CHE323/CHE384
Chemical Processes for Micro- and Nanofabrication
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Lecture 13
Diffusion, part 1

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Reading:
Chapter 3, *Fabrication Engineering at the Micro- and Nanoscale*, 4th edition, Campbell

Diffusion – Historical Perspective

- The term 'diffusion' has been used in two different ways in the semiconductor industry
  - – Dopant introduction
  - – Dopant redistribution
- Today, most processes introduce dopants into the wafer via ion implantation
  - – Diffusion refers to the redistribution of dopants after implant

Diffusion as Dopant Introduction

- Performed in a furnace (similar to oxidation)
- Dopant introduced to wafers in three ways:
  - – Solid source: disks of BN, $AlAsO_4$, etc., placed between wafers in the carrier
  - – Liquid source: $POCl_3$, BBr_3, etc., with N_2 bubbler (most common)
  - – Gas Source

Diffusion as Dopant Introduction

- Dopant introduced at top of wafer, then diffuses in
- Run at concentrations exceeding the solid solubility limit in silicon to improve control
- Applications:
  - – Device generations older than 2 μm
  - – Bipolar high dopant steps (emitter)
  - – Polysilicon doping

Diffusion as Dopant Redistribution

- Initial distribution of dopant supplied, usually by ion implantation
  - – Ion implantation destroys the crystal structure, creating regions of amorphous silicon
  - – High temperatures are required to regrow the crystal and activate the dopant (annealing)
  - – These high temperatures result in diffusion of the dopants
- Our goal: predict the final dopant distribution

Diffusion Review

- Fick's First Law (in one dimension):

Dopant concentration

material flux

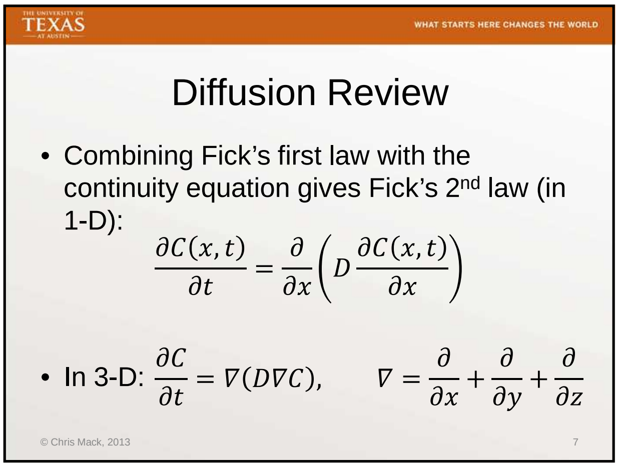
$$J = -D\frac{\partial C(x,t)}{\partial x}$$

Diffusivity of dopant in silicon

- Continuity equation (mass balance)

$$\frac{\partial C(x,t)}{\partial t} = -\frac{\partial J}{\partial x}$$

Change in flux causes accumulation of material

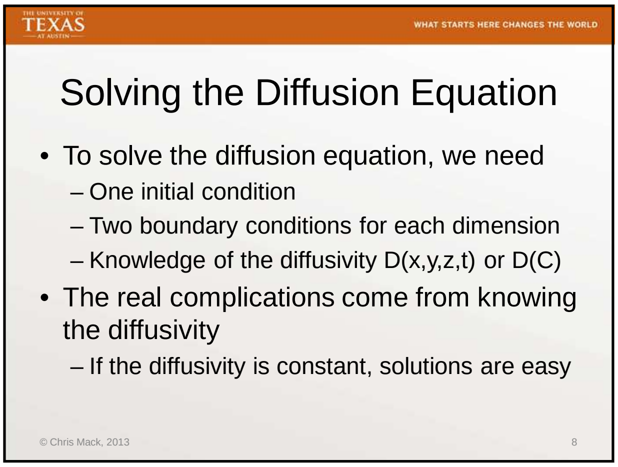


Diffusion Review

- Combining Fick's first law with the continuity equation gives Fick's 2nd law (in 1-D):

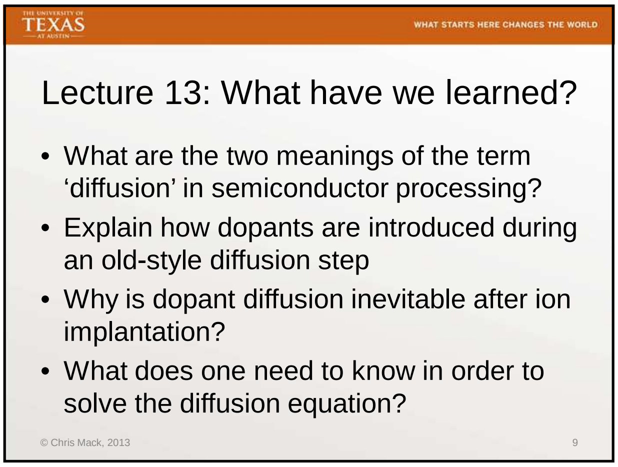
$$\frac{\partial C(x,t)}{\partial t} = \frac{\partial}{\partial x}\left(D\frac{\partial C(x,t)}{\partial x}\right)$$

- In 3-D: $\frac{\partial C}{\partial t} = \nabla(D\nabla C)$, $\quad \nabla = \frac{\partial}{\partial x} + \frac{\partial}{\partial y} + \frac{\partial}{\partial z}$



Solving the Diffusion Equation

- To solve the diffusion equation, we need
  - One initial condition
  - Two boundary conditions for each dimension
  - Knowledge of the diffusivity D(x,y,z,t) or D(C)
- The real complications come from knowing the diffusivity
  - If the diffusivity is constant, solutions are easy



Lecture 13: What have we learned?

- What are the two meanings of the term 'diffusion' in semiconductor processing?
- Explain how dopants are introduced during an old-style diffusion step
- Why is dopant diffusion inevitable after ion implantation?
- What does one need to know in order to solve the diffusion equation?