Primer on Semiconductors

Unit 1: Material Properties

Lecture 1.2: Crystalline, polycrystalline, and amorphous semiconductors

Mark Lundstrom

lundstro@purdue.edu
Electrical and Computer Engineering
Purdue University
West Lafayette, Indiana USA

PURDUE UNIVERSITY

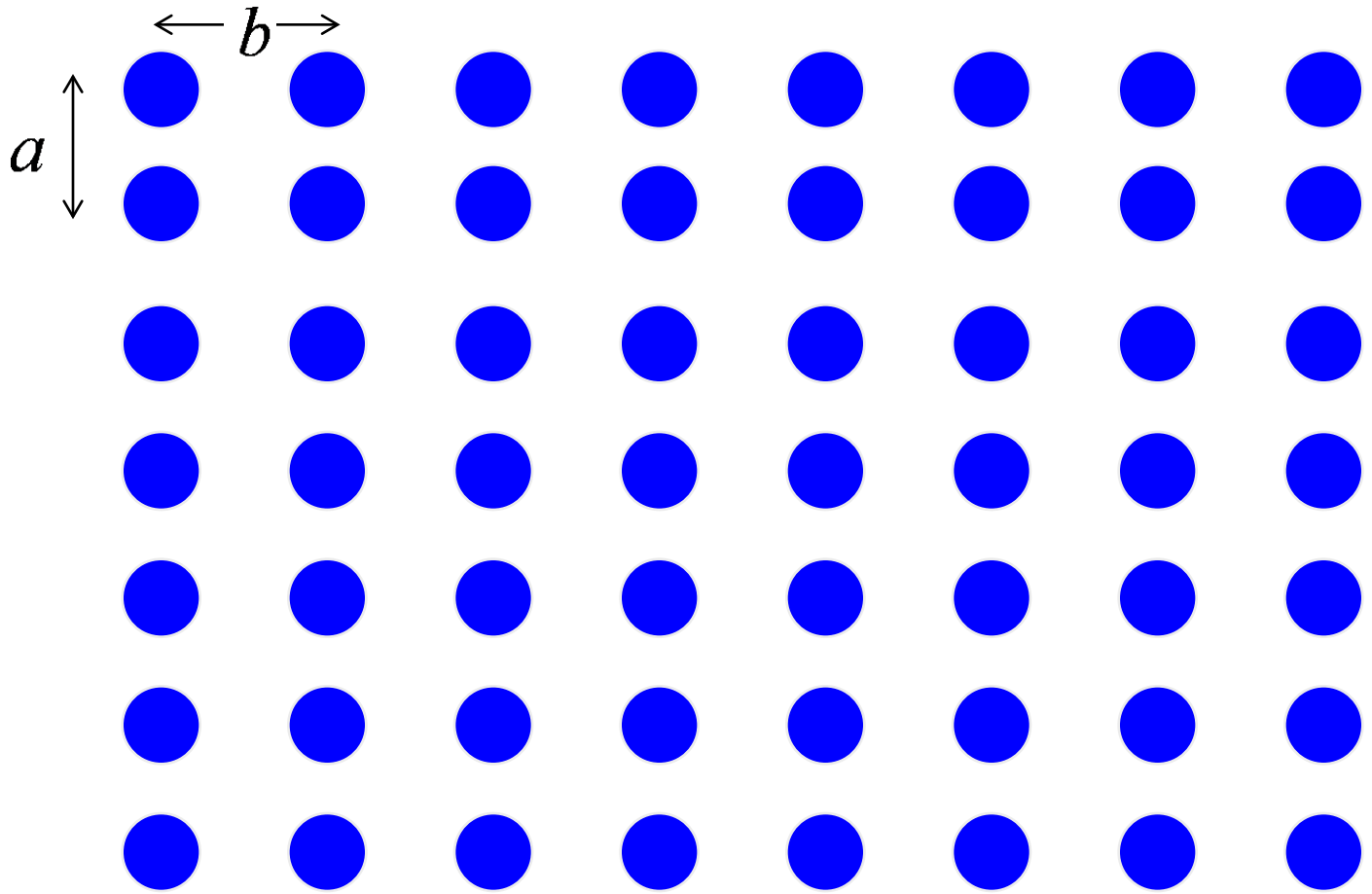
Semiconductor materials

1) In a semiconductor **crystal**, each atom occupies a specific location in a “crystal lattice”.

2) **Polycrystalline** semiconductors consist of many crystalline “grains” with different orientations.

