

EE2800 Assignment 1

Due: 9:00 AM, Feb. 20, 2024

1. Considering the following solid materials, write down their relevant solid forms: single-crystalline, poly-crystalline, or amorphous. (10 marks)
 - a. Si ingot
 - b. Raw material for the Czochralski (CZ) growth of Si
 - c. Diamond in a ring
 - d. Gate SiO_2 in a MOSFET
 - e. Quartz
2. Calculate the Miller indices for the crystal planes shown in the below figure. (15 marks)

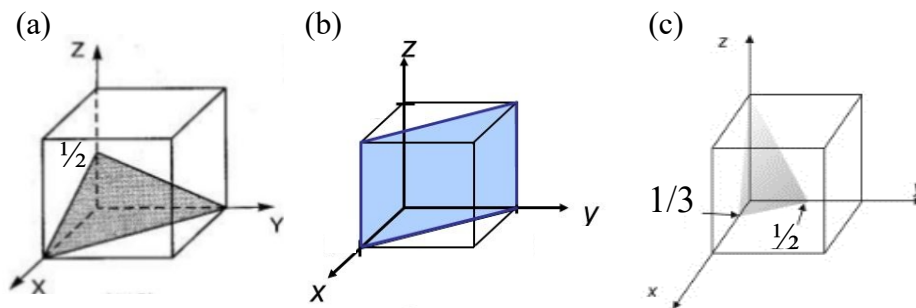


Figure 1. Various crystal planes in a cubic lattice

3. In class we discussed the covalent bonds in a Si crystal and the effects of n/p-doping using the planar (2D) picture shown in Fig. 2. We also mentioned that although this is a very clear way of illustration, it is indeed not correct because the real Si crystal sits in a 3D space. (15 marks)
 - a. Using your knowledge on the 3D structure of Si crystal, draw the actual 3D arrangement of a Si atom and its nearest neighbors (how many are there in total?). In your plot, please also include the outer-shell electrons that form the covalent bonds, in a similar way as in Fig. 3. (5 marks)
 - b. Now consider the case where the central Si atom in your plot is replaced by a doped Boron atom, re-draw the 3D arrangement of this Boron atom with its nearest neighbors, **and** the locations of outer-shell electrons/holes. (5 marks)
 - c. In your plot, which three atoms form a (111) plane, and which three atoms form a (110) plane? Please illustrate clearly in the plot. (5 marks)

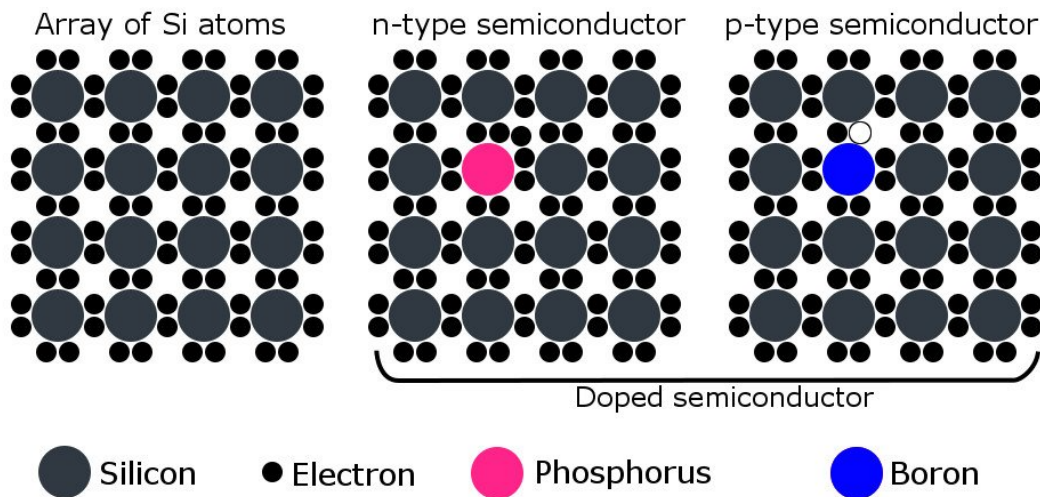


Figure 2. Planar schematic illustration of intrinsic/doped Si crystals.

