Lecture #2 — Crystal Structure of Solids

100 years ago we....
- .... were just beginning to understand the atom.
- .... had very little idea about how atoms were arranged in a solid.
- .... had no practical use for semiconductors.
- .... had no conceptualization for how electrons move through a solid.

Now? We have this class!

Semiconductors

periodic table

III	IV	V
5 B		
13 Al	14 Si	15 P
31 Ga	32 Ge	33 As
49 In		51 Sb

Silicon: Foremost semiconductor thanks to abundance and native oxide (SiO_2)

Germanium: other elemental semiconductor

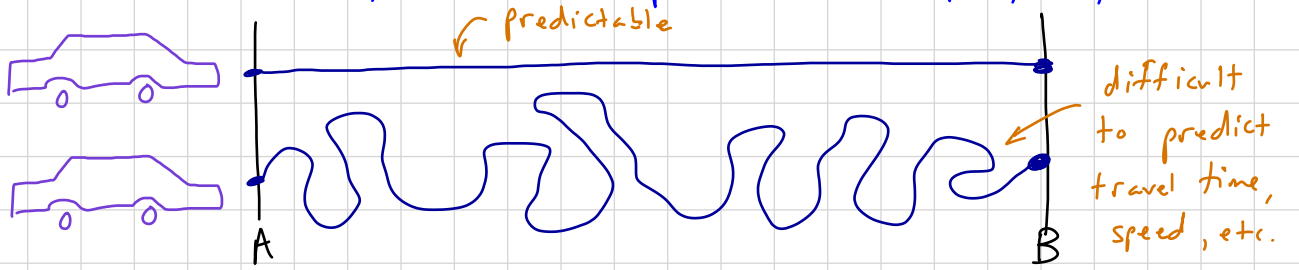
- Dopants used to modulate the conductivity of a semiconductor (Si)
- Compound Semiconductors, or "III-V's" e.g. GaAs, InP, AlGaAs, etc.

Solids

How do the atoms arrange themselves within a solid semiconductor?

- Does it matter?

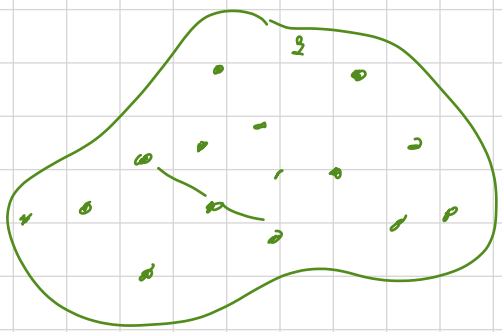
YES! Think of two cars and one has path A, the other path B. Same linear distance, but will the path matter for speed, time, etc.?



Three options:

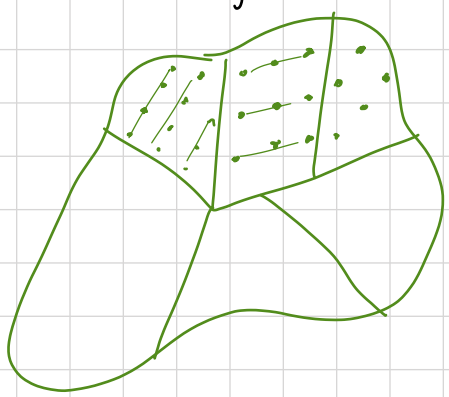
Amorphous

No recognizable long-range order



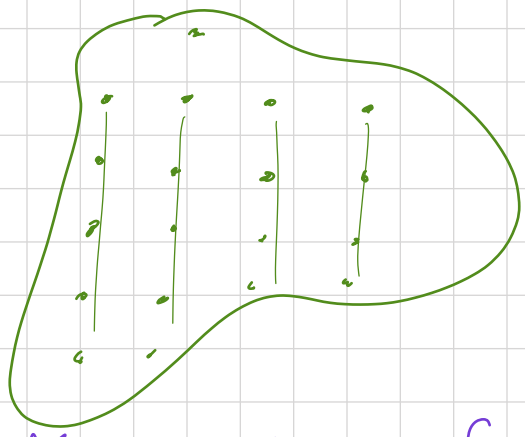
Polycrystalline

completely ordered in segments



Single Crystal

Entire solid is made up of atoms in ordered array

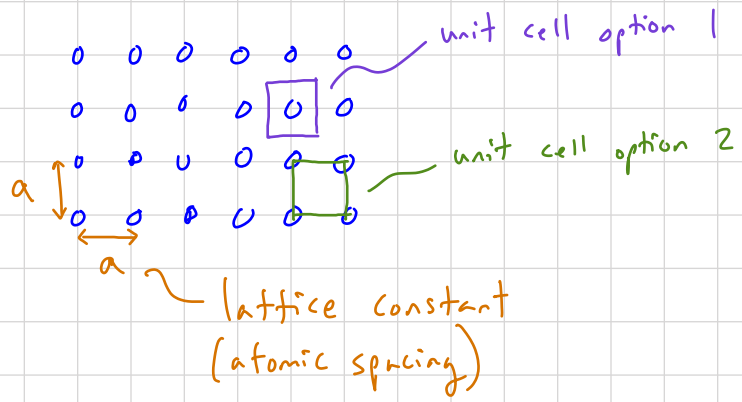


★ This is what we focus on

Crystal lattice

unit cell:

