Lecture 8: Ion Implantation

Chapter 9 Wolf and Tauber

Announcements

Homework 1/4:

- Please pick up your graded homework from me at the end of this lecture if you have not already done so.
- The solutions are now available online:
  - [http://classes.engr.oregonstate.edu/eecs/fall2019/ece611/downloads/ECECHE611%20Fall%202019%20-%20Solutions%201.pdf](http://classes.engr.oregonstate.edu/eecs/fall2019/ece611/downloads/ECECHE611%20Fall%202019%20-%20Solutions%201.pdf)
Announcements

Homework 2/4:
- The second homework is online now.
- Total of 25 marks.
- Each homework contributes an equal weight.
  - All homework contributes to 40% of overall grade.
  - Each homework contributes 10% of overall grade.
- **A physical copy is due Tuesday 29th October before the midterm examination starts (10:00 am).**
- I will return it one week later (5th November).
  - I will post solutions online when I return the homework.
  - Homework 1 will consist of content covered in Lectures 5-8.

Announcements

Lecture Cancelation
- The midterm examination will take place on Tuesday October 29th at 10:00am in Kearney Hall 124.
- More details coming up....
- **The Lecture on Thursday (October 24th) is cancelled.**
  - This is to give you time to prepare for the midterm and complete the homework.
Information on Midterm Examination

Midterm Exam Details

• Tuesday October 29\textsuperscript{th} at 10:00am in Kearney Hall 124.
• Exam will last 80 minutes.
  • The exam will start exactly at 10:00am!
• Closed book and closed notes.
  • You can, and are expected to, use a calculator.
• Choose 2 out of 3 questions.
  • If you answer 3 I will take best 2 scores.
• It will contribute 20% of overall grade for class.
• The exam will material covered in lectures 2-8 (inclusive).
• There will be 50 marks per question. 100 total.
Midterm Exam Details

- The format will be similar to homeworks.
- Several sub-questions per question.
- The number of marks will be shown at the end of every sub-question. E.g. [5 marks].
- Read through all questions before deciding which 2 you wish to answer.
- There will be a mixture of descriptive and quantitative questions.
- I will not expect you to conduct any numerical methods (e.g. numerical differentiation / fitting).
- I would provide the results of such a method.

Front Page of Midterm

- This is the front page of the exam:

  ECE / CHE 611  
  OREGON STATE UNIVERSITY  
  Midterm Examination October 29th 2019  
  Electronic Material Processing

  Answer 2 out of 3 questions. If more than 2 questions are answered, the 2 questions with the highest marks will be considered.

  A maximum of 50 marks will be awarded for each question. The mark assigned to each part of the question is indicated by a number in square brackets at the end of the sub-question, e.g. [3 marks].

  You have 80 minutes to complete this exam; please pace yourself accordingly.

  No notes of any kind are allowed. You may use calculators for this exam.

  Questions Start on page 5.
Equations

- All relevant formulae will be provided.
- Parameters will be labeled as clearly as possible.

Constants

- All constants will also be provided.
- Even $\pi$!

<table>
<thead>
<tr>
<th>Name</th>
<th>Symbol</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fundamental unit of charge</td>
<td>$e$</td>
<td>$1.60 \times 10^{-19}$ C</td>
</tr>
<tr>
<td>Boltzmann Constant</td>
<td>$k_B$</td>
<td>$1.38 \times 10^{-23}$ J/K</td>
</tr>
<tr>
<td>Pi</td>
<td>$\pi$</td>
<td>3.14</td>
</tr>
<tr>
<td>Rest mass of electron</td>
<td>$m_e$</td>
<td>$9.11 \times 10^{-31}$ kg</td>
</tr>
<tr>
<td>Planck Constant</td>
<td>$h$</td>
<td>$6.63 \times 10^{-34}$ Js</td>
</tr>
<tr>
<td>Vacuum permittivity</td>
<td>$\varepsilon_0$</td>
<td>$8.85 \times 10^{-12}$ F/m</td>
</tr>
</tbody>
</table>
Equations Not Provided

• You will be given most equations. However, simple relationships you would be expected to know.

