

Wet Etch Limitations (cont.)

7. Bubble formation (as a reaction by-product)
 ↳ If bubbles cling to the surface → get nonuniform etching

Solution: Agitate wafers during reaction.

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Some Common Wet Etch Chemistries

Wet Etching Silicon:

Common: $\text{Si} + \text{HNO}_3 + 6\text{HF} \rightarrow \text{H}_2\text{SiF}_6 + \text{HNO}_2 + \text{H}_2 + \text{H}_2\text{O}$
 (isotropic)

(nitric acid) (hydrofluoric acid)
 ↓ ↓
 (1) forms a layer of SiO_2 (2) etches away the SiO_2

Different mixture combinations yield different etch rates.

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Silicon Crystal Orientation

• Silicon has the basic diamond structure
 ↳ Two merged FCC cells offset by $(a/4)$ in x, y, and z axes
 ↳ From right:

- # available bonds/cm² <111> ↑
- # available bonds/cm² <110> ↑
- # available bonds/cm² <100> ↑

Increasing

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Anisotropic Wet Etching

Anisotropic etches also available for single crystal Si:

↳ Orientation-dependent etching: <111>-plane more densely packed than <100>-plane

↑ ↑
 Faster E.R. Slower E.R.

...in some solvents

One such solvent: KOH + isopropyl alcohol
 (e.g., 23.4 wt% KOH, 13.3 wt% isopropyl alcohol, 63 wt% H₂O)

⇒ E.R._{<100>} = 100 × E.R._{<111>}

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Anisotropic Wet Etching (cont.)

Can get the following:

(on a <100> - wafer)

(on a <110> - wafer)
⇒ Quite anisotropic!

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Wet Etching SiO₂

$$\text{SiO}_2 + 6\text{HF} \rightarrow \text{H}_2 + \text{SiF}_6 + 2\text{H}_2\text{O}$$

Generally used to clear out residual oxides from contacts

Problem: Contact hole is so thin that surface tensions don't allow the HF to get into the contact
Generally the case for VLSI circuits

native oxide
can get this just by exposing Si to air → 1-2nm-thick

300nm

Solution: add a surfactant (e.g., Triton X) to the BHF before the contact clear etch

1. Improves the ability of HF to wet the surface (hence, get into the contact)
2. Suppresses the formation of etch by-products, which otherwise can block further reaction if by-products get caught in the contact

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More Wet Etch Chemistries

- Wet etching silicon nitride
 - Use hot phosphoric acid: 85% phosphoric acid @ 180°C
 - Etch rate ~ 10 nm/min (quite slow)
 - Problem: PR lifts during such etching
 - Solution: use SiO₂ as an etch mask (E.R. ~2.5 nm/min)
 - A hassle → dry etch processes more common than wet
- Wet etching aluminum
 - Typical etch solution composition:
 - 80% phosphoric acid, 5% nitric acid, 5% acetic acid, 10% water
 - (H₂PO₄) (HNO₃) (CH₃COOH) (H₂O)
 - (1) Forms Al₂O₃ (aluminum oxide)
 - (2) Dissolves the Al₂O₃
 - Problem: H₂ gas bubbles adhere firmly to the surface → delay the etch → need a 10-50% overetch time
 - Solution: mechanical agitation, periodic removal of wafers from etching solution

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Wet Etch Rates (f/ K. Williams)

Wet-Etch Rates for Micromachining and IC Processing (Aluminum)

The top etch rate was measured by the authors with fresh solutions, etc. The center and bottom values are the low and high etch rates observed by the authors and others in our lab under less carefully controlled conditions.