2D lattice

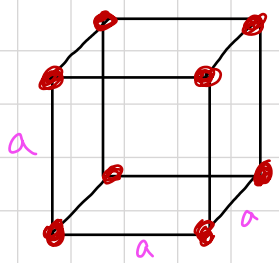


1 atom

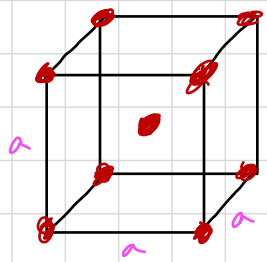
Both work (same # atoms!)

$\frac{1}{4}(4) = 1$ atom

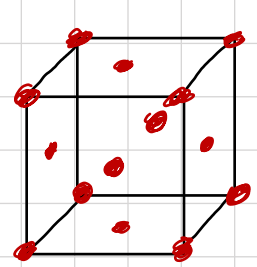
Cubic unit cells:



Simple Cubic



Body-Centered Cubic (BCC)



Face-centered Cubic (FCC)

- Volume density of atoms in a crystal

Ex: FCC with $a = 4.25$ Å

a) # atoms per unit cell?

$\frac{1}{8}(8) + \frac{1}{2}(6) = 4$

(corners) (faces)

$1\text{ Å} = 10^{-8}\text{ cm}$

b) Volume density of atoms

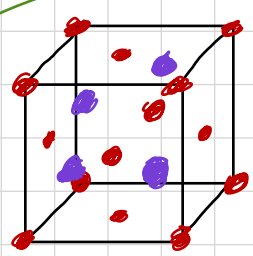
$$V_D = \frac{\#\text{ atoms/unit cell}}{\text{Volume unit cell}} = \left(\frac{4}{a^3}\right) = 5.21 \times 10^{22}\ \text{atoms/cm}^3$$

use "cm"

Semiconductor unit cell:

Diamond lattice → FCC lattice with additional FCC included with a shift of $\left(\frac{a}{4}, \frac{a}{4}, \frac{a}{4}\right)$

Zincblende lattice → Same as diamond, but the 4 add'tl atoms come from other element (e.g. GaAs)



(If Si, then all are same atoms)

Si: $a = 5.43$ Å

Miller Indices (crystallographic planes) → orientation of certain cuts, or planes, in a crystal structure

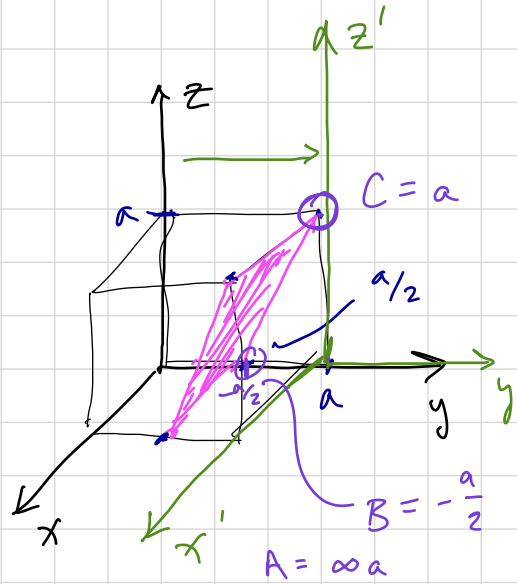
↳ (h k l) ✱ no commas! ✱ parentheses!

How do you determine Miller indices for a given plane?

(1) Intercepts to x, y, z axes:

A B C

If not intersecting axes, then move coord. system but be sure does not pass through origin.



A = ∞ a
↑ parallel to axis

(2) Reciprocate and multiply by integer if needed:

$$h = \frac{n\,a}{A} \qquad k = \frac{n\,a}{B} \qquad l = \frac{n\,a}{C}$$

n ≡ integer multiple

$$h = \frac{a}{\infty} \qquad k = \frac{a}{-a/2} \qquad l = \frac{a}{a}$$

$$\therefore (0\ \bar{2}\ 1)$$

(3) If an indice is negative then use bar above # to indicate (not "minus" sign)