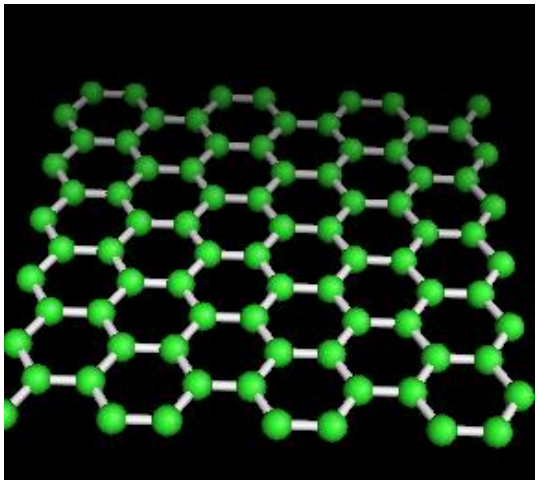
3) In **amorphous** semiconductors, the atoms are more or less randomly distributed throughout the solid.

A 2D crystal



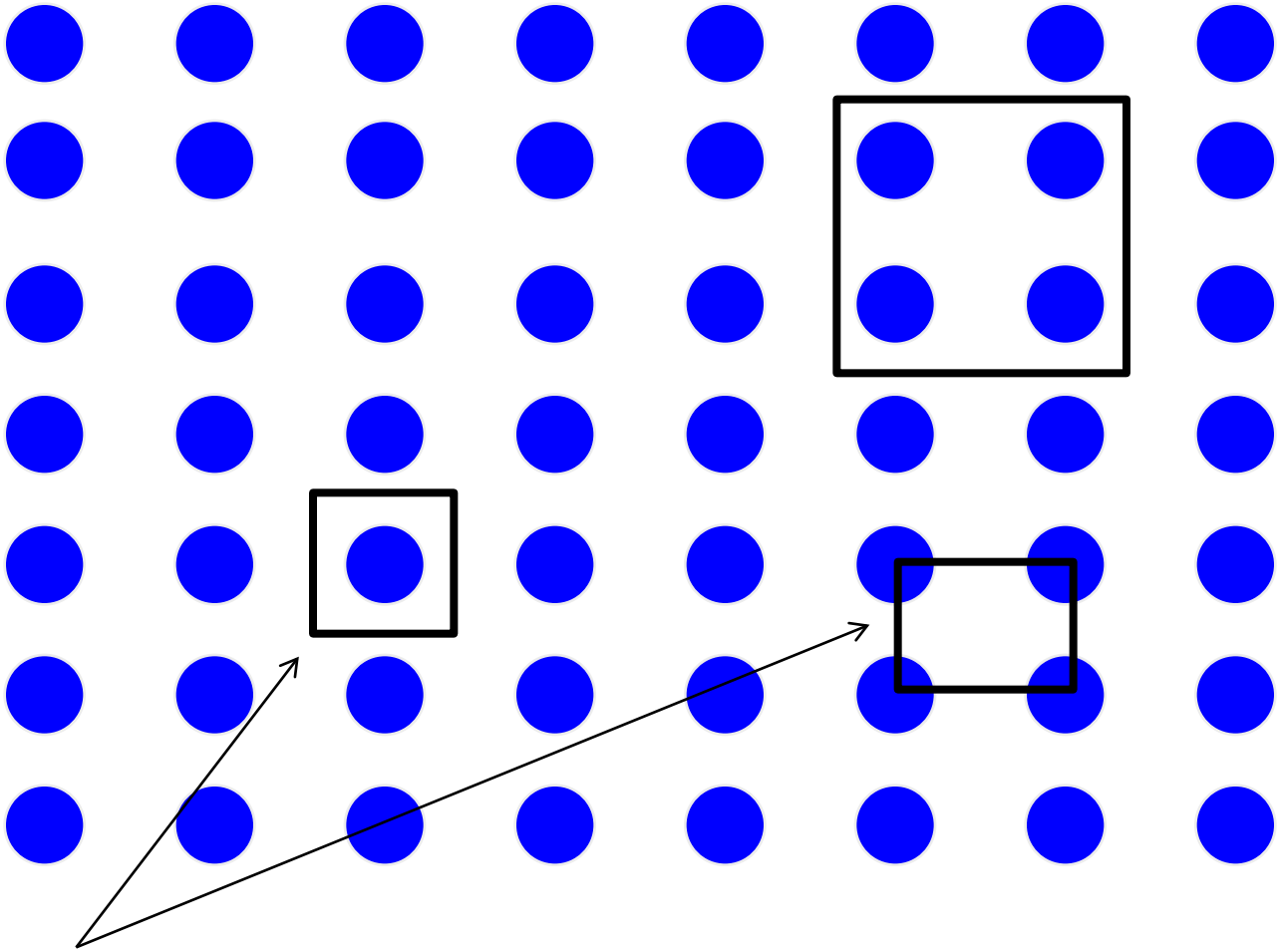
Graphene: 2011 Nobel Prize in Physics

Graphene is a one-atom-thick planar carbon sheet with a honeycomb lattice.



