Molecular Beam Epitaxy (MBE)

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

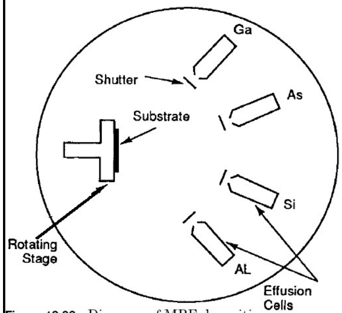


Figure 12.23 Diagram of MBE deposition system.

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

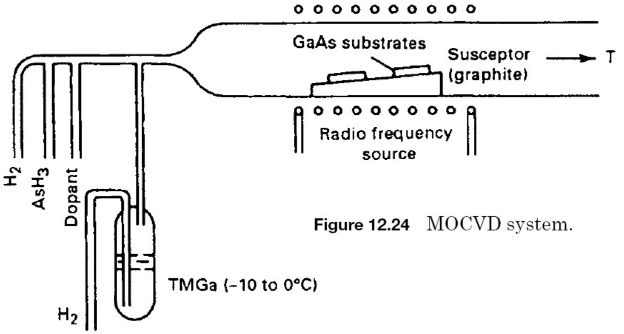


Figure 12.24 MOCVD system.

MOCVD process for GaAs

Two chemistries are used, halides & metalorganic.

– halide process. $\frac{\mathrm{GaAs}}{\text{(solid)}} + \frac{\mathrm{HCl}}{\text{(gases)}} \leftrightarrow \frac{\mathrm{GaCl}}{\text{(gas)}} + \frac{1/2\mathrm{H}_2}{\text{(gas)}} + \frac{1/4\mathrm{As}_4}{\text{(gas)}}$

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

– metalorganic process $(\mathrm{CH}_3)_3\mathrm{Ga} + \mathrm{AsH}_3 \rightarrow \mathrm{GaAs} + 3\mathrm{CH}_4$

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

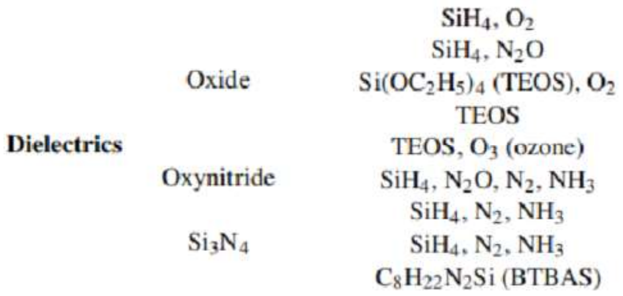
Dielectric Layer Deposition

Layers in IC

Fabricating IC requires different kinds of thin films which can be classified into five groups:

- a) epitaxy layers,
- b) thermal oxides
- c) ***dielectric layers***
  - Thermally grown
  - Deposited
- d) polycrystalline silicon
- e) metal films.

Dielectric layers

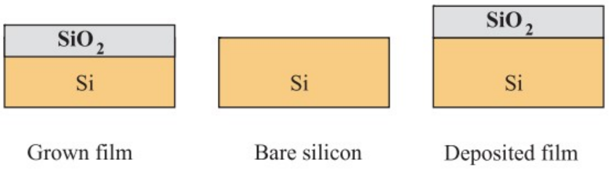


Dielectrics	Oxide	SiH_4, O_2 SiH_4, N_2O $Si(OC_2H_5)_4$ (TEOS), O_2 TEOS TEOS, O_3 (ozone)
	Oxynitride	SiH_4, N_2O, N_2, NH_3 SiH_4, N_2, NH_3
	Si_3N_4	SiH_4, N_2, NH_3 $C_8H_{22}N_2Si$ (BTBAS)

The main role of **dielectric thin film** is as a dielectric layer for electrical insulation in multilevel metal interconnections.

Thermally grown Vs Deposited layer

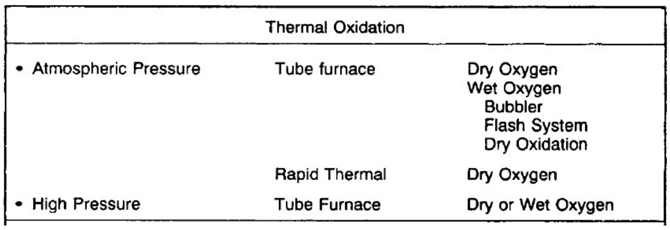
The fundamental difference between **thermally grown** and **deposited** thin films is that grown film consumes silicon from the substrate, while deposited film does not.



For thermally grown SiO_2, O_2 comes from the gas phase, and Si comes from the Si substrate. This process consumes silicon from the substrate, and the film grows into the substrate.

For deposited oxide, both silicon and oxygen come from the gas phase, so there is no consumption of silicon substrate.

