EE20011 Introduction to Physical Electronics

Fall 2025

Midterm Exam

October 22, 2025

Wednesday 10:00 – 11:30 am

- **CLOSED BOOK**
- **Show all your work! Partial credit may be given.**
- **Use a calculator but no cell phones.**
- **You have 1.5 hours to complete this exam.**
- **There are total of 6 problems.**

Problem	Score Assigned	Score Earned
1 (T, F)	30	
2	15	
3	10	
4	15	
5	15	
6	15	
Total	100	

GOOD LUCK!

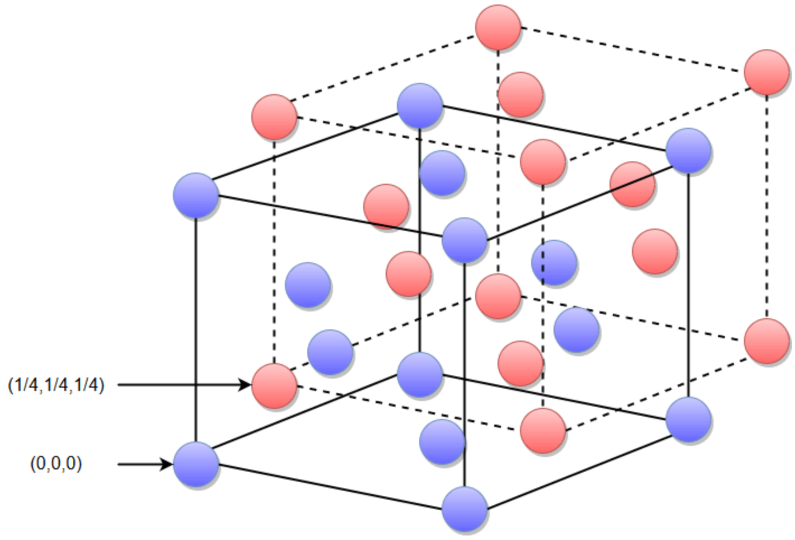
Problem 1. Conceptual True/False (30 points (3 points each))

Read following descriptions and answer with writing T or F depending on your decision. Correct *the inclined part* when your answer is F.

		T/F	Corrections
1	The atom density of a (110) surface in a Si crystal is *less than* that of (111) surface.	F	larger than
2	Regarding a particle in a 1-D infinite potential box, the energy difference of eigenstates n and n+1 becomes *the larger* as the mass m decreases.	T	
3	Since effective mass of electron is smaller than that of hole in silicon, the intrinsic Fermi level is located slightly *below* the mid-energy of the bandgap.	F	above
4	In general, the density of states in energy space *is not dependent* on energy.	F	is dependent
5	Effective mass of electrons at the top of the valance band in silicon has *negative* value and that of hole has *positive* value.	T	
6	The intrinsic carrier density of n-type Si is usually *much smaller* than the extrinsic carrier density at room temperature but becomes larger at above 500K.	T	
7	In a n-type Si semiconductor, the most of the electrons in the conduction band are created *with creating holes* in the valance band.	F	without
8	Minority carrier concentration of a p-type semiconductor *decreases* as the accepter doping density increases.	T	
9	In a Si n-n^+ junction device in an equilibrium of which the left half region is doped with 10^{16} cm^{-3} n-type impurities and the right half is doped with 10^{18} cm^{-3} n^+-type ones, the conduction band edge(bottom) is *closer to* the Fermi level in the right half than in the other half.	T	
10	The n_0p_0 product of a large bandgap semiconductor is *larger* than that of a small bandgap semiconductor.	F	smaller

Problem 2. Diamond Structure (15 points)

Si has the diamond structure which is considered as interpenetrated two face centered cubic lattices as shown the figure below. The atomic constant is 5.45A.



a) Find the Si atomic distance. (SQRT(3)/4) x 5.45 = 2.36 A

b) Find the distance to the second nearest neighbor atoms. (SQRT(2)/2) x 5.45 =3.85

c) How many nearest neighbors does a Si atom have? The number is 4.