• Examples:
  
  • Density:

  \[ n_{2D} = \frac{1}{A} \quad n_{3D} = \frac{1}{V} \]

  • Area:

  \[ A = \pi r^2 \]

  • Surface area of sphere:

  \[ A = 4\pi r^2 \]

Equations Not Provided

• You will be given most equations. However, simple relationships you would be expected to know.

• Examples:
  
  • Chain rule:

  \[ \frac{df}{dx} = \frac{df}{dg} \frac{dg}{dx} \]

  • Standard derivatives:

  \[ \frac{d}{dx} (ae^{bx}) = abe^{bx} \quad \frac{d}{dx} (\ln(ax)) = \frac{1}{x} \]

  \[ \frac{d}{dx} (\sin(ax + b)) = -a \cos(ax + b) \]

  \[ \frac{d}{dx} (\cos(ax + b)) = -a \sin(ax + b) \]
Equations Not Provided

- You will be given most equations. However, simple relationships you would be expected to know.

- Examples:
  - Velocity: \( v = \frac{x}{t} \)
  - Current from charge: \( I = \frac{Q}{t} \)
  - Ohm’s Law: \( V = IR \)
  - Kinetic Energy: \( E = \frac{1}{2}mv^2 \)
  - Momentum: \( p = mv \)
  - Mass density: \( \rho = \frac{m}{V} \)

- Limits of exponentials:
  \[
  e^0 = 1 \quad e^{-\infty} = 0 \\
  e^{\pm 1/\infty} = e^0 = 1
  \]

- Unit conversions
  \[
  1\text{Å} = 10^{-10}\text{m} \\
  1\mu\text{m} = 10^{-6}\text{m}
  \]

  etc ...
Grading

• Hopefully I will not have to curve.
• But it depends on results.
• I may try to ~match grade distributions from previous years.
• Although if everyone does well the mean will be higher.
• I will return your examinations 2 weeks later (Tuesday 12th November).

Preparation

• Go through the lectures and consider what questions you could be asked on the notes given.
• Go back through the homework and solutions, and make sure you understand everything (not just memorize a procedure).
• The textbook is another good resource – it explains things in more depth.
  • There are plenty of good problems to study.
  • I have purposely not used any of the problems in the textbook for homework, so they should all be new to you.
Last Time

- We studied the physics and mathematics of diffusion.

Useful Links

Berkley:
- [http://www-inst.eecs.berkeley.edu/~ee143/fa10/lectures/Lec_08.pdf](http://www-inst.eecs.berkeley.edu/~ee143/fa10/lectures/Lec_08.pdf)

Georgia Tech:
- [http://alan.ece.gatech.edu/ECE6450/Lectures/ECE6450L5-Ion%20Implantation.pdf](http://alan.ece.gatech.edu/ECE6450/Lectures/ECE6450L5-Ion%20Implantation.pdf)

MIT:
Lecture 8

• Review of Diffusion.
• Ion Implantation.
• Ion Implantation Process.
• Implantation Parameters.
• Depth Profiles.
• Issues with Implantation.
• Implant Monitoring Techniques.
• Safety Issues.

Review of Diffusion
What we know about Diffusion

• Dopants diffuse by substitutional and interstitial mechanisms. These have different activation energies ($E_0$) and pre-factors ($D_0$).

• Fick's laws allows us to calculate concentrations as a function of time and distance due to diffusion.

• These have analytical solutions in standard cases where $D$ is constant:
  • Limitless Source of Dopant “pre-deposition” (erfc solution).
  • Single “dose” of Dopant “drive-in” (Gaussian solution).

What we know about Diffusion

• Everything about the motion is encapsulated in the diffusion coefficient: $D$.

• $D$ changes as result of:
  • Doping.
  • Oxidation.
  • Internal electric fields.