Grown Oxide

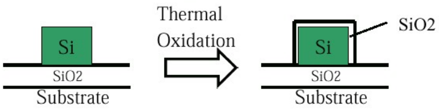


Thermal Oxidation		
• Atmospheric Pressure	Tube furnace	Dry Oxygen Wet Oxygen Bubbler Flash System Dry Oxidation
	Rapid Thermal	Dry Oxygen
• High Pressure	Tube Furnace	Dry or Wet Oxygen

Thermal SiO_2 Properties

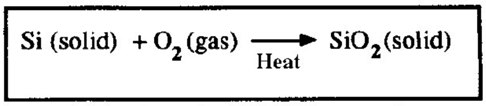
(1) Excellent Electrical Insulator
Resistivity > 1E20 ohm-cm
Energy Gap ~ 9 eV
(2) High Breakdown Electric Field
> 10MV/cm
(3) Stable and Reproducible Si/SiO_2 Interface

(4) Conformal oxide growth on exposed Si surface



Thermal Oxidation Mechanisms

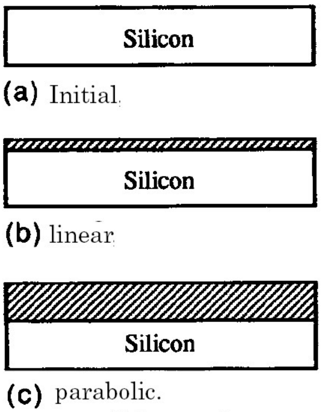
- Thermal oxide growth is a simple chemical reaction as shown in Fig. 7.7. This reaction takes place even at room temperature. However, an elevated temperature is required to achieve quality oxides in reasonable process times for practical use in circuits and devices. Oxidation temperatures are between 900 and 1200°C.



$$\text{Si (solid)} + O_2\text{(gas)} \xrightarrow[\text{Heat}]{} SiO_2\text{(solid)}$$

Figure 7.7 Reaction of silicon and oxygen to form silicon dioxide.

Thermal Oxidation Mechanisms….



(a) Initial

(b) linear

(c) parabolic.

Figure 7.8 SiO_2 growth states.

Thermal Oxidation Mechanisms….

Thermal oxidation: Dry & Wet

Dry oxidation

Initially, the oxygen atoms combine readily with the silicon atoms. This stage is called *linear because* the oxide grows in equal amounts for each unit of time

$X = B/A\ t$
Linear oxidation of silicon

$X = \sqrt{B\ t}$
Parabolic oxidation of silicon

X = oxide thickness
B = parabolic rate constant
B/A = linear rate constant
t = oxidation time

Figure 7.9 Linear and parabolic growth of silicon dioxide.

Wet oxidation

- One way to achieve faster oxidations is to use water vapor (H_2O) instead of oxygen as the oxidizing gas (oxidant). Water vapor at the oxidation temperatures is in the form of steam, and the process is called either ***steam oxidation***, ***wet oxidation***, or ***pyrogenic steam***.

$$\text{Si (solid)} + H_2O\ \text{(gas)} \xrightarrow[\text{Heat}]{} SiO_2\text{(solid)} + 2H_2\ \text{(gas)}\uparrow$$

Figure 7.12 Reaction of silicon and water vapor to form silicon dioxide and hydrogen gas.

Influences on the oxidation rate

- **Wafer orientation**
- **Wafer dopant redistribution**
- **Oxide impurities**

Thermal nitridation

- In the 100-Å (or less) range, silicon dioxide films tend to be of poor quality and difficult to control. An alternative to silicon dioxide films is a thermally grown silicon nitride (Si_3N_4) film. Si_3N_4 is denser than silicon oxide and has fewer pinholes in these thin ranges. It also is a good diffusion barrier.

- Growth of silicon nitride is formed by the exposure of the silicon surface to ammonia (NH_3) between 950 and 1200°C.

Sputtering (PVD)

Sputter deposition (sputtering) is another old process adapted to semiconductor needs. Sputtering (in general) can deposit any material on any substrate.

It has a better step coverage that made sputtering the metal deposition technique of choice for most silicon-based technologies.

Sputtering

Argon gas in the chamber is ionized. The positively charged argon atoms are attracted to the grounded target and strike the target. These ions “knock off” atoms and molecules from the target into the chamber. These atoms and molecules are deposited in the wafer.

Increasing ion energy

E<10eV: Adsorption, bouncing off surface, or surface damage

E=10eV-5keV: *Sputtering*

E > 5keV: *Ion implantation*

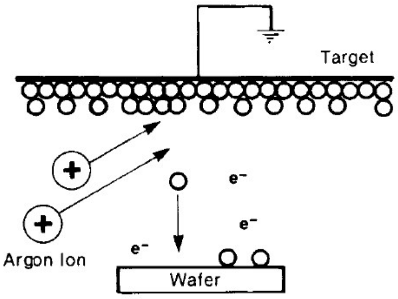


Figure 13.19 Principle of sputtering.