Silicon

The starting material for the microelectronics revolution
My new five-year plan looks like this.

How can you have a five-year plan when you don't know what will happen in five minutes?

We have this room now.

Bad timing. Shoo! Shoo!
Our CEO appreciates pushback.
The last thing he wants is a bunch of yes men.
Don't be afraid to stand your ground. He respects that.
My plan is to form business units around each product line.

Excuse me. We tried that once and it didn't work.

You're fired.
Leave now.

Cruelty or convenience?
I needed a cubicle to store my extra binders.
NOW THAT OUR PROFITS ARE IMPROVING, CAN I HAVE A RAISE?

IF I START GIVING PEOPLE RAISES, THEN PROFITS WILL PLUMMET AND WE'LL BE NOWHERE.

DOES YOUR BONUS DEPEND ON HOW EFFECTIVELY YOU OPPRESS ME?

IF YOU DON'T LIKE IT, TRY COMMUNISM.
Materials

- Conductive materials – valence band overlaps the conduction band
- Non conductive materials – valence band is separated from conduction band and electrons cannot easily get to the conduction band
- Semiconductor materials – conduction band is close to valence band and electrons can easily jump from the valence band to the conduction band with an energy source
Silicon

- Silicon is an element
- Silicon is the first or second most abundant element on the earth
- Sand is a form of silicon
- Silicon is known as a semiconductor because under certain conditions it can conduct electricity (electrons)
- Silicon is the most widely used material for today’s microelectronics
- Silicon was not the first semiconductor material used, germanium was first.
Silicon needs to be in crystalline form for microelectronics

- Atoms are in a uniform structure and spacing apart
- Compare a pile of bricks to bricks forming in a wall

Amorphous silicon – random structure
Crystalline silicon – uniform spacing
Elemental silicon is melted and grown into a single crystal ingot.

Single crystal ingot being grown

Completed silicon ingot
1. Silicon material preparation process from crystal growth through shaping of the polished wafer.
Once the ingot is complete, wafers are sawn from the ingot and the top side is polished to a mirror finish.
• Pure silicon is rarely grown
• Typically as the silicon crystal is grown, an impurity element is introduced into the growth process to create an electrically positive (missing electron) p-type silicon or electrically negative (extra electron) n-type silicon
• This process is called doping and the elements used are called dopants
• Boron, a group 3 element, is the most common p-type dopant
• Phosphorus, antimony and arsenic are the most common dopants for n-type silicon.
Silicon

- From the periodic chart you can see that silicon is a group 4 element.
- Group 4 elements have 4 electrons in their outermost electron shell.
- Silicon is the most common material currently used for solar cells.
Why is silicon an excellent microelectronics material?

1. It is very abundant
2. It can be grown into a single orientation crystal
3. It can be made electrically active easily by doping with group 3 and 5 elements
4. It can be made to conduct electrons with a small applied potential
5. It has a naturally forming oxide that acts as an insulating and diffusion barrier
Group 4
Two dimensional schematic of three dimensional crystal
P type doping –
Positive, electron short, also called a hole
### Group 5 elements

**PERIODIC TABLE OF THE ELEMENTS**

#### Table of Selected Radioactive Isotopes

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The A & B subgroup designations, applicable to elements in rows 4, 5, 6, and 7, are those recommended by the International Union of Pure and Applied Chemistry. The names for elements 108-106 have been proposed, but not yet formally accepted by the IUPAC.
N-type doping
– N is negative, electron rich
Combing n-type silicon and p-type silicon gives a pn junction.
Silicon crystal planes and Miller Index

Diamond Unit Cell  {100} planes  {110} planes  {111} planes
Silicon wafers have “flats” to denote what type of wafer it is.

**Wafer Flats**

**Purpose and Function**

1. Orientation for automatic equipment
2. Indicate type and orientation of crystal.

**Primary flat** – The flat of longest length located in the circumference of the wafer. The primary flat has a specific crystal orientation relative to the wafer surface; major flat.

**Secondary flat** – Indicates the crystal orientation and doping of the wafer. The location of this flat varies.

These links provide specific information on each orientation.

- **<100>**
  - flat at 180 deg for n-type and 90 deg for p-type.

- **<111>**
  - flat at 45 deg for n-type, no secondary for p-type.

very few 8” or 8” <111> wafers are manufactured.
So

- Dopants are used to change the conductivity of the silicon crystal.
- The amount of dopant introduced into the crystal as it is being grown determines the resistivity of the silicon crystal and thus the resulting wafers cut from this crystal.
- Resistivity plays a major role in the performance of the resulting devices.
Resistivity vs Impurity Concentration

The graph shows the relationship between resistivity (in ohm cm) and dopant density (in /cm³) for n-Si (phosphorous) and p-Si (boron). The resistivity decreases as the dopant density increases for both types of silicon.
Reading a Log-Log graph

- 1.0 x 10^{14}
- 3.5 x 10^{14}
- 1.5 x 10^{15}
Once the wafer has been created with the appropriate dopant (resistivity level) it is ready for additional dopant layers.

Boron continues to be the most common p-type dopant and phosphorus is now the most common dopant for n-type regions.
Dopants can be introduced into the silicon crystal in a variety of ways:

1. **High Temperature** plus time
   - 1. Solid sources
   - 2. Liquid sources
   - 3. Gaseous sources
2. **Ion Implantation**
Solid Dopant Sources

- A solid wafer of born (boron nitride), antimony, arsenic, or phosphorus is placed in close proximity to the silicon wafer at high temperature.
- Atoms are transferred via gas flow on to the silicon wafer and allowed to diffuse into the silicon crystal
Gaseous Sources

- A gaseous source is introduced into a chamber to supply the dopant material.
- Requires an air tight chamber because many of the gases used are dangerous.
- Most commonly used for growing the crystal and in ion implantation.
Liquid Source

• With the wafers in a high temperature furnace, a nitrogen carrier gas is bubbled through a flask of phosphorus oxychloride (POCl3). This phosphorus laden gas is flowed into the furnace.

• This method provides a high concentration of phosphorus which is often desirable.

• This is the process we will use for the solar cell.
Another liquid source is a “spin on” film

This film is spun on the wafer, like photoresist, to a uniform layer

The wafer is then inserted into a high temperature furnace and the film is then the source of dopant.

Depending on time and temperature, the dopant diffuses into the silicon to a certain depth
High Temperature Furnaces for dopant diffusion
Dopants can be introduced into the silicon crystal with an “ion implanter”
Ion Implantation

- Tool is very expensive – greater than $1 million
- Requires high level technical support, operation, and maintenance
- Implantation of ion causes crystal damage that needs to be annealed out
- Still requires a high temperature furnace for diffusion of impurities
- Not a University option BUT foundries offer the service
The future

- Silicon will continue to play a dominant role but other semiconductor materials will play an increasing role.

- III-V semiconductor materials made from group III and group V elements are now common (GaAs, InP, AlN)

- II-VI semiconductor materials are being investigated for special applications.

- SiC, “diamond like carbon”, and SiGe are also of interest.
Assignment due next class

Resistivity vs Concentration
Worksheet from the web site