositing atoms have no structure to which they can align. The resulting film structure is polysilicon.

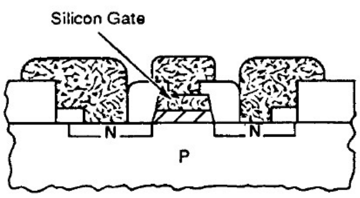
Epitaxial process.

Cycle	Temperature	Gas	Purpose
1	Room	N_2	Purge air from system
2	Room	H_2	Reduce any organic contaminants of wafers in system
3	(Heating)	N_2	Bring system to deposition temperature
4	Deposition Temperature	HCl	Etch wafer to prepare surface for epi deposition
5	Deposition Temperature	Source + Dopant + Carrier	Grow epitaxial film
6	(Heat Off)	N_2	Purge system of reactant gases

Figure 12.33 Typical $SiCl_4$ epitaxial deposition process.

Application of polysilicon

- MOS gates
- Use as load resistors in SRAM devices
- As part of silicide metallization schemes
- Multilayer poly in EEPROMs
- Contact barrier layers
- Emitters in bipolar devices, &
- Trench fills



Cross section of silicon gate MOS transistor

Polysilicon Deposition

Most polysilicon layers are deposited with LPCVD systems that provided good productivity and lower deposition temperatures.

Typical polysilicon deposition processes take place in the 600 to 650°C range. The deposition may be from either 100 percent silane or from gas streams containing N_2 or H_2.

During the early stages of deposition, at temperatures below 575°C, the structure is amorphous (no structure). The polysilicon structure formed by deposition techniques consists of small pockets (crystallites or grains) of single-crystalline silicon separated by grain boundaries. This structure is called *columnar poly*.

SOS and SOI

- SOS: *silicon on sapphire* and
- SOI: *silicon on insulator*

Both refer to the deposition of silicon on a nonsemiconductor surface.

Aadvantages of the PVD

- *Temperature resistance:* PVD films can withstand temperatures over 400 degrees Celcius.
- *Abrasion and impact resistance*: PVD techniques can create a very thin layer of only 2.5 micrometres that provides superior resistance to abrasions.
- *Environmental friendliness*: Unlike CVD, PVD does not produce hazardous byproducts and does not use hazardous gases in its processes. Instead of using a reactive gas, PVD uses high-power electricity or lasers to gasify the coating material.
- *Wear-resistant coating:* Manufacturers use PVD for many coating applications, including improving wear resistance and reducing the friction of cutting tools.