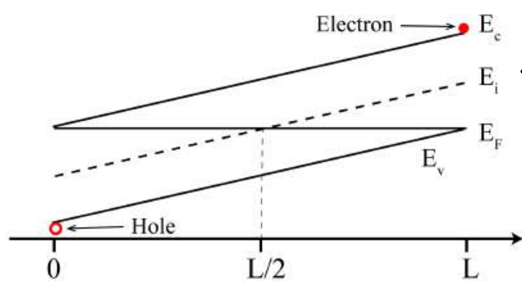
ISD 2023 - Week 3 Assignment

There are 10 questions for a total of 20 marks.

For Q1-Q2: Consider a silicon sample maintained at 300 K, and the schematic of the energy band diagram is illustrated as shown in the figure. Consider E_F as the reference energy level.



→ Constant

$$q\mathscr{E} = \frac{dE_c}{dx} = \frac{dE_v}{dx}$$

1. (2 marks) Do equilibrium conditions prevail? Why?

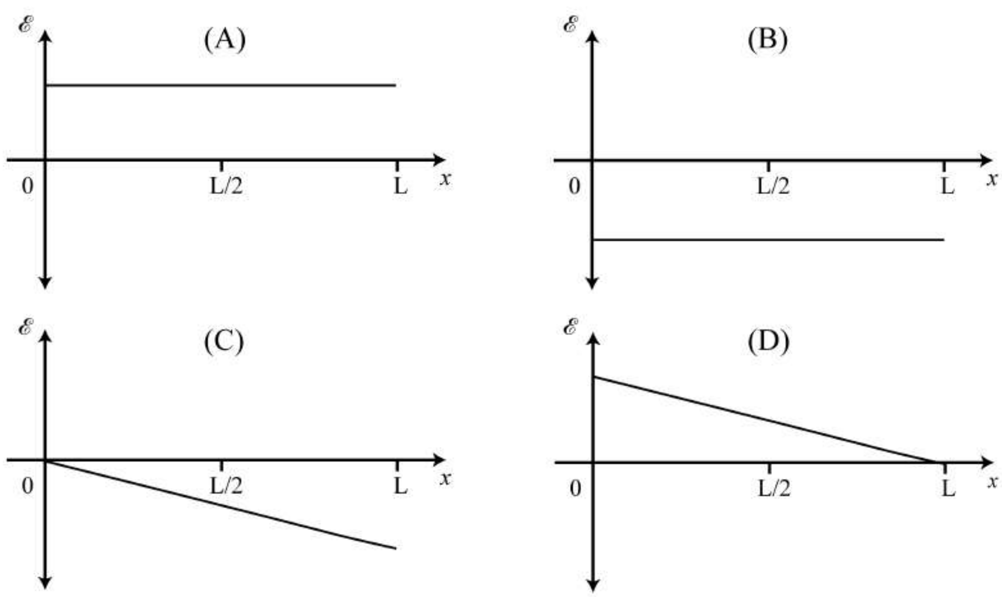
   A. No. Because energy bands E_c, E_v are bending.

   B. Yes. Because energy difference between E_c and E_i, E_i and E_v is same.

   C. Yes. Because Fermi level E_F is constant along x

   D. No. Because E_F is not parallel to E_c

2. (2 marks) The sketch of electric field ($\mathscr{E}$) inside the Si as a function of x is best described by ______



A. A B. B C. C D. D

630nm ⟷ 1.97eV

3. (2 marks) A sample of semiconductor has a cross-sectional area of $1\ cm^2$ and a thickness of $0.1\ cm$. A number of electron–hole pairs are generated per unit volume per unit time by the uniform absorption of $1\ W$ of light at a wavelength of $630\ nm$. What is the approximate steady-state excess carrier concentration, if the excess minority carrier lifetime is $10\ \mu s$? Assume each photon creates one electron–hole pair.