| ETCHANT EQUIPMENT COMMENTS | TARGET MATERIAL | MATERIAL | | | | | | | | | | | | | | | |
|---|----------------------------------|----------|------|------|------|------|------|-----|------|-----|-----|------|------|------|------|-----|------|
| | | Si | Poly | Wet | Dry | LTO | PSG | PSG | Si | Si | Al | Si | Si | Si | Si | Si | |
| Concentrated HF (49%) Wet Slit Room Temperature | Silicon oxides | - | 0 | - | 238 | 196 | 238 | 238 | 238 | 238 | 238 | 238 | 238 | 238 | 238 | 238 | 238 |
| 10:1 HF Wet Slit Room Temperature | Silicon oxides | - | 7 | 0 | 230 | 230 | 240 | 154 | 470 | 11 | 3 | 2500 | 2500 | 136 | 0 | 114 | <10 |
| 10:1 HF Wet Slit Room Temperature | Silicon oxides | - | 0 | 0 | 97 | 95 | 130 | W | 1500 | 6 | 1 | W | 0 | - | - | - | 0 |
| 5:1 HF Wet Slit Room Temperature | Silicon oxides | - | 9 | 2 | 1000 | 1000 | 1200 | 600 | 4400 | 9 | 4 | 1400 | <20 | 3 | 0.25 | 0 | 0 |
| Phosphoric Acid (85%) Heated Bath with Reflux HF | Silicon nitrides | - | 7 | - | 0.7 | 0.8 | <1 | 37 | 34 | 28 | 19 | 9000 | - | - | - | - | 550 |
| Silicon Etchant (126 HNO ₃ , 40 H ₂ O, 3 H ₂ SO ₄) Wet Slit Room Temperature | Silicon | 1500 | 3000 | 1000 | 87 | W | 110 | 400 | 1700 | 2 | 3 | 4000 | 130 | 3000 | - | - | 0 |
| KOH (1.5M): 2 H ₂ O by weight Heated Slotted Bath 80°C | <100> Silicon | 148 | >15k | F | 77 | - | 94 | W | 380 | 0 | 0 | F | 0 | - | - | - | F |
| Aluminum Etchant Type A (16 H ₂ PO ₄ , 1 HNO ₃ , 1 HAc, 2 H ₂ O) Heated Bath 80°C | Aluminum | - | <10 | <9 | 0 | 0 | 0 | 0 | <10 | 0 | 2 | 6000 | - | 0 | - | - | 0 |
| Titanium Etchant (20 H ₂ O, 1 H ₂ O ₂ , 1 HF) Wet Slit Room Temperature | Titanium | - | 12 | - | 130 | W | W | W | 2100 | 8 | 4 | W | 0 | 8500 | - | - | 0 |
| H ₂ O ₂ (30%) Wet Slit Room Temperature | Tungsten | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | <20 | 190 | 0 | 60 | <2 | 0 |
| Phenyl (-10 H ₂ SO ₄ , 1 H ₂ O) Heated Bath 120°C | Cleaning off metals and organics | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1800 | - | 2400 | - | - | F |
| Adhesive Wet Slit Room Temperature | Photoresist | - | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | >10k |

Notes: - was not performed; W was performed, but known to be slow (> 100 Å/min); F was performed, but known to be fast (> 10 Å/min); P was performed during etch or when etched; A was visibly attacked and etched. Each area are all of a 4 inch wafer for the suspension Slit and half of the wafer for single-crystal silicon and the metals. Etch rates will vary with temperature and prior use of solutions, rate of exposure of film, other materials present (e.g., photoresist), film impurities and microstructure, etc. Some variation should be expected.