4. Consider a simple cubic crystal structure shown in Fig. 3, with a lattice constant of a . (15 marks)
 - a. Illustrate the (210) plane of this crystal. (Redraw Fig. 3 on your answer sheet before illustration) (5 marks)
 - b. Calculate the areal density of atoms on the (210) plane, which is defined as the number of atoms per unit area. (10 marks)

Note: as we discussed in class, the areal/volume density can only be calculated within a repeating unit cell. If your initially drawn area does not form a repeating unit, enlarge it until you see the periodicity.

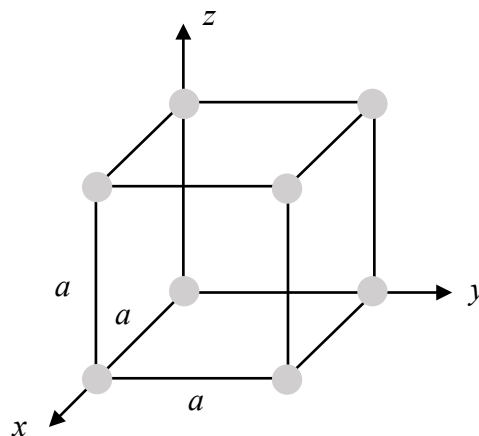


Figure 3. A simple cubic crystal structure.

5. In class, we have given the primitive cells of BCC and FCC lattices, which are also copied here as Fig. 4. The primitive basis vectors of the two primitive cells can be written as:

BCC lattice: $\mathbf{a} = \frac{a}{2}(-\hat{i} + \hat{j} - \hat{k})$, $\mathbf{b} = \frac{a}{2}(-\hat{i} + \hat{j} + \hat{k})$, and $\mathbf{c} = \frac{a}{2}(-\hat{i} - \hat{j} + \hat{k})$

FCC lattice: $\mathbf{a} = \frac{a}{2}(-\hat{i} + \hat{j})$, $\mathbf{b} = \frac{a}{2}(\hat{j} + \hat{k})$, and $\mathbf{c} = \frac{a}{2}(-\hat{i} + \hat{k})$

(30 marks)

- a. Using proper vector analysis, calculate the volumes of the BCC and the FCC primitive cells, respectively. (12 marks)

Hint: the volume formed by three basis vectors can be calculated as $\mathbf{a} \cdot (\mathbf{b} \times \mathbf{c})$

- b. Following the definition, each primitive cell should only own one atom. Using the above results, calculate the atomic volume densities of the BCC and the FCC lattices (10 marks).
- c. Re-calculate the atomic volume densities by counting the number of atoms in the original cubic cells (the conventional unit cell). Do your results in part b) and part c) match with each other? (8 marks)

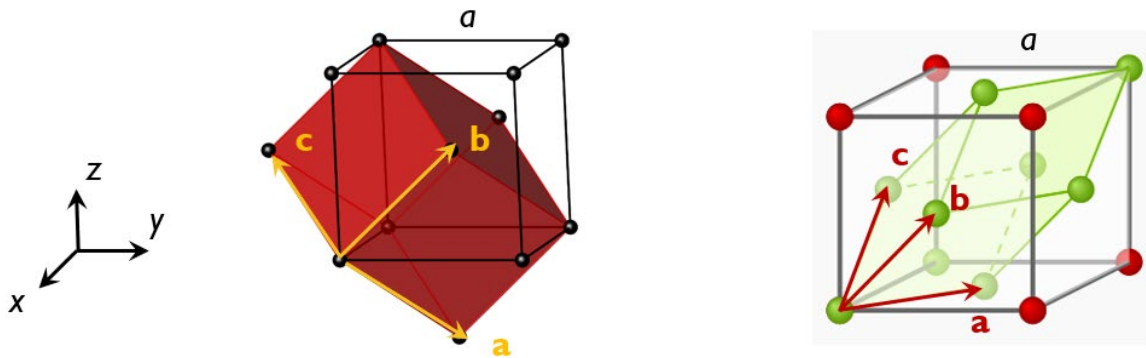


Figure 4. Primitive cells of a BCC and an FCC lattice.

6. In class, we have discussed the quantum models of electrons. For a Si atom with an electron configuration of $1s^2 2s^2 2p^6 3s^2 3p^2$, write down the four quantum numbers (n, l, m, s) of the six 2p electrons ($2p^6$). (15 marks)

Note: the six electrons do not have the same quantum numbers. Explicitly write down the quantum numbers of the six electrons.