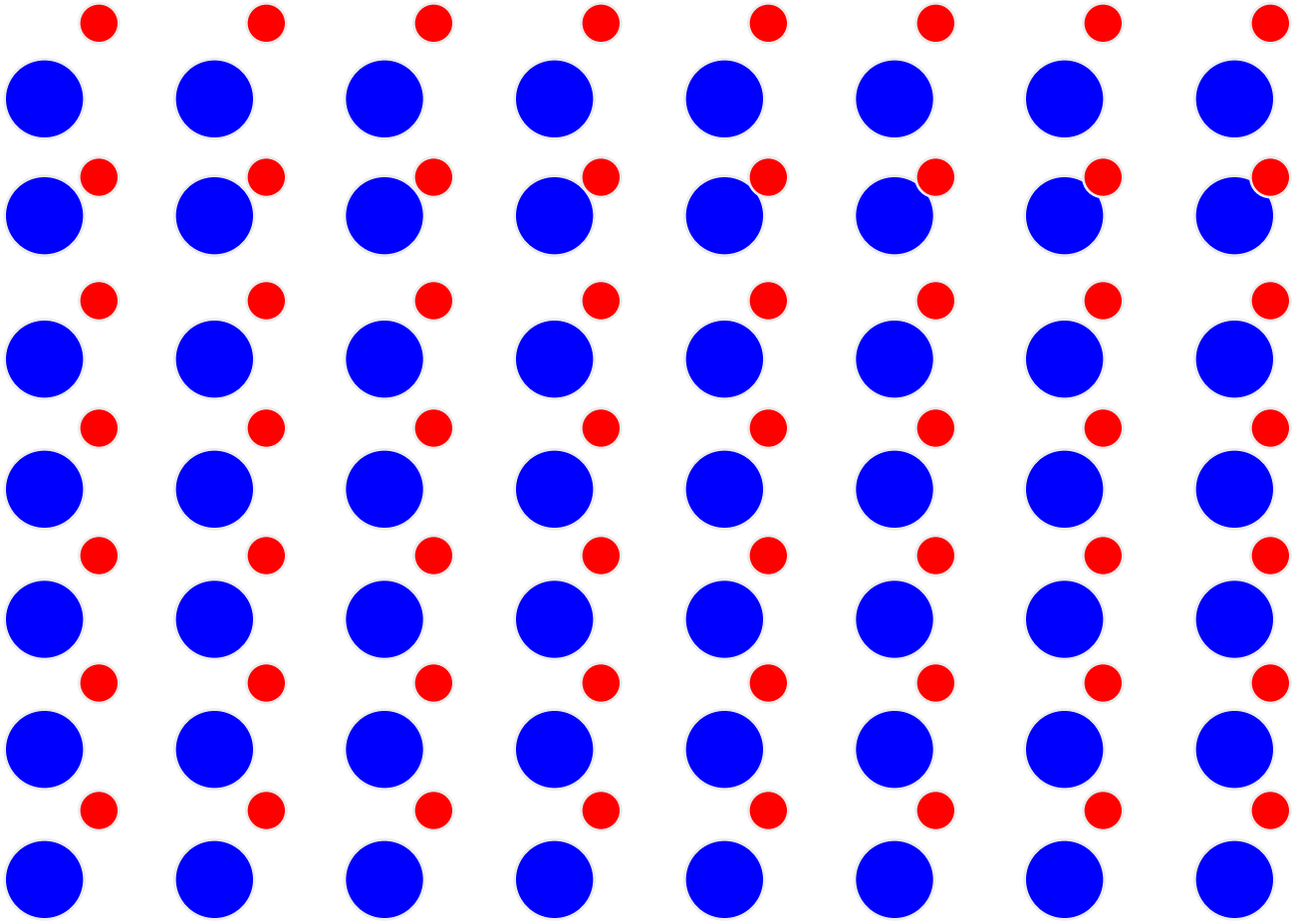
source: CNTBands 2.0 on nanoHUB.org

Unit cells



primitive unit cells

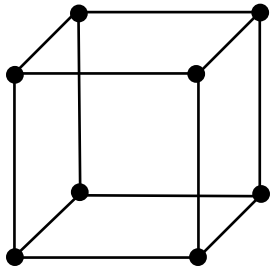
Lattice plus basis



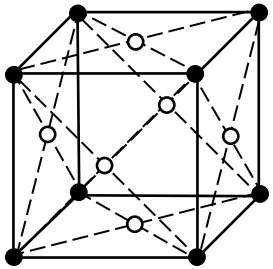
3D crystal structures

In 3D, there are 14 different ways to arrange lattice points such that at any point, the view is the same as at any other point.