• If $D$ is anisotropic or is a function of concentration, the diffusion equation does not have easy solutions and must be solved analytically.
Pre-Deposition Solution

• In this case assume there is an infinite supply of impurity.

\[ C(z, t) = C_0 \text{erfc} \left( \frac{z}{2\sqrt{Dt}} \right) \]

\[ \text{erfc}(x) = 1 - \text{erf}(x) \]

\[ \text{erf}(x) = \frac{1}{\sqrt{\pi}} \int_{-x}^{x} e^{-\bar{x}^2} d\bar{x} \]

Drive-In Solution

• The initial impurity is described as a “dose” at a single position \((z = 0)\).
• Mathematically it is described as a delta-function:

\[ C(z, 0) = f(z) = Q\delta(z) \]

\[ \int_{-\infty}^{\infty} C(z, 0)dz = Q \]

\[ C(z, t) = \frac{Q}{\sqrt{\pi Dt}} \exp \left[ -\frac{z^2}{4Dt} \right] \]
Forming a Device By Diffusion

- Start with n-type wafer, \( N_D \), to create collector.
- Carry out pre-deposition and drive-in to create:
  - p-type base region.
  - pn junction formed.
- Pre-deposition of final n+ emitter region.
- However, little design flexibility: doping profiles consist of super-imposed Gaussians centered at the surface.

Solubility Limits

- The maximum amount of a dopant that can dissolve in the Si is given by the solid solubility → limits \( C_0 \).
- This adds a another design constraint.
Problems with Diffusion Doping

- Cannot exceed solid solubility.
- Difficult when desiring light doping level.
- High dopant concentration at the surface.
- These are limitations on what we can achieve.
- **Ion implantation is preferred over diffusion doping:**
  - Depth of implant can be controlled.
  - A low dose can be introduced ($10^{11}$ to $10^{18}$ cm$^{-3}$).
  - But significant damage results.
  - Low thru-put $\rightarrow$ high cost.

Comparison of Diffusion and Ion Implantation

- Distribution peak is below surface for ion implantation.
Ion Implantation

- A beam of energetic dopant ions is fired into the surface of the wafer.
- Energies are 5 - 200 keV.
- This will lead to implantation (burial) of the ions into the substrate.
- Dopant atoms are generated (from feed gas, e.g. BF$_3$, AsH$_3$, PH$_3$, or heated solid source), then ionized in arc chamber by electrons from hot filament.
- Ions are accelerated by an E-field (after selecting the desired species $q/m$, using a magnet), focused using electrostatic lenses.
- Ions impact substrate (a bend removes neutrals) in a raster pattern.
Ion Implantation

• An ion implanter is used to dope silicon.
• Doping is done by implanting ions of Phosphorus, Boron or Arsenic on the wafers.
• Ions implanted from the ion beam damage the lattice.

Anneal: Activation & Diffusion

• Annealing is a process where the wafer is heated to repair the damage to the lattice.
• The dopant ions become part of the crystal lattice (Activation)
• The ions also spread out during anneal (Diffusion)
Stopping Power

• An implanted ion loses energy by two types of interaction:
  • Elastic collisions with nuclei ($S_n$).
  • Inelastic collisions with electrons ($S_e$).

\[
\frac{dE}{dx} = -N[S_n(E) + S_e(E)]
\]

• Where:
  • $N$ is the number of target atom.
  • $E$ is the energy of the incident ions.
  • $x$ is the depth.
  • $S_i$ is the stopping power (eV cm$^2$).

Stopping Power

• Ion projected range ($R_p$) is the vertical distance traveled before ion stops moving:

\[
R_p = \frac{1}{N} \int_0^{E_0} \frac{dE}{S_n(E) + S_e(E)}
\]

• The standard deviation quantifies the spread in the ion distribution:

\[
\Delta R_p \approx \frac{2}{3} R_p \frac{\sqrt{M_1 M_2}}{M_1 + M_2}
\]
Nuclear Stopping Power

- This process is due to Coulomb Scattering (assumed elastic).

\[ b \]

\[ \Theta \]

\[ \Phi \]

\[ E_1, M_1 \]

\[ M_2 \]

- Incident ion \((E_1, M_1)\) interacts with nucleus of stationary ion \((M_2)\).
- \( b \) = impact parameter.
- Energy transferred by incoming ion:

\[
\Delta E = E_1 \left[ 1 - \frac{\sin^2 \phi}{\cos \Theta \sin \phi + \cos \phi \sin \Theta} \right]
\]

- The angles depends on masses on \( b \).
- The maximum energy transfer when \( b = 0, \phi = 0 \) (head-on collision):

\[
\Delta E = E_1 \frac{4M_1 M_2}{(M_1 + M_2)^2}
\]
Nuclear Stopping Power

- Displacement force:

\[ F \propto \frac{Q_1 Q_2}{r^2} \]

\[ \theta \]

\[ \phi \]

- The impulse on the ion is the integral over time when the ion is close to the nucleus:

\[ \text{Impulse} = \int_0^t F(t) dt = \Delta p \]


At 100 keV an ion of 15 amu has velocity, \( v_{\text{ion}} \approx 10^6 \text{ m/s} \).

