Announcement

1. Take home assignment has been posted on NTULearn. Deadline for submission: submit at the last tutorial class on 7 Nov.

2. Part 2 topics:
- Thermal Oxidation (Week 7)
- Diffusion (Week 8)
- Ion-Impantation *Week 9)
- PN Junction/Diode (Week 10)
- Bipolar Junction Transistor (BJT) (Week 11)
- Metal Semiconductor Field Effect Transistor (MOSFET) (Week 13)

3. CA 2 will be on Week 12 (31 Oct) in tutorial class. Covering oxidation, diffusion and implantation. Will provide more details when closer.

4. Need to have make-up lesson on 24 Oct due to Deepavali.

NANYANG TECHNOLOGICAL UNIVERSITY

Course: EE3013/ Semiconductor Devices and Processing

School: School of Electrical and Electronic Engineering

Part I - Highlights

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Week 8 - Thermal Diffusion

Thermal Diffusion

- Diffusion is the key process for introducing impurities in the selected regions of a semiconductor.

When to use diffusion process:

- To use it when damage from Ion Implantation is unacceptable, electrical junctions need to be very deep, or a cheap, easy solution is needed.
- Not to use for ultra-shallow junctions, or total impurity "dose" is critical.

Two principal mechanisms for dopants to diffuse in the crystal:

(1) Interstitial diffusion:

- Impurity atoms diffuse between interstitial spaces (do not replace atoms in the crystal lattice).
- They do not directly contribute to doping

(2) Substitutional diffusion:

- Impurity atoms jump from one lattice site to another lattice site.
- Since the number of lattice vacancies are limited, it is a slow process.
- Substitutional diffusion is responsible for doping effects.

Impurity Concentration Profile

There are two types of boundary conditions important in modeling the impurity diffusion in Si - **Constant-source diffusion** and **Limited-source diffusion**.

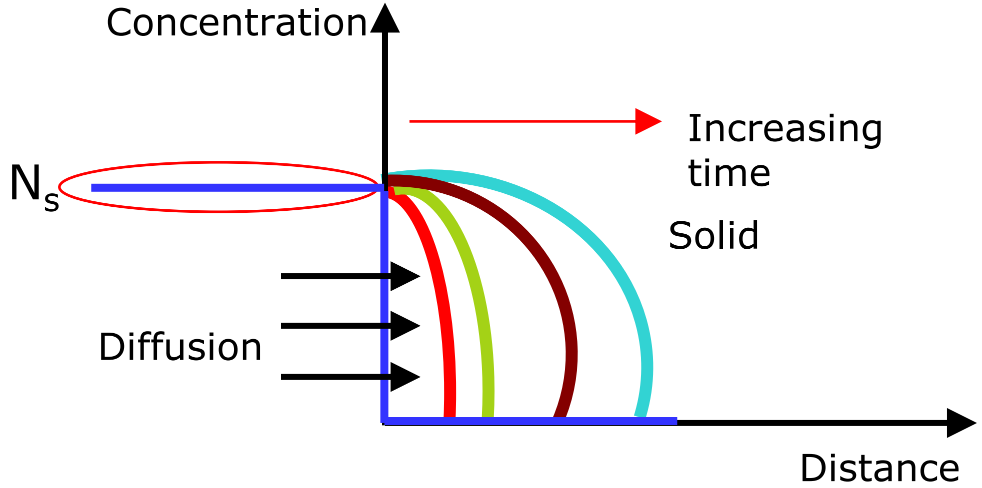
(1) <u>Constant-source diffusion:</u>

- The impurity concentration at the surface of the solid remains constant, N_s (unlimited supply of excess impurity atoms is available at surface).
- The diffusion profile is given by:

$$N(z) = N_s \operatorname{erfc}\left(\frac{z}{2\sqrt{Dt}}\right)$$

erfc: Complementary error function

$\sqrt{Dt}$: Characteristic diffusion length.



- Total number of the impurity atoms entered into the Si per unit area is called dose:

$$Q(t) = \int_0^{\infty} N_s \operatorname{erfc}\left(\frac{z}{2\sqrt{Dt}}\right) dz \rightarrow Q(t) = \frac{2N_s}{\sqrt{\pi}}\sqrt{Dt}$$ *(Equation 7.39)* where $D = D_0 \exp\left(-\frac{E_a}{kT}\right)$

D_o is called diffusion coefficient (cm^2/s) extrapolated to infinite temperature.