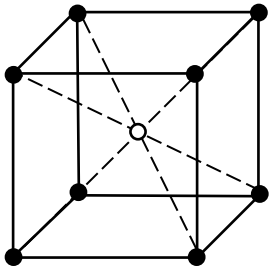
14 Bravais lattices; 3 are cubic:



simple cubic



face centered cubic

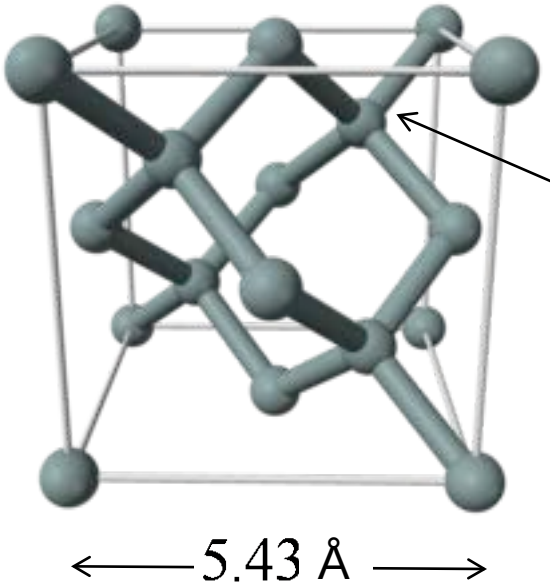


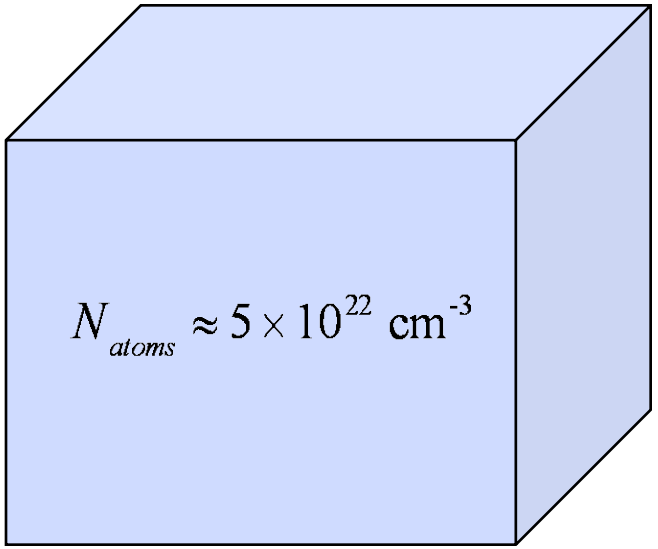
body centered cubic

http://en.wikipedia.org/wiki/Bravais_lattice

Si crystal structure (diamond lattice)

