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Diffussion

Introduction

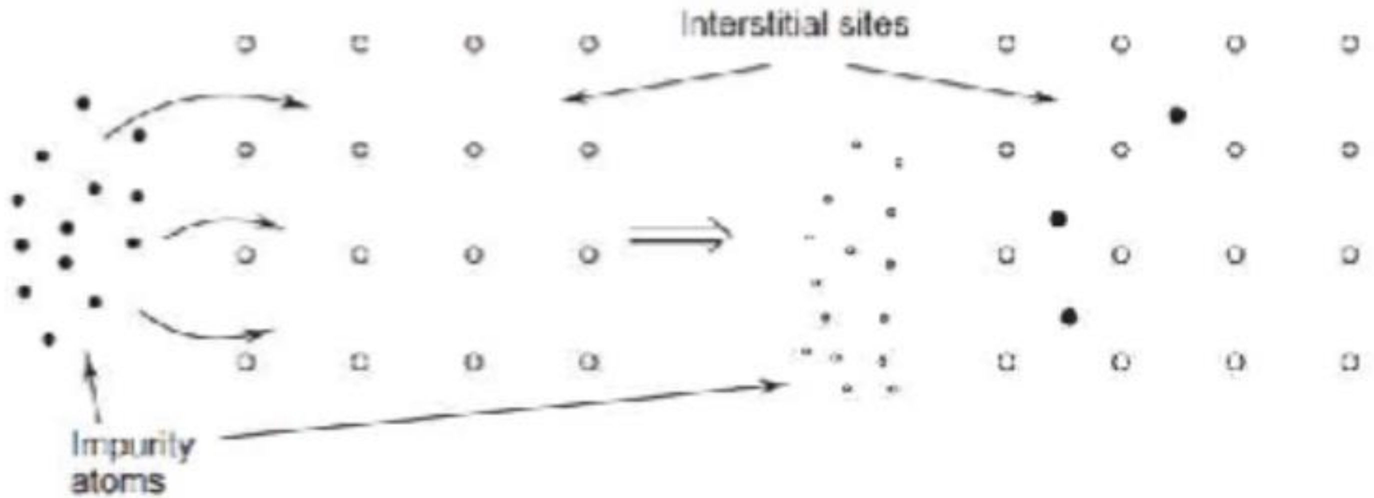
- Diffusion is done to implant impurity atoms in semiconductor.
- It is spontaneous and automatic process.
- It is a process of movement of small molecules from an area of higher concentration to the area of lower concentration.
- In VLSI fabrication, by this process controlled amount of impurity is introduced into semiconductor, by subjecting the semiconductor at high temperature in an ambient containing the dopant impurity.

Introduction

- Diffusion is governed by the following factors:
  - Concentration gradient
  - Temperature
  - Nature of impurity atom
  - Crystal structure of target material
  - Total time for which semiconductor is placed under diffusing environments.
  - Defects in Crystal
    - Vacancy
    - Interstitial

Models of diffusion in Solids:Interstitial Diffusion

- The process in which impurity atom moves through crystal lattice by jumping from one interstitial site to the next.
- The process is relatively fast.
- An atom smaller than the host atom that does not form covalent bonds with silicon often moves interstitially.
- Group I and VIII element have smaller radii, and they diffuse by the same mechanism



Diffusion by Vacancy

- At elavated temperature the lattice atom acquires sufficient energy and leaves the lattice site ,becoming a self interstitial atom and creating a vacancy.
- When a neighbouring atom (either host or the impurity atom) migrates to the vacancy site,it is called diffusion by vacancy.
  - Host atom-self diffusion
  - Impurity atom-impurity diffusion

Interlatency diffusion

- Here the interstitial atom can be anihilated by pushing substitutionally located impurity atom into interstitial sites.
- These impurity atom can diffuse to adjacent substitutional sites and create new self interstitials.
- Thus, the interstitial position of the diffusing impurity atom is purely a transition state, in moving from one substitutional site to another.
- Boron and phosphate diffuse in silicon in similar fashion

Fick's One dimensional Diffusion Equation

- Fick assumed that in a dilute liquid or gaseos solution , in the absence of convection, the transfer of solute atoms per unit area in a one dimensional flow can be described by the following equation:
- $J = -D \partial C(x,t) / \partial x$ ……………………….(1)
  - J=rate of transfer of solute per unit area or the diffusion flux,
  - C=concentration of solute (function of x and t)
  - X=coordinate axis in the direction of the solute flow
  - t=diffusion time
  - D=diffusvity

Fick’s One dimensional Diffusion Equation

- Equation 1 states that the local rate of transfer (local diffusion rate) of solute per unit area per unit time is proportional to the concentration gradient of the solute, and defines the proportionality constant as the diffusivity of the solute.
- The –ve sign indicates on the RHS of Eq.1 states that the matter flows in the direction of decreasing solute concentration.
- Eq.1. is called Fick’s first law of diffusion.