Problem 3. Density of states (10 points)

Show that the energy density of states of electrons (effective mass m) in 2-dimensional space is given as follows.

$$g(E) = \frac{m}{\pi\hbar^2}$$

Problem 4. E-k diagram in Silicon (15 points)

The minimum energy in the conduction band of silicon is appeared in the [100] direction in k-space. The energy in this one dimensional direction near the minimum value can be approximated by $E_{k(Conduction)} = E_C + E_{c1}(k - ko)^2 + E_{c2}(k - ko)^3$. The energy near the maximum value at k = 0 in the valance band can be approximated by $E_{k(Valence)} = E_V - E_{v1}k^2 + E_{v2}k^3$.

This is indirect bandgap material since the bottom of the conduction band and the top of the valance band are not appeared at the same k.

(a) Is this a direct bandgap semiconductor or an indirect bandgap one? Explain why?

(b) Find the bandgap of this semiconductor? Ec - Ev

(c) What is the effective mass for a hole in the top of valance band?

hbar^2/2/Ev1

Problem 5. Silicon at T =300 K is doped with boron atoms such that N(boron) = 5×10^{15} cm^{-3}. Assume that $n_i = 1.5 \times 10^{10}$ cm^{-3} at room temperature. Hint: The boron is a group III material. **(15 points)**

(a) Determine n_0, p_0 in cm^{-3}. p0 = 5 x 10^15, n0 =4.5 x 10^4

(b) Is this semiconductor in extrinsic region or intrinsic region at room temperature? Extrinsic region

(c) Determine $E_{Fi} - E_F$ in eV.

p0 = ni exp((Efi - Ef) /kT)

Efi-Ef = kT ln (p0/ni)
= 26 meV ln (5/4.5 x 10^11)
= 661 meV

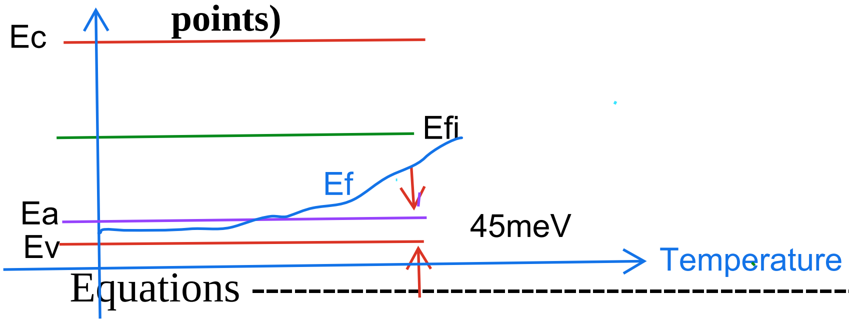
Problem 6. Answer the following questions briefly. (less than 4 lines each) (15 points)

a) When do we use Maxwell-Boltzmann distribution instead of the Fermi-Dirac one for electrons? (Non-degenerate semiconductor approximation) **(5 points)** | E-Ef | >> kT

b) Explain the effective density of states of electron. **(5 points)**

All energy states in the conduction band are assumed to be at the bottom level of the conduction band Ec.

c) Consider a semiconductor which is doped with 10^{16} cm^{-3} boron with 45meV binding energy. Draw the band diagram indicating the accepter level. **(2 points)** Draw the Fermi level in the bandgap as the temperature increases from 0 K to 500 K. **(3 points)**



Equations --

$$\boxed{n_0 = N_C \exp\left[\frac{-(E_C - E_F)}{kT}\right]} \quad N_C = 2\left(\frac{2\pi m_n^* kT}{h^2}\right)^{3/2}$$

$$\boxed{p_0 = N_v \exp\left[\frac{-(E_F - E_v)}{kT}\right]} \quad N_v = 2\left(\frac{2\pi m_p^* kT}{h^2}\right)^{3/2}$$

$$\boxed{n_0 = n_i \exp\left[\frac{(E_F - E_{Fi})}{kT}\right]}$$