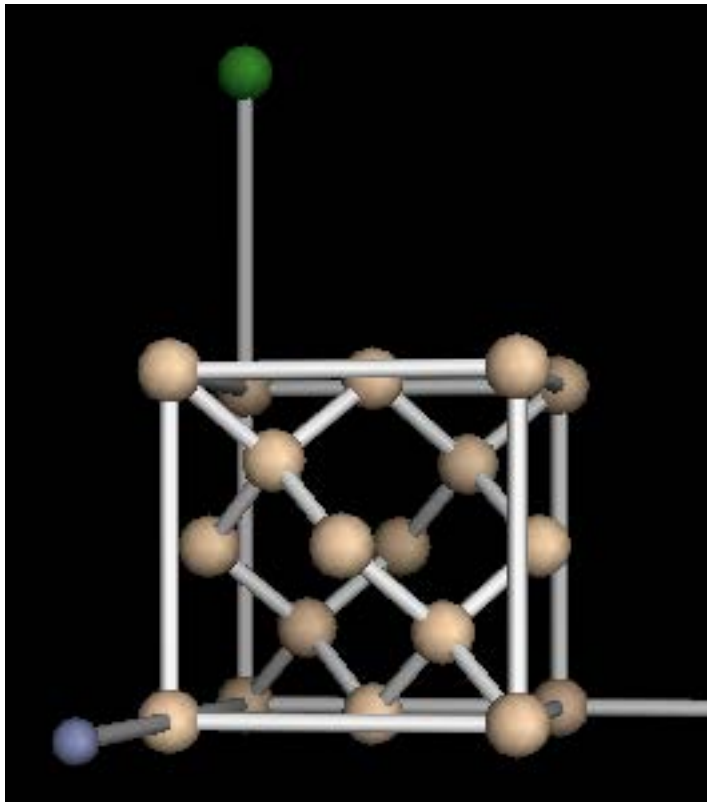
(this is not a primitive unit cell)





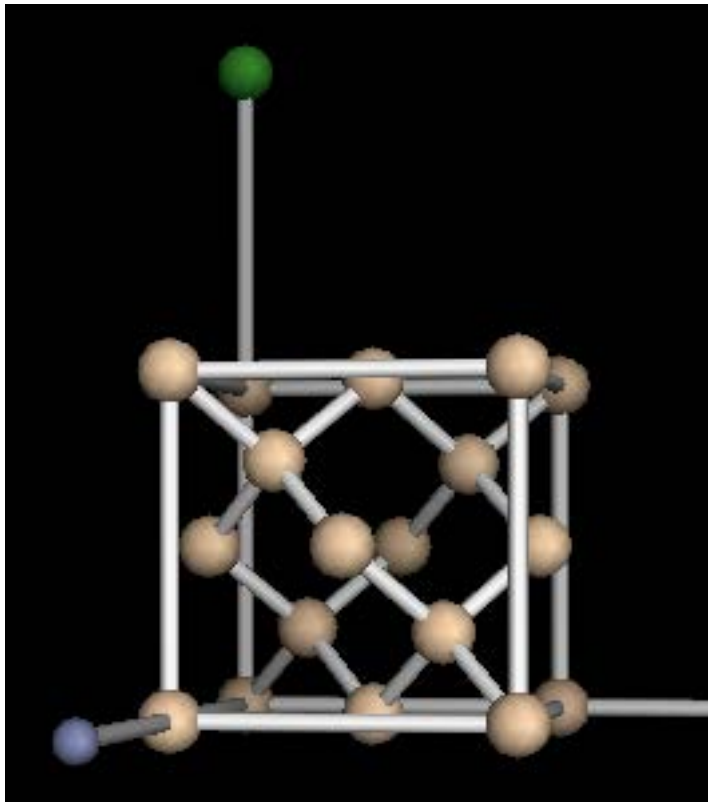
Two interpenetrating fcc lattices offset by ¼ of the body diagonal.

Diamond lattice



https://nanohub.org/tools/crystal_viewer

Diamond lattice: atoms per unit cell



The 8 atoms on the corners are each shared with 8 neighboring cubes.

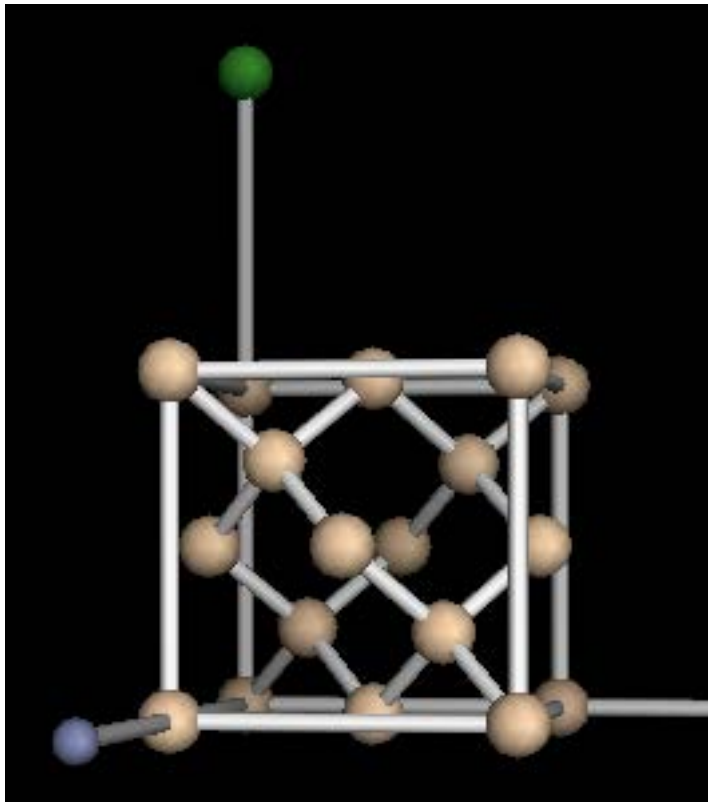
The 6 atoms on the faces are each shared with the face of an adjacent cube.