Fick's One dimensional Diffusion Equation

- From the law of conservation of matter, the change of solute concentration with time must be the same as the local decrease of the diffusion flux, in the absence of a source or a sink;that is
- $\partial C(x,t)/ \partial t= - \partial J(x,t)/ \partial x$ ....(2)
- Substituting eq.1 in eq.2,yeilds Fick's second law of diffusion in one dimension form
- $\partial C(x,t)/ \partial t= \partial / \partial x\ (D \partial C(x,t)/ \partial x)$ ......(3)

Fick's One dimensional Diffusion Equation

- When the concentration of the solute is low , the diffusivity at a given temperature can be considered as constant and the above eq can be written as
- $\partial C(x,t)/ \partial t= D\partial^2 C(x,t)/ \partial x^2$ ....(4)
- This is known as **Fick's second law of diffusion**

Constant Diffusivity

- **Constant surface Concentration:** the intial condition at t=o is C(x,o)=o,and the boundary condition are C(o,t)=Cs and C(∞,t)=o.
  - Solution to Eq4 satisfying above intial and boundary conditions is given by
  - $C(x,t)=C_s\,\mathrm{erfc}(x/2\sqrt{Dt})$

Constant Diffusivity

- **Constant Total Dopant:** suppose that a thin layer of dopant is deposited onto the silicon surface with a fixed(constant) total amount of dopant Qt per unit area, and the dopant diffuses only into the silicon: that is, all of the dopant atoms remain in the silicon. The initial and boundary conditions, and the solution of the diffusion equation that satisfy these conditions are:
  - Intial condition C(x,t)=0, boundary condition and C(∞,t)=0 $\int_0^\infty C(x,t)dx = Q_t$

The solution of the diffusion eq.4 that satisfies the above boundary condition is

$$C(x,t) = \frac{Q_t}{\sqrt{\pi D t}} \exp\left(-\frac{x^2}{4Dt}\right)$$

Diffusion System

Diffusion systems: The dopant can be a gaseous liquid or a solid source. And, hence the dopant diffusion system can be of following three types:

(*a*) **Solid source diffusion system:** In solid source diffusion system, a solid compound of the dopant is taken. A solid source diffusion system is shown in Fig. 7.16.

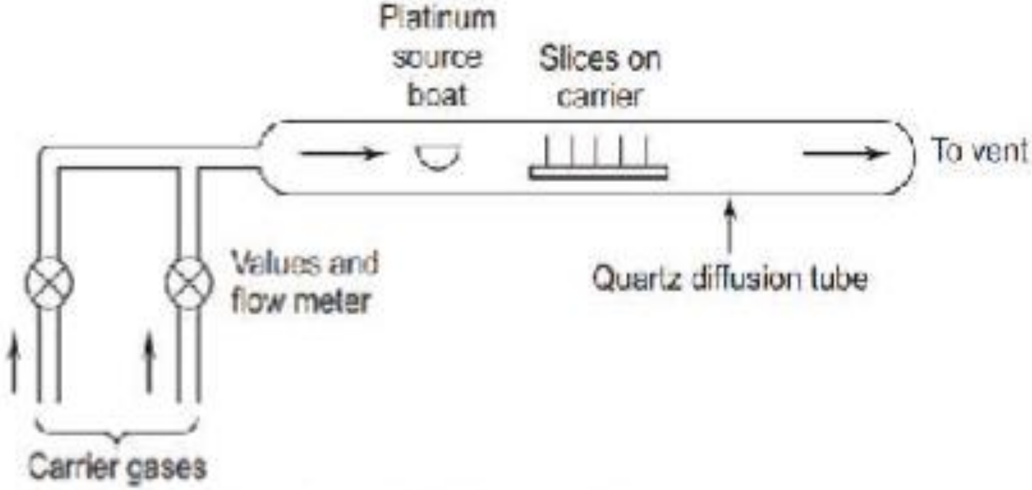


Fig. 7.16 *Solid Source Diffusion System*

Diffusion System

Here, a platinum boat is used to hold a solid source of dopant species upstream from the carrier with the semiconductor wafers. In operation, the carrier gas transports vapours from this source and deposits them on the semiconductor slices. Source shutoff is usually accomplished by moving the dopant source to a colder region of the furnace.