- So fast that ion is far past nucleus before nucleus can displace in response to Coulomb force.

- Nuclear scattering is weak at high ion velocity – only significant when ion slows down.
Electronic Stopping Power

- Ions interact with electrons as well, but we describe the interaction as inelastic.
- Non-Local:
  - Ion experiences drag due to "free" or polarizable electrons.
  - No change in direction.
  - Only viscous damping.

\[ E_1, M_1 \Rightarrow E, M_1 \]

Electronic Stopping Power

- Ions interact with electrons as well, but we describe the interaction as inelastic.
- Local:
  - Passing ion causes internal electronic transitions or ionization:
  - Energy loss and momentum transfer.
  - Because electrons can respond to fields up to optical frequencies electronic losses are more significant at higher ion velocities.

\[ S_e (E) \propto v_{ion} \propto E^{1/2} \]

\[ E_1, M_1 \Rightarrow E_1, M_1 \]
Stopping Power in Substrate

- With each interaction, ion loses some energy. It travels through a vertical projected range $R_p$ before stopping.
- Ion loses energy by:
  - Vicious Drag
  - Electron excitation
  - Nuclear collisions
  
  More effective at larger $v_{\text{ion}}$
  More effective at smaller $v_{\text{ion}}$

Annealing after Ion Implantation

- Most damage is done by nuclear interactions.
- About 15 eV needed to displace Si from lattice site, create vacancy/interstitial pair
- Most damage occurs near $R_p$ and over a width of $\Delta R_p$. 

Depth Profiles

- Knowing $S_e$ and $S_n$, can determine $R_p$ and $\Delta R_p$.

![Graphs showing depth profiles in Si and GaAs](image)

Composition Profile for Ions

- If the depth is $z$, the impurity concentration $c(z)$ is (approximated by a Gaussian).

$$c(z) = c_p \exp\left(-\frac{(z - R_p)^2}{2\Delta R_p^2}\right)$$

- Where:
  - $c_p$ is the peak concentration.
  - $R_p$ is the projected range.
  - $\Delta R_p$ is the standard deviation of the projected range (vertical straggle or spread).
  - The implanted dose is given by $Q$ (#/cm$^2$):

$$Q = \int_{-\infty}^{\infty} c(z)dz = \sqrt{2\pi}\Delta R_p c_p$$
200 keV Implants in Si

• Concentration distribution for implantation of various ions at 200 keV.

![](image1)

- $m_B < m_P < m_{AS} < m_{Sb}$
- Greater velocity $\rightarrow$ longer $R_p$.
- Less loss / collision $\rightarrow$ larger $\Delta R_p$.

Distorsion of Dopant Profiles

• Concentration distribution for implantation of boron at various energies:

![](image2)

- Composition profiles are not always perfect Gaussians; there can be a skew or distortion (kurtosis) making the profile asymmetric.
Distorsion of Dopant Profiles

- Can deposit at several different energies to get ~ uniform dopant distribution:

Ion Implantation Process
Ion Implanter

- The major sub-units of an ion implanter are shown below.

- All the parts of an implanter shown here are under high vacuum.
Ion Source: Operation

(1) The filament is heated.
(2) Electrons are “boiled” off the heated filament.
(3) The electrons are attracted to the positive wall.
(4) On their way to the wall they hit neutrals and ionize them.

- Many different ions are made when the gas is ionized.
- Some possible ions from BF$_3$ are shown here.

• Boron trifluoride
• Electrons from filament
• Neutral Molecule BF$_3$

• Now we want to move the ions out of the source and towards the wafer.
Extractor

- The extractor extracts ions from the ion source by providing them a lower voltage.
- Ions fall down the energy hill.
- Now we have a beam of ions that is moving towards the wafer.
- We want to make sure that we get the ions we need.