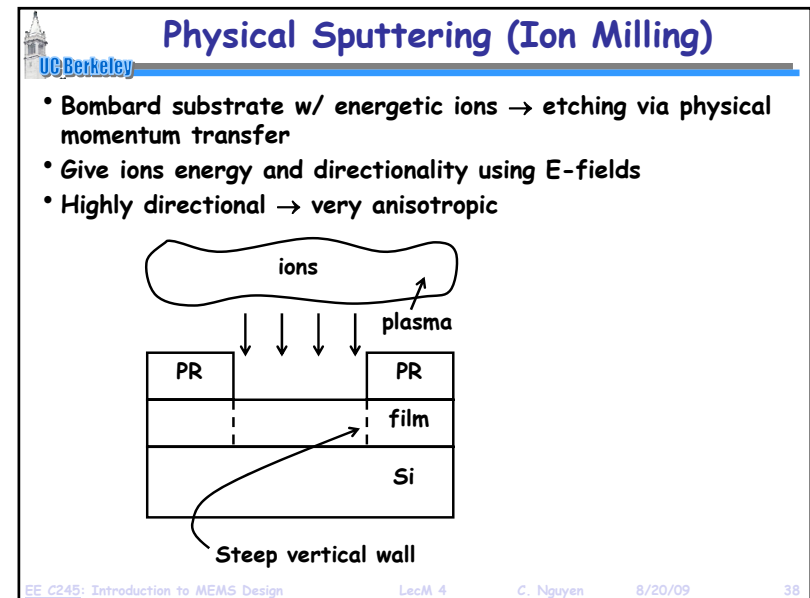
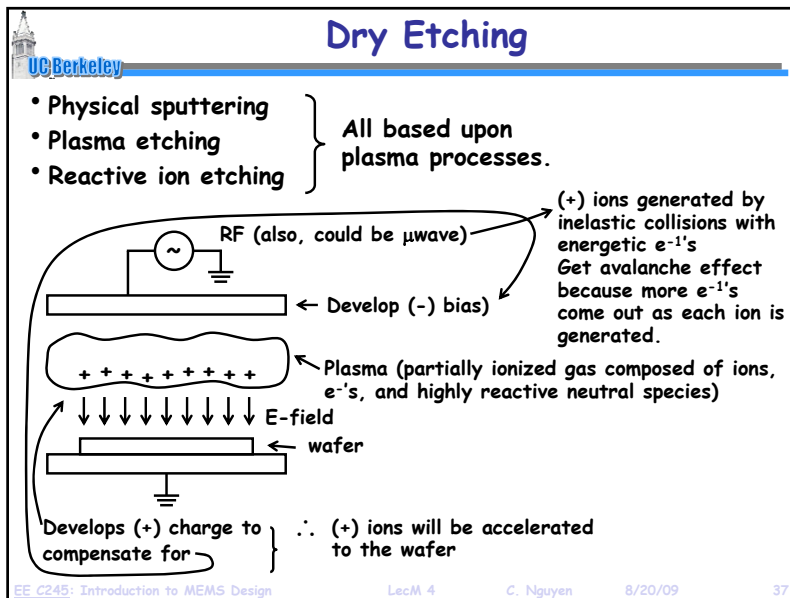
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Film Etch Chemistries

• For some popular films:

| Material | Wet etchant | Etch rate [nm/min] | Dry etchant | Etch rate [nm/min] |
|-----------------|--|--------------------|-------------------------------------|--------------------|
| Polysilicon | HNO ₃ :H ₂ O: NH ₄ F | 120-600 | SF ₆ + He | 170-920 |
| Silicon nitride | H ₃ PO ₄ | 5 | SF ₆ | 150-250 |
| Silicon dioxide | HF | 20-2000 | CHF ₃ + O ₂ | 50-150 |
| Aluminum | H ₃ PO ₄ :HNO ₃ : CH ₃ COOH | 660 | Cl ₂ + SiCl ₄ | 100-150 |
| Photoresist | Acetone | >4000 | O ₂ | 35-3500 |
| Gold | KI | 40 | n/a | n/a |

Dry Etching



Problems With Ion Milling

PR etched down to here

Once through the film, the etch will start barreling through the Si

grass → Bad!

1. PR or other masking material etched at almost the same rate as the film to be etched → very poor selectivity!
2. Ejected species not inherently volatile → get redeposition → non-uniform etch → grass!

- Because of these problems, ion milling is not used often (very rare)

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Plasma Etching

- Plasma (gas glow discharge) creates reactive species that chemically react w/ the film in question
- **Result:** much better selectivity, but get an isotropic etch

Plasma Etching Mechanism:

1. Reactive species generated in a plasma.
2. Reactive species diffuse to the surface of material to be etched.
3. Species adsorbed on the surface.
4. Chemical reaction.
5. By-product desorbed from surface.
6. Desorbed species diffuse into the bulk of the gas

← **MOST IMPORTANT STEP!** (determines whether plasma etching is possible or not.)

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Ex: Polysilicon Etching w/ CF₄ and O₂

$$\text{CF}_4 \xrightarrow{\text{plasma}} \text{CF}_4^+ + \text{CF}_3^+ + \text{CF}_2^+ + \text{CF}^+ + \text{F}^+ + \text{F}^0 + \text{CF}_2^+ + \dots$$

Neutral radical (highly reactive!)

$$e^- + \text{CF}_4 \rightarrow \text{CF}_3 + \text{F} + e^-$$

SiCF₆, SiF₄ ← both volatile ∴ dry etching is possible.