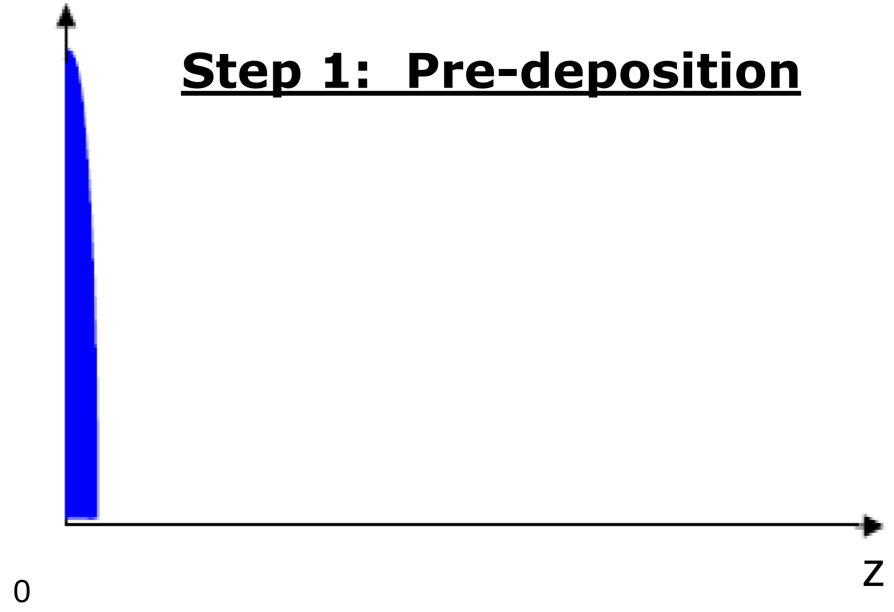
(2) Limited Source Diffusion

Consider a case when a thin layer of fixed amount of dopant, (Q atoms /cm^2) is initially deposited onto the semiconductor surface, and then, diffusion is carried out. **The total amount of impurity atoms at surface is fixed.**

- The diffusion profile is given by:

$$N(z) = \frac{Q}{\sqrt{\pi D t}} exp - \left(\frac{z}{2\sqrt{Dt}}\right)^2$$

Gaussian profile



- The surface concentration (at z=0) is:

$$N(0,t) = N_s = \frac{Q}{\sqrt{\pi D t}}$$

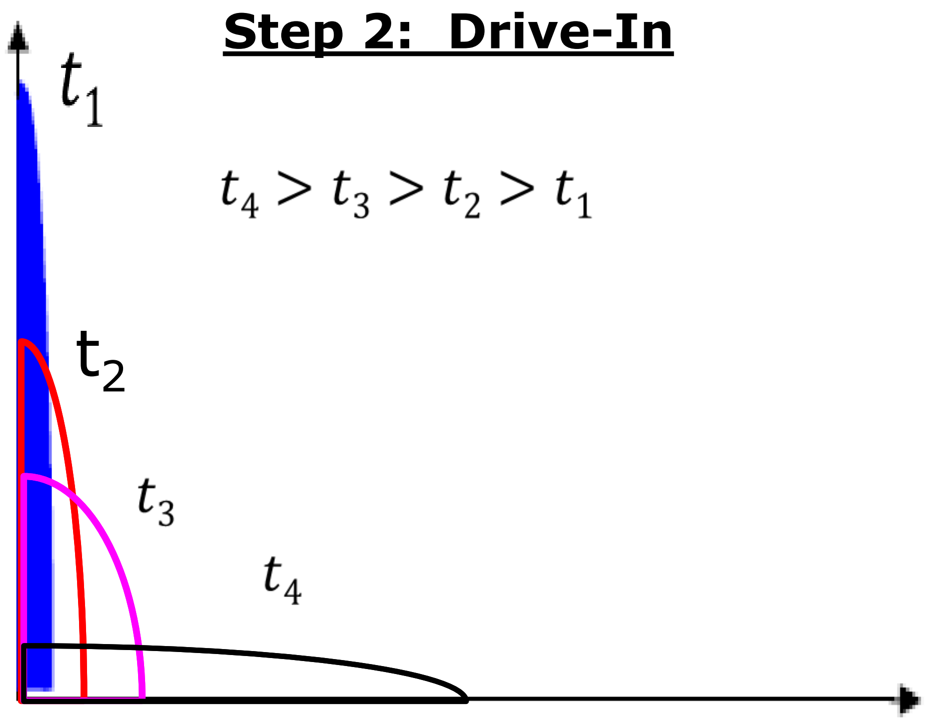
(2) Limited Source Diffusion (Cont'd.)

A limited source diffusion is a combination of two processes, pre-deposition and drive in.

(1) Pre-deposition, a thin layer with limited amount of dopants is deposited on surface at a short time t. The total amount gives a dose:

$$Q = 2N_s\sqrt{\frac{Dt}{\pi}}$$

(2) <u>Drive in</u>, the pre-deposited dopants on the surface (with fixed amount) are made to diffuse deeper into the solid thus makes the dopants redistribute following the **Gaussian profile**. With the increase of diffusion time, the dopants go deeper and deeper but the total amount does not change.



Junction Formation by Diffusion

- **p - type** dopant with **N(z, t)> N$_B$**
- For constant source diffusion, Junction is located at z_j such that:

$$\boxed{N_s \mathrm{erfc}\left(\frac{z_j}{2\sqrt{Dt}}\right) = N_B.}$$