(8 times 1/8) + (6 times ½) + 4 =

8 atoms per unit cell

https://nanohub.org/tools/crystal_viewer

Silicon: # atoms / cc



Lattice constant: a = 5.4307 Å

8 atoms per unit cell.

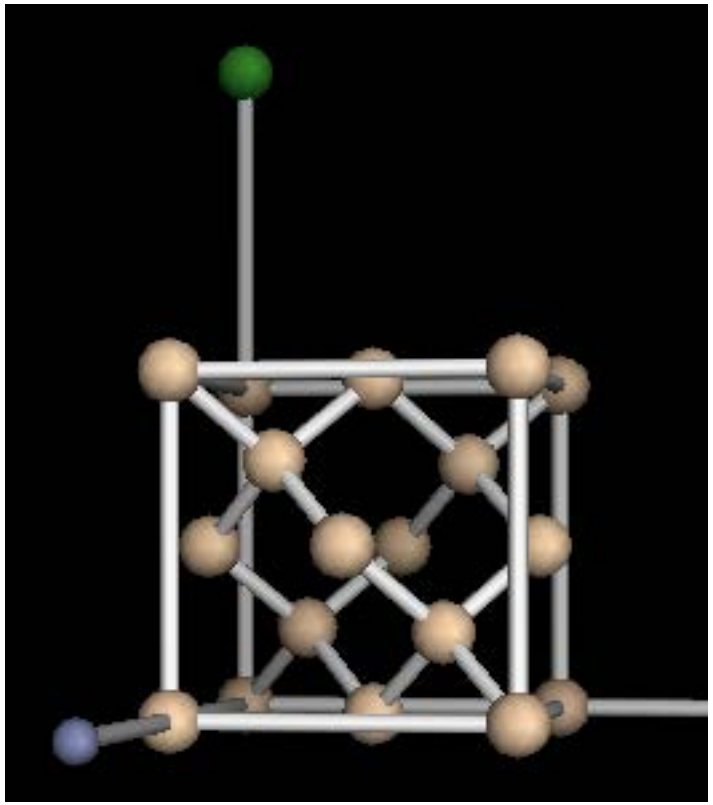
$$N_{atoms} = \frac{8}{\left(5.4307 \times 10^{-10}\right)^3} \quad /\mathrm{m}^3$$

$$= 4.99 \times 10^{28} \ /\mathrm{m}^3$$

$$= 4.99 \times 10^{22} /\mathrm{cm}^3$$

https://nanohub.org/tools/crystal_viewer

Silicon: density



Lattice constant: a = 5.4307 Å

Density = total mass/vol. of unit cell.