- F⁰ is the dominant reactant → but it can't be given a direction → thus, get isotropic etch!

isotropic component → F⁰

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Ex: Polysilicon Etching w/ CF₄ and O₂

- **Problems:**
 1. Isotropic etching
 2. Formation of polymer because of C in CF₄
 - ↳ **Solution:** add O₂ to remove the polymer (but note that this reduces the selectivity, S_{poly/PR})
- **Solution:**
 - ↳ Use Reactive Ion Etching (RIE)

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Reactive Ion Etching (RIE)

- Use ion bombardment to aid and enhance reactive etching in a particular direction
 - Result: directional, anisotropic etching!
- RIE is somewhat of a misnomer
 - It's not ions that react ... rather, it's still the neutral species that dominate reaction
 - Ions just enhance reaction of these neutral radicals in a specific direction
- Two principle postulated mechanisms behind RIE
 - Surface damage mechanism
 - Surface inhibitor mechanism

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RIE: Surface Damage Mechanism

- Relatively high energy impinging ions (>50 eV) produce lattice damage at surface
- Reaction at these damaged sites is enhanced compared to reactions at undamaged areas

Result: E.R. at surface >> E.R. on sidewalls

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RIE: Surface Inhibitor Mechanism

- Non-volatile polymer layers are a product of reaction
- They are removed by high energy directional ions on the horizontal surface, but not removed from sidewalls

(+) ions breakup the polymer layer get reaction

Result: E.R. @ surface >> E.R. on sidewalls

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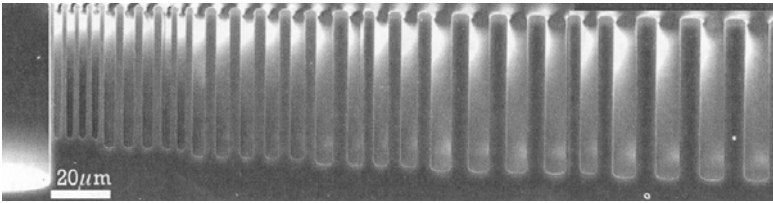
Deep Reactive-Ion Etching (DRIE)

The Bosch process:

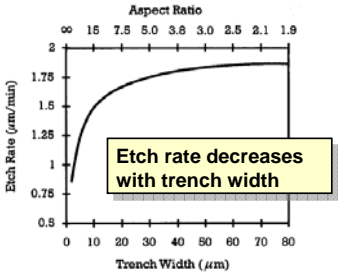
- Inductively-coupled plasma
- Etch Rate: 1.5-4 $\mu\text{m}/\text{min}$
- Two main cycles in the etch:
 - Etch cycle (5-15 s): SF_6 (SF_x^+) etches Si
 - Deposition cycle: (5-15 s): C_4F_8 deposits fluorocarbon protective polymer (CF_2)_n
- Etch mask selectivity:
 - $\text{SiO}_2 \sim 200:1$
 - Photoresist $\sim 100:1$
- Issue: finite sidewall roughness
 - scalloping < 50 nm
- Sidewall angle: $90^\circ \pm 2^\circ$

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DRIE Issues: Etch Rate Variance



- Etch rate is diffusion-limited and drops for narrow trenches
 - Adjust mask layout to eliminate large disparities
 - Adjust process parameters (slow down the etch rate to that governed by the slowest feature)



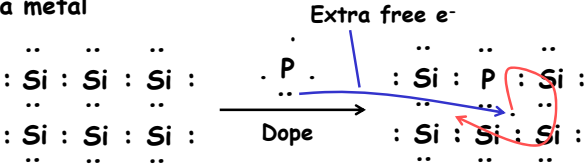
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Semiconductor Doping

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Doping of Semiconductors

- Semiconductors are not intrinsically conductive
- To make them conductive, replace silicon atoms in the lattice with dopant atoms that have valence bands with fewer or more e⁻s than the 4 of Si
- If more e⁻s, then the dopant is a donor: P, As
 - The extra e⁻ is effectively released from the bonded atoms to join a cloud of free e⁻s, free to move like e⁻s in a metal



- The larger the # of donor atoms, the larger the # of free e⁻s → the higher the conductivity

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Doping of Semiconductors (cont.)