Beam Blowup

- Lets take another look at the ion source and extractor.
- Only positive ions come out of the source.
  - The beam will spread or “blow up” because like charges repel each other.
Blowup: Control

- The blow up is controlled in the extractor.
- The first plate is at 58 KV. It is called the suppresser plate.
- The second plate is at 60 KV. It is called the extractor plate.

- Ions in the divergent part of the beam hit the extractor plate at high speeds. They knock off electrons from the plate which prevent beam blow up.
- The negative charge of the electrons balances the positive charge of the ions and thus prevents beam blowup.
Analyzer

- The analyzer makes sure that only the ions we need reach the wafer.
- It magnetically filters out the specified ions from the other ions in the ion beam.
- Separation is based on the difference in mass.

Radius of the arc:
\[ r = \frac{1}{B} \sqrt{\frac{1mV_{ext}}{q}} \]

Accelerating Column

- Positive ions gain energy as they fall down the energy hill.
Resolving Unit

• Magnets in the resolving unit focus the beam onto the wafer.

- Magnets
- Ion beam from accelerator
- Ion beam gets focused

• Now the ion beam is focused.
• We are ready to send it onto the wafer.

Process Chamber

• The wafers are in the process chamber.
• They are held on a large disk, called the implant disk.
• The implant disk can be tilted to allow implant at different angles.
Scanning

- The ion beam must be scanned over the wafer surface to cover the entire area.
- There are three methods of scanning:
  - Mechanical.
  - Electrostatic.
  - Magnetic.

Mechanical Scanning

- The ion beam is fixed and the wafers are moved.
- Advantages:
  - Used for high energy and high current processes.
  - Ion beam is efficiently used.
  - More wafers can be placed on the implant disk.
Mechanical Scanning

- The ion beam is fixed and the wafers are moved.
- Disadvantages:
  - Low throughput.
  - Movement of machinery generates particle contaminants.

Electrostatic Scanning

- The ion beam is scanned by deflecting it across the wafer.
- Advantages:
  - Fast scan.
  - Good uniformity.
  - No particulate contaminants.
**Electrostatic Scanning**

- The ion beam is scanned by deflecting it across the wafer.
- Disadvantages:
  - Ion beam falls on the wafer at an angle and forms shadows. This is called shadowing.

**Magnetic Scanning**

- Magnetic scanning is similar to electrostatic scanning except we use magnets instead of charged plates to scan the beam.
- Advantages:
  - Fast scan.
  - Good uniformity.
  - No particulate contaminants.
Magnetic Scanning

- Magnetic scanning is similar to electrostatic scanning except we use magnets instead of charged plates to scan the beam.
- Disadvantages:
  - Ion beam falls on the wafer at an angle and forms shadows. This is called shadowing.
Implant Parameters

Input Parameters:
• Time
• Current
• Energy
• Implant Angle
• Implant Species

Output Parameters:
• Dose
• Uniformity
• Dose Depth

Implant Time

• Implant time can be controlled by:
  • Adjusting scan speed of the scanning mechanism.
  • Adjusting the rotation speed of the implant disk.
• Many semiconductor processes require implant times of a few seconds (4-10 sec).
**Implant Current**

- Implant current is a measure of number of ions in the ion beam.
- Typical ranges are from around 10 µA to 30 mA.
- More ions are present at high currents.
- Current also controls how many ions get implanted.

**Implant Energy**

- Implant energy is measured in electron-volts (eV)
- Typical ranges are from 0.2-2000 keV.
- Ions with more energy go deeper into the crystal.
Projected Range of n- and p-Type Dopants in Si Vs Energy

- Range is the peak concentration.
- Sigma is the standard deviation in concentration.

Implant Angle

- Range is the peak concentration.