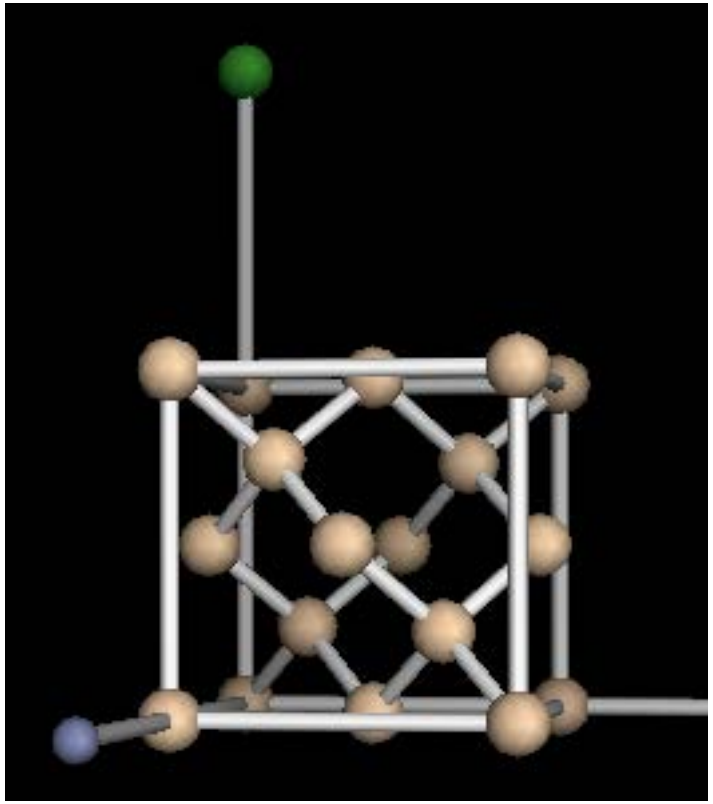
Atomic mass of Si: 28.0855 amu

1 amu = 1.6605 x 10^{-27} kg

$$\rho = \frac{8 \times 28.0855 \times 1.6605 \times 10^{-27}}{\left(5.4307 \times 10^{-10}\right)^3} \quad \text{kg/m}^3$$

$$\rho = 2.3296 \ \text{g/cm}^3$$

Silicon: NN spacing



Lattice constant: a = 5.4307 Å

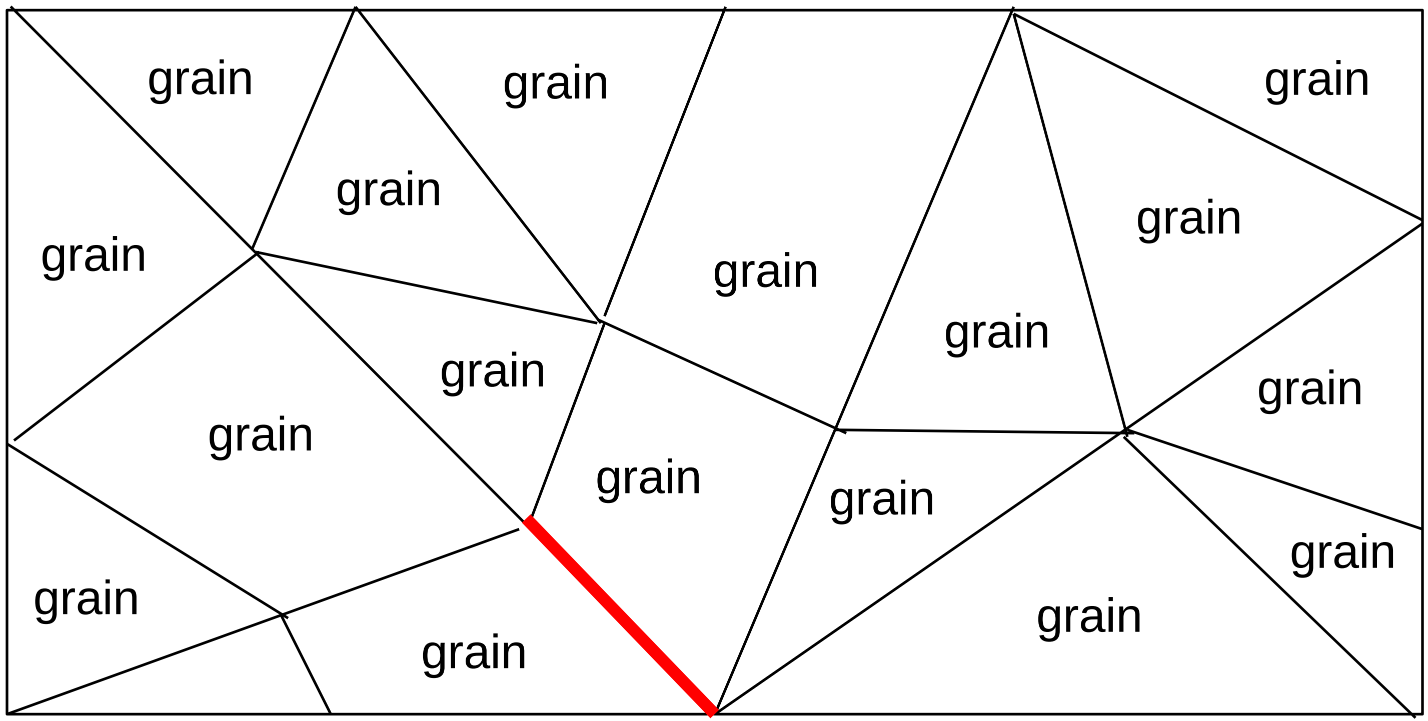
Body diagonal = sqrt(3) a.