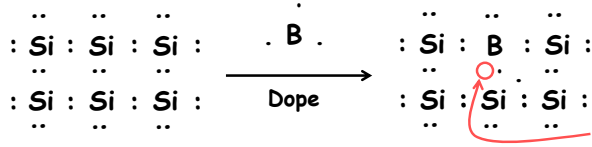
Conductivity Equation:

$$\sigma = q\mu_n n + q\mu_p p$$

Labels for the equation:

- σ: conductivity
- q: charge magnitude on an electron
- μ_n: electron mobility
- n: electron density
- μ_p: hole mobility
- p: hole density

- If fewer e⁻s, then the dopant is an acceptor: B



- Lack of an e⁻ = hole = h⁺
- When e⁻s move into h⁺s, the h⁺s effectively move in the opposite direction → a h⁺ is a mobile (+) charge carrier

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Ion Implantation

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Ion Implantation

- Method by which dopants can be introduced in silicon to make the silicon conductive, and for transistor devices, to form, e.g., pn-junctions, source/drain junctions, ...

The basic process:

Charged dopant accelerated to high energy by an E-Field (e.g., 100 keV)

Control current & time to control the dose.

Masking material (could be PR, could be oxide, etc.)

Depth determined by energy & type of dopant

Result of I/I

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Ion Implantation (cont.)

Result of I/I

Damage → Si layer at top becomes amorphous

B not in the lattice, so it's not electrically active.

High Temperature Anneal (also, usually do a drive-in diffusion) (800-1200°C)

Now B in the lattice & electrically active! (serves as dopant)

Ion collides with atoms and interacts with e⁻s in the lattice → all of which slow it down and eventually stop it.

This is a statistical process → implanted impurity profile can be approximated by a Gaussian distribution.

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Statistical Modeling of I/I

Impurity concentration → $N(x)$

Unlucky ions

Avg. ions

Lucky ions

One std. dev. away → $0.61N_p$

2 std. dev. away → $0.14N_p$

3 std. dev. away → $0.11N_p$

Distance into Si material, x

R_p Projected range = avg. distance on ion trends before stopping

ΔR_p Straggle = std. deviation characterizing the spread of the distribution.

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Analytical Modeling for I/I

Mathematically:

$$N(x) = N_p \exp\left[-\frac{(x - R_p)^2}{2(\Delta R_p)^2}\right]$$

Area under the impurity distribution curve } **Implanted Dose** = $Q = \int_0^{\infty} N(x) dx$ [ions / cm²]

For an implant completely contained within the Si:

$$Q = \sqrt{2\pi} N_p \Delta R_p$$

Assuming the peak is in the silicon: (putting it in one-sided diffusion form) → So we can track the dopant front during a subsequent diffusion step.

$D_1 = Q$ → $D_1/2 = \frac{D_1}{2} \exp\left[-\frac{(x - R_p)^2}{2(\Delta R_p)^2}\right]$, where $(Dt)_{eff} = \frac{(\Delta R_p)^2}{2}$

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I/I Range Graphs

• R_p is a function of the energy of the ion and atomic number of the ion and target material

• Lindhard, Scharff and Schiott (LSS) Theory:

- Assumes implantation into amorphous material, i.e., atoms of the target material are randomly positioned
- Yields the curves of Fig. 6.1 and 6.2
- For a given energy, lighter elements strike Si with higher velocity and penetrate more deeply

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I/I Straggle Graphs

• Results for Si and SiO₂ surfaces are virtually identical → so we can use these curves for both

CMOS:

MEMS:

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Diffusion

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Diffusion in Silicon

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- Movement of dopants within the silicon at high temperatures
- Three mechanisms: (in Si)

(a)

(b)

(c)

Substitutional Diffusion

- Impurity moves along vacancies in the lattice
- Substitutes for a Si-atom in the lattice

Interstitialcy Diffusion

- Impurity atom replaces a Si atom in the lattice
- Si atom displaced to an interstitial site

Interstitial Diffusion

- Impurity atoms jump from one interstitial site to another
- Get rapid diffusion
 - ↳ Hard to control
 - ↳ Impurity not in lattice so not electrically active