- Ions in beam 1 will go quite deep into the crystal before stopping.
- Ions in beam 2 will not go as far.
## Summary

<table>
<thead>
<tr>
<th>Input parameter</th>
<th>Effect on process</th>
</tr>
</thead>
<tbody>
<tr>
<td>Time</td>
<td># of dopant ions (dose)</td>
</tr>
<tr>
<td>Current</td>
<td># of dopant ions (dose)</td>
</tr>
<tr>
<td>Energy</td>
<td>Depth of dopant ions</td>
</tr>
<tr>
<td>Angle</td>
<td>Depth of dopant ions</td>
</tr>
</tbody>
</table>

## Depth Profiles
Dose

- Dose is the concentration of dopant ions.
- It is given as “number of ions per square centimeter” (#/cm²).
- Semiconductor devices may require anywhere from $10^{11}$ ions/cm² to more than $10^{16}$ ions/cm².
- Dose depends on implant current and time.
- Dose uniformity depends on proper scanning and implant angle.

Dose Depth

- Dopant profile tells us about the concentration of ions at varying depth from the surface.
- A Gaussian profile is sometimes used:

$$c(z) = c_p \exp \left( -\frac{(z - R_p)^2}{2\Delta R_p^2} \right)$$
Dose Depth After Annealing

- During annealing the wafer is heated to repair the damage to the lattice.
- The ions spread out during anneal (Diffusion):

\[
\frac{\partial C}{\partial t} = D \frac{\partial^2 C}{\partial x^2}
\]

Resist Mask and Cure

- Photoresist or oxide acts as a mask to cover part of the wafer from the ion beam.
Resist Mask and Cure

- If the resist is not strong enough it will break up when ions hit it.
- When resist breaks up, it can form:
  - Particulates (solid products) that contaminate and cover the implant region.
  - Gas products that neutralize the ion beam. Neutralization slows down and scatters the ionic species.
- Resist is cured by exposing it to UV light forming new bonds.

Channeling

- In single crystal lattices there are some directions in which the ions can go for long distances without hitting atoms in the lattice.
Channeling

- There are several directions in a Si crystal can lead to channeling:

(110)  (100)  (111)

Channeling – Solution

- Change the angle at which ions enter the crystal.
  - Ions in beams 1 & 2 will channel through the lattice.
  - Ions in beam 3 will hit the atoms or bonds in the lattice and stop early.
Issues with Implantation

Wafer Charging

- Wafer charging happens when ions accumulate on insulating surfaces like resist.
- The resist gets a net positive charge which repels incoming ions.
- This affects the dose uniformity across a wafer.
Wafer Charging: Solution

- An electron shower is used to neutralize wafer charge.
- A shower of electrons balances out the positive charge on the wafer.
- Electrons boil off the filament.
- The electrons hit the target and produce more electrons.
- The electrons from the target move towards the wafer and neutralize its positive charge.

![Diagram of Wafer Charging]

Contaminants

- Contamination in ion implantation can come from:
  - Metallic contaminants:
    - When high speed ions hit metal surfaces they knock off metal atoms (Fe, Ci, Cr, Ni).
  - Cross contaminants:
    - Cross contamination occurs when the same implant tool is used to implant different species.
    - Cross contamination is avoided by using an Argon ion beam in-between implant processes.
  - Particulates.
Metallic contaminants

- When high speed ions hit metal surfaces they knock off metal atoms.
- This causes metal contamination.

- Metallic contaminants can be reduced by using graphite fixtures on the implant disk.

- Iron, copper, chromium and nickel are common contaminants.

- Metal atoms knocked off from metal parts deposit on the wafer and affect its properties.
Cross Contaminants

- Cross contamination occurs when the same implant tool is used to implant different species.

- If a tool is used to implant one species (e.g. boron) then boron may “stick” to the walls with time.
- Now, if this tool is switched to use for phosphorous implant, those ions will knock off the boron from the walls and deposit them on the wafer.

Cross Contaminants

- Cross contamination is avoided by using an Argon ion beam in-between implant processes.
Safety Issues

Safety: Chemical

• Chemical hazard arises from the following sources:
  • Source gases.
  • Pump and tool cleaning.
  • Cryo-pump regeneration.
• The source gases get adsorbed on the tool and pumps.
• So cleaning, servicing and regeneration must be done by trained operators in a properly exhausted room.
Chemical Hazard: Source Gas