(*b*) **Liquid source diffusion system:** Here, a carrier gas is bubbled through the liquid which is transported in vapour form to the surface of the slices. It is common practice to saturate the gas with the vapour so that the concentration is relatively independent of gas flow. The surface concentration is thus set by the temperature of the bubbler and of the diffusion system. Additional lines are also provided for other gases in which the diffusion is performed and for flushing out the system after use.

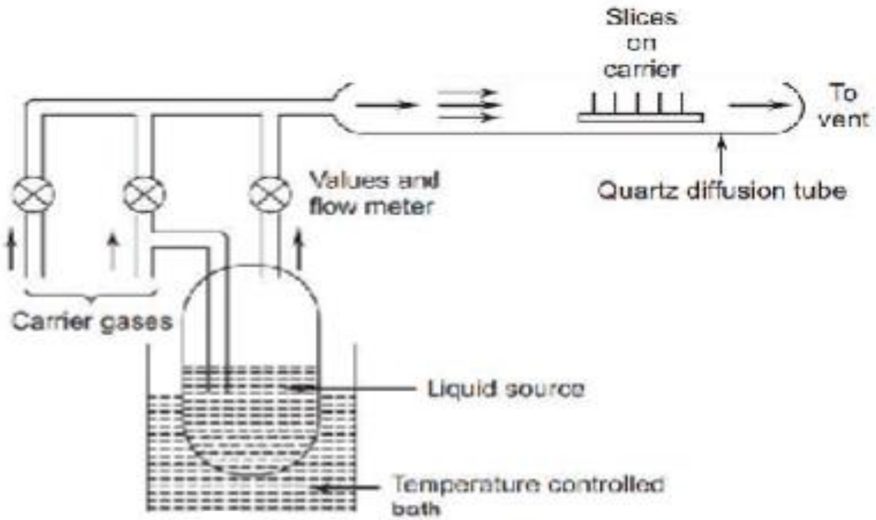


Fig. 17 *Liquid Source Diffusion System*

Diffusion System

(*c*) **Gaseous source diffusion system:** It is more convenient than the liquid source diffusion system. Here, provision is made for an ambient carrier gas in which the diffusion takes place. A chemical trap is often incorporated to dispose of unrelated dopant gases, which are generally highly dangerous. All vapour transport methods rely on the fact that the surface concentration of the incorporated dopant is solid-solubility limited, so that it is relatively insensitive to the vapour pressure of the reactant species.

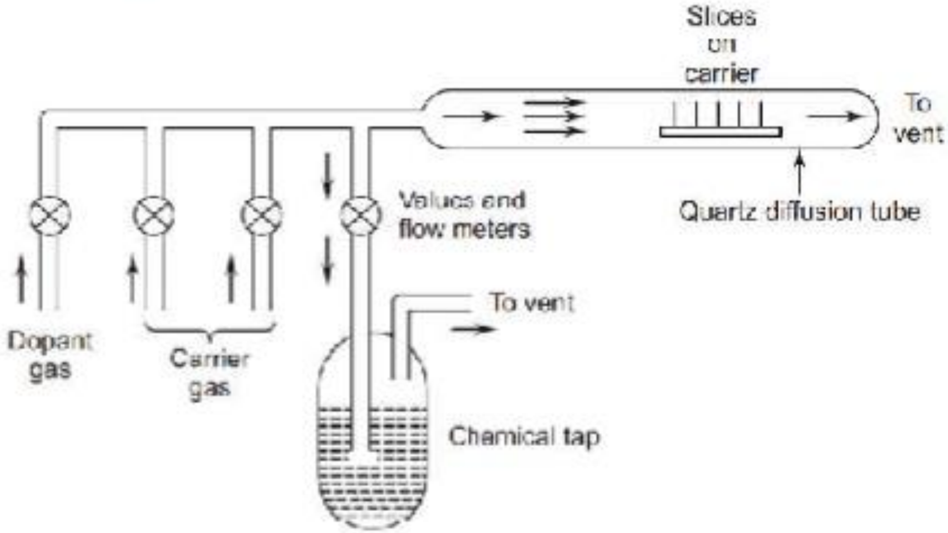


Fig. 7.18 *Gaseous Source Diffusion System*