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Diffusion in Polysilicon

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- In polysilicon, still get diffusion into the crystals, but get more and faster diffusion through grain boundaries
- **Result:** overall faster diffusion than in silicon

Fast diffusion through grain boundaries Regular diffusion into crystals

- In effect, larger surface area allows much faster volumetric diffusion

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Basic Process for Selective Doping

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1. Introduce dopants (introduce a fixed dose Q of dopants)
 - (i) Ion implantation
 - (ii) Predeposition
2. Drive in dopants to the desired depth
 - ↳ High temperature $> 900^\circ\text{C}$ in N_2 or N_2/O_2

• **Result:**

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Predeposition

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- Furnace-tube system using solid, liquid, or gaseous dopant sources
- Used to introduced a controlled amount of dopants
 - ↳ Unfortunately, not very well controlled
 - ↳ Dose (Q) range: $10^{13} - 10^{16} \pm 20\%$
 - ↳ For ref: w/ ion implantation: $10^{11} - 10^{16} \pm 1\%$ (larger range & more accurate)
- **Example:** Boron predeposition

Predeposition Temp: $800-1100^\circ\text{C}$

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Ex: Boron Predeposition

Basic Procedure:

1. Deposit B_2O_3 glass
2. B diffuses from $B_2O_3 \rightarrow Si$

Difficult to control dose Q , because it's heavily dependent on partial pressure of B_2H_6 gas flow
 ↳ this is difficult to control itself
 ↳ get only 10% uniformity

Furnace tube cross-section
Less B concentration

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Ex: Boron Predeposition (cont.)

For better uniformity, use solid source:

Reactions:
 $B_2H_6 + 3O_2 \rightarrow 3H_2O + B_2O_3$
 $Si + O_2 \rightarrow SiO_2$

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General Comments on Predeposition

- Higher doses only: $Q = 10^{13} - 10^{16} \text{ cm}^{-2}$ (I/I is $10^{11} - 10^{16}$)
- Dose not well controlled: $\pm 20\%$ (I/I can get $\pm 1\%$)
- Uniformity is not good
 - ↳ $\pm 10\%$ w/ gas source
 - ↳ $\pm 2\%$ w/ solid source
- Max. conc. possible limited by solid solubility
 - ↳ Limited to $\sim 10^{20} \text{ cm}^{-3}$
 - ↳ No limit for I/I \rightarrow you force it in here!
- For these reasons, I/I is usually the preferred method for introduction of dopants in transistor devices
- But I/I is not necessarily the best choice for MEMS
 - ↳ I/I cannot dope the underside of a suspended beam
 - ↳ I/I yields one-sided doping \rightarrow introduces unbalanced stress \rightarrow warping of structures
 - ↳ I/I can do physical damage \rightarrow problem if annealing is not permitted
- Thus, predeposition is often preferred when doping MEMS

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Diffusion Modeling

Modeling $N(x)$

\Rightarrow Dopants from points of high conc. move to points of low conc. w/ flux J
 \Rightarrow Question: What's $N(x,t)$?
 ↳ fun of time

Fick's Law of Diffusion - (1st law)

$$J(x,t) = -D \frac{\partial N(x,t)}{\partial x} \quad (1)$$

Flux [$\#/\text{cm}^2 \cdot \text{s}$] Diffusion Coefficient

Continuity Equation for Particle Flux -
 General form: $\frac{\partial N(x,t)}{\partial t} = -\nabla \cdot \vec{J}$

rate of increase of conc. w/ time negative of the divergence of particle flux

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Diffusion Modeling (cont.)