- Operators must be aware of the specific effects of the source gases being used on their tools.
- They should also know the emergency procedures properly.
- Operators must read the Material Safety Data Sheets (MSDS) of the source gases being used.
- The MSDS is a document that provides the following important information:
  - Chemical Identity
  - Chemical characteristics
  - Special protection
  - Ingredients
  - Physical Hazards
  - Special precautions
  - Physical characteristics
  - Health Hazard
  - Additional information

Source Gas: Arsine

- Name of gas: Arsine
- Chemical formula: \( \text{AsH}_3 \) [for N-type As implant]
- Odor: Mild garlic odor
- Immediate exposure symptoms: Headache, Dizziness, Nausea
- Stomach pain, Bloody urine
- Immediate toxic danger: High
- Fire hazard: Moderate
- Dangerous exposure dose: 0.2 mg/m\(^3\) over a 40 hour working week
### Source Gas: Phosphine

<table>
<thead>
<tr>
<th>Name of gas:</th>
<th>Phosphine</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical formula:</td>
<td>PH$_3$ [for N-type P implant]</td>
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<tr>
<td>Odor:</td>
<td>Decaying fish</td>
</tr>
<tr>
<td>Immediate exposure symptoms:</td>
<td>Restlessness with tremors, Nausea</td>
</tr>
<tr>
<td></td>
<td>Fatigue, Drowsiness</td>
</tr>
<tr>
<td>Immediate toxic danger:</td>
<td>High</td>
</tr>
<tr>
<td>Fire hazard:</td>
<td>High</td>
</tr>
<tr>
<td>Dangerous exposure dose:</td>
<td>0.4 mg/m$^3$ over a 40 hour working week</td>
</tr>
</tbody>
</table>

### Source Gas: Boron Trifluoride

<table>
<thead>
<tr>
<th>Name of gas:</th>
<th>Boron Trifluoride</th>
</tr>
</thead>
<tbody>
<tr>
<td>Chemical formula:</td>
<td>BF$_3$ [for P-type B implant]</td>
</tr>
<tr>
<td>Odor:</td>
<td>Sharp, stinging, irritating, biting</td>
</tr>
<tr>
<td>Immediate exposure symptoms:</td>
<td>Severe irritation to lungs, eyes &amp; skin</td>
</tr>
<tr>
<td>Immediate toxic danger:</td>
<td>High</td>
</tr>
<tr>
<td>Fire hazard:</td>
<td>None</td>
</tr>
<tr>
<td>Dangerous exposure dose:</td>
<td>3.0 mg/m$^3$ over a 40 hour working week</td>
</tr>
</tbody>
</table>
Other Gases

- Other gases used in the implant process are:
  - Sulfur hexafluoride.
  - Argon.
- Gas handling is the main safety issue with these gases.
- Sulfur hexafluoride is used in the implant tools to avoid sparking due to high voltages.
  - It is a colorless, odorless, non-toxic and nonflammable gas.
  - High quantities can cause breathing difficulties.
- Argon (inert) is used to clean the implant tools.

Safety: Radiation

- The main radiation hazard comes from X-rays.
- High speed ions knock off electrons from parts of the tool.
- These electrons hit metallic parts and make X-rays.
**X-Rays: Prevention**

- X-ray hazard is avoided by good design of the tool.
  - Areas on which electrons may fall are coated with materials that make less X-rays.
  - The suppresser plates, used in the extraction assembly reduce the number of electrons hitting metal parts of the tool.
  - Radiation shields are placed around parts where X-rays are generated.

**Safety: High Voltage**

- High voltage is used in the implant tool to generate and move ions.
  - The voltages used range from:
    - 5V in the filament power supply to 180,000 V in the acceleration unit.
  - The operator should be aware of the location of high voltage hazards and the safety procedures.
Safety: Mechanical

- The main mechanical hazard can be the implant disk.
- It rotates at very high speeds (900 rpm). If it breaks off it can cause serious damage and injury.

Other sources of mechanical hazards are:
- Moving valves, drive belts, drive shafts etc.
- Mechanical hazard from the implant disk is avoided by:
  - Sensors that turn it off if it is not rotating properly.
  - Steel frames inside the tool to stop it from tearing out of the tool in case it gets loose.
- In general all moving parts should be electrically disabled before service.
Summary

- We looked at ion implantation.

Next Time...

- After the midterm exam we will look at modeling growth with Athena / Atlas.