NN spacing = sqrt(3)a/4

NN = 2.35 Å

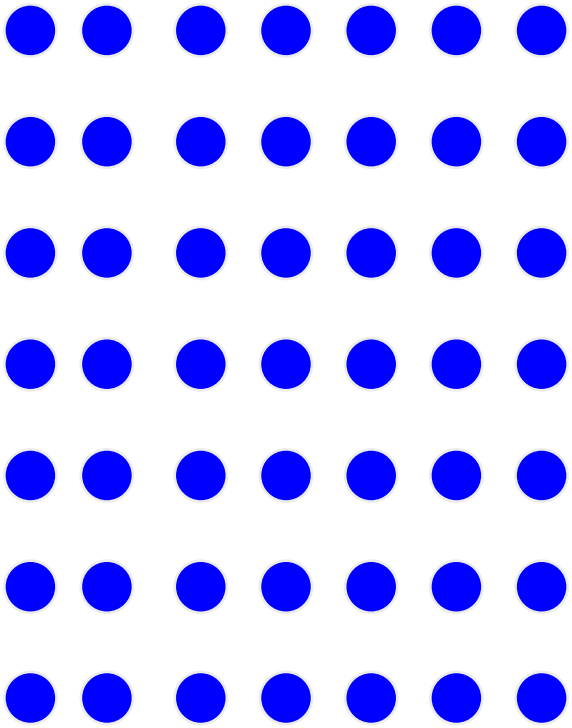
https://nanohub.org/tools/crystal_viewer

Polycrystalline materials

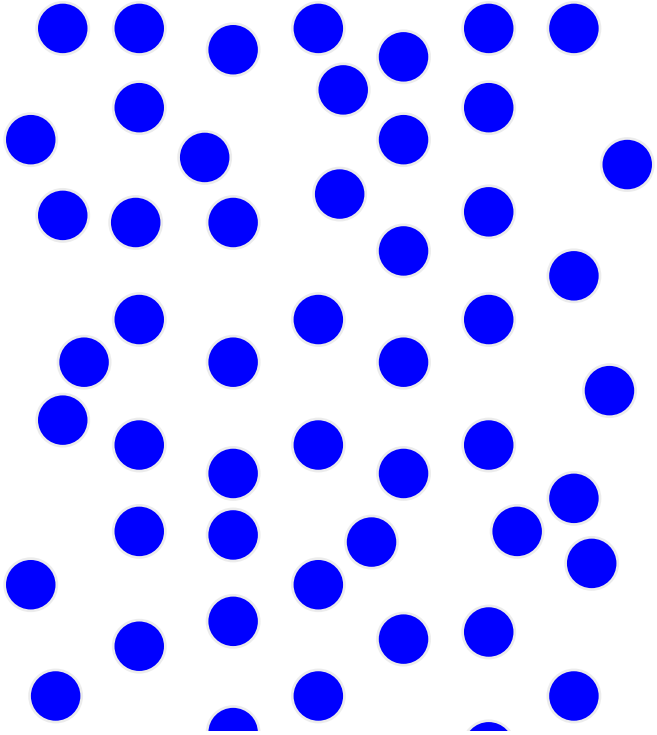


Each grain is crystalline, but the grains are oriented differently.

Crystalline vs. amorphous



Crystal: long range order.



Amorphous: no long range order, but often short range order.

Crystalline, polycrystalline, and amorphous

Crystalline semiconductors are the most expensive, but they are the highest quality because they have the fewest defects.

Polycrystalline semiconductors are less expensive, but grain boundaries can impede current flow. They are used when the highest quality is not needed, but cost is important (e.g. solar cells).

Amorphous semiconductors are the least expensive, but their electrical properties are the poorest. They are used when cost is a critical consideration (e.g. flat panel displays).

Summary

Semiconductors crystalize in specific structures (e.g. the diamond lattice for Si and Ge).

Crystalline, polycrystalline, and amorphous semiconductors are all used – depending on cost and performance considerations.

We will focus on crystalline semiconductors, but the general concepts apply to polycrystalline and amorphous semiconductors as well.