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⇒ We're interested for now in the one-dimensional form:

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

$$\left[\frac{\partial}{\partial x} (1) \text{ and substitute (2) in (1)} \right] \Rightarrow \frac{\partial N(x,t)}{\partial t} = D \frac{\partial^2 N(x,t)}{\partial x^2} \quad \left[\text{Fick's 2nd Law of Diffusion in 1-D} \right]$$

Solutions: → dependent upon boundary conditions
↳ use variable separation or Laplace Xform techniques

Case 1: Predeposition → constant source diffusion: surface concentration stays the same during the diffusion

surface conc. stays constant N_0 impurity conc. $t_1 < t_2 < t_3$ high T ($D_1 < D_2 < D_3$) complementary error function profile

background conc. N_B

surface x , distance fr. surface

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Diffusion Modeling (Predeposition)

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⇒ if plotted on a linear scale, would look like this:

⇒ **Boundary Condition:**

$$\begin{cases} \text{(i) } N(0,t) = N_0 \\ \text{(ii) } N(\infty,t) = 0 \end{cases} \Rightarrow N(x,t) = N_0 \left[1 - \frac{1}{\sqrt{\pi}} \int_0^{\frac{x}{2\sqrt{Dt}}} e^{-y^2} dy \right]$$

$$N(x,t) = N_0 \operatorname{erfc}\left(\frac{x}{2\sqrt{Dt}}\right) \Rightarrow \text{again, complementary error function (read tables or graph)}$$

Dose, $Q \triangleq$ total # of impurity atoms per unit area in the Si
= area under the curve

$$Q = \int_0^\infty N(x,t) dx \Rightarrow Q(t) = N_0 \frac{2\sqrt{Dt}}{\sqrt{\pi}} \text{ cm}^2$$

$$2\sqrt{Dt} \triangleq \text{characteristic diffusion length}$$

$N(x)$ ← linear scale N_0 area under this square is same as under the curve! $2\sqrt{Dt}$

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Diffusion Modeling (Limited Source)

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Case 2: Drive-in → limited source diffusion, i.e., constant dose Q

$N_0(t_1)$ $N_0(t_2)$ $N_0(t_3)$ N_B x , distance fr. the surface

⇒ **Boundary Condition:**

$$\begin{cases} \text{(i) } N(\infty,t) = 0 \\ \text{(ii) } \frac{\partial N(x,t)}{\partial x} \Big|_{x=0} = 0 \end{cases}$$

Why? Constant Dose: $\int_0^\infty N(x,t) dx = Q \leftarrow \text{const.}$

This is equivalent to saying that there's no flux going out of the Si, i.e., and that's what this says!

$J=0$ $N(x)$ x

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Diffusion Modeling (Limited Source)

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(ii) Usually make delta fn. approx.: $N(x,0) = Q \delta(x)$

⇒ we can do this, because for sufficiently long diffusion times, no matter what the original shape of the dopant distribution, the diffused distribution will be the same

Get Gaussian Distribution: $N(x,t) = \frac{Q}{\sqrt{Dt}} \exp\left[-\frac{x^2}{4Dt}\right]$ corresponds to a half Gaussian in this Equation

$N(x)$ x $\frac{D_1}{2}$ When the starting conc. profile is completely contained in the Si, then $Q = \frac{D_1}{2} = \text{half the implant dose}$

$\log N$ x

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Two-Step Diffusion

- Two step diffusion procedure:
 - Step 1: predeposition (i.e., constant source diffusion)
 - Step 2: drive-in diffusion (i.e., limited source diffusion)
- For processes where there is both a predeposition and a drive-in diffusion, the final profile type (i.e., complementary error function or Gaussian) is determined by which has the much greater Dt product:
 - $(Dt)_{\text{predep}} \gg (Dt)_{\text{drive-in}} \Rightarrow$ impurity profile is complementary error function
 - $(Dt)_{\text{drive-in}} \gg (Dt)_{\text{predep}} \Rightarrow$ impurity profile is Gaussian (which is usually the case)

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Successive Diffusions

- For actual processes, the junction/diffusion formation is only one of many high temperature steps, each of which contributes to the final junction profile
- Typical overall process:
 - Selective doping
 - Implant \rightarrow effective $(Dt)_1 = (\Delta R_p)^2/2$ (Gaussian)
 - Drive-in/activation $\rightarrow D_2 t_2$
 - Other high temperature steps
 - (eg., oxidation, reflow, deposition) $\rightarrow D_3 t_3, D_4 t_4, \dots$
 - Each has their own Dt product
 - Then, to find the final profile, use

$$(Dt)_{\text{tot}} = \sum_i D_i t_i$$
 in the Gaussian distribution expression.

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The Diffusion Coefficient

$$D = D_0 \exp\left(-\frac{E_A}{kT}\right) \quad (\text{as usual, an Arrhenius relationship})$$

Table 4.1 Typical Diffusion Coefficient Values for a Number of Impurities.

| Element | D_0 (cm ² /sec) | E_A (eV) |
|---------|------------------------------|------------|
| B | 10.5 | 3.69 |
| Al | 8.00 | 3.47 |
| Ga | 3.60 | 3.51 |
| In | 16.5 | 3.90 |
| P | 10.5 | 3.69 |
| As | 0.32 | 3.56 |
| Sb | 5.60 | 3.95 |

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Diffusion Coefficient Graphs

Substitutional & Interstitial Diffusers

Interstitial Diffusers

Note the much higher diffusion coeffs. than for substitutional

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Metallurgical Junction Depth, x_j

x_j = point at which diffused impurity profile intersects the background concentration, N_B

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Expressions for x_j

- Assuming a Gaussian dopant profile: (the most common case)

$$N(x_j, t) = N_o \exp\left[-\left(\frac{x_j}{2\sqrt{Dt}}\right)^2\right] = N_B \rightarrow x_j = 2\sqrt{Dt \ln\left(\frac{N_o}{N_B}\right)}$$

- For a complementary error function profile:

$$N(x_j, t) = N_o \operatorname{erfc}\left(\frac{x_j}{2\sqrt{Dt}}\right) = N_B \rightarrow x_j = 2\sqrt{Dt} \operatorname{erfc}^{-1}\left(\frac{N_B}{N_o}\right)$$

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Sheet Resistance

- Sheet resistance provides a simple way to determine the resistance of a given conductive trace by merely counting the number of effective squares
- Definition:**

$$R = \frac{\rho L}{A} = \left(\frac{\rho}{t}\right) \frac{L}{W} = R_s \left(\frac{L}{W}\right)$$

ohms per square
Ω/D

sheet resistance # unit squares of material in the resistor

uniformly doped material w/ resistivity $\rho = \frac{1}{\sigma}$
 $\sigma = \text{conductivity} = q(\mu_n n + \mu_p p)$

eg., $\therefore R = R_s \times 5$

- What if the trace is non-uniform? (e.g., a corner, contains a contact, etc.)

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Squares From Non-Uniform Traces

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Sheet Resistance of a Diffused Junction

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For diffused layers:

Majority carrier mobility

Net impurity concentration

Effective resistivity

Sheet resistance

$$R_s = \frac{\rho}{x_j} = \left[\int_0^{x_j} \sigma(x) dx \right]^{-1} = \left[\int_0^{x_j} q\mu N(x) dx \right]^{-1}$$

[extrinsic material]

- This expression neglects depletion of carriers near the junction, $x_j \rightarrow$ thus, this gives a slightly lower value of resistance than actual
- Above expression was evaluated by Irvin and is plotted in "Irvin's curves" on next few slides
 - illuminates the dependence of R_s on x_j , N_0 (the surface concentration), and N_B (the substrate background conc.)

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Irvin's Curves (for n-type diffusion)

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Example. p-type

Given:

$N_B = 3 \times 10^{16} \text{ cm}^{-3}$

$N_0 = 1.1 \times 10^{18} \text{ cm}^{-3}$

(n-type Gaussian)

$x_j = 2.77 \text{ } \mu\text{m}$

Can determine these given known predep. and drive conditions

Determine the R_s .

Using Fig. 7.7:

$R_s x_j = 470 \text{ } \Omega \cdot \mu\text{m}$

$\therefore R_s = \frac{470}{2.77} = 170 \text{ } \Omega/\square$

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Irvin's Curves (for p-type diffusion)

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Example. n-type

Given:

$N_B = 3 \times 10^{16} \text{ cm}^{-3}$

$N_0 = 1.1 \times 10^{18} \text{ cm}^{-3}$

(p-type Gaussian)

$x_j = 2.77 \text{ } \mu\text{m}$

Can determine these given known predep. and drive conditions

Determine the R_s .

Using Fig. 7.9:

$R_s x_j = 800 \text{ } \Omega \cdot \text{cm}$

$\therefore R_s = \frac{800}{2.77} = 289 \text{ } \Omega/\square$

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