   A. $1.96 \times 10^{19}\ cm^{-3}$

   B. $1.96 \times 10^{15}\ cm^{-3}$

   C. $3.17 \times 10^{14}\ cm^{-3}$

   D. $3.17 \times 10^{19}\ cm^{-3}$

$g = \Delta n/\tau$

$\Delta n = g.\tau.$

$= 3.17\times10^{19}\times10^{-5}$

$= 3.17\times10^{14}/cm^3$

$g = \frac{1}{1.97\times1.6\times10^{-19}} \times \frac{1}{0.1\,cm^3}.$

$= 3.17\times10^{19}/cm^3/sec.$

4. (2 marks) The approximate thermal velocities of electrons and holes in silicon at room temperature is ______ $\times 10^7\ cm/s$? Assume the electron effective mass $m^* = 0.26 m_0$.

   A. 23 B. 10 **C. 2.3** D. 1

$\frac{1}{2}mv^2 = \frac{3}{2}KT$

$v = \sqrt{3KT/m}$

> **Reflect and remember:** Average kinetic energy of the carrier is $\boxed{KE = \frac{3}{2}kT}$. Electrons and holes move at the thermal velocity but not in a simple straight-line fashion. Their directions of motion change frequently due to collisions or scattering with imperfections in the crystal. The mean free time between collisions is typically in the order of ps, and the distance between collisions is a few tens of nm.
>
> The **net** or average thermal velocity is zero. Thus, thermal motion does not create a steady electric current, but it introduces a thermal noise.

5. (2 marks) In a very long p-type Si bar with cross-sectional area $= 0.5\ cm^2$ and $N_A = 10^{17}\ cm^{-3}$, holes are injected such that the steady-state excess hole concentration is $5 \times 10^{16}\ cm^{-3}$ at $x = 0$. Assume that $\mu_p = 500\ cm^2/Vs$, $kT/q = 26\ mV$ and $\tau_p = 10^{-10}\ s$. What is the hole diffusion length L_p in (μm)?

   A. 13 **B. 0.36** C. 36 D. 0.13

$L_p = \sqrt{D\tau_p} = \sqrt{\mu_p KT/q \cdot \tau_p} = \sqrt{500\times0.026\times10^{-10}}$

$= 3.6\times10^{-5}\ cm$

> **Reflect and remember:** Minority carrier diffusion length is the average distance a minority carrier diffuses before recombining. It depends on both the diffusion coefficient (mobility) and minority carrier lifetime. In a device like solar cells, photoexcited carriers must be able to move from the point of generation to where they can be collected. Longer diffusion lengths result in better performance.

6. (2 marks) Consider a n-type semiconductor with non-uniform doping $N_d = 10^{16} e^{-x/L}$ where $L = 200\ \mu m$ at T=300 K. Determine the induced electric field (V/cm) in the semiconductor at $x = 100\ \mu m$.

   A. 1

   B. 1.3

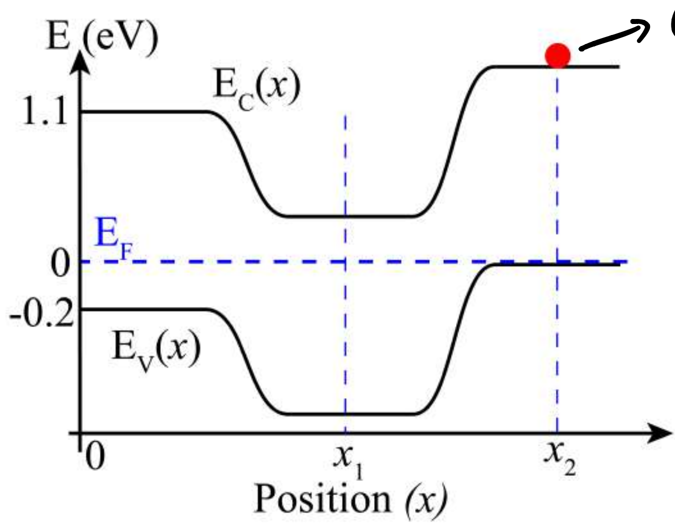
   C. 0.02

   D. 200

$$\mathcal{E} = -\frac{kT}{q} \cdot \frac{1}{N_d} \cdot \frac{dN_d}{dx} = \frac{kT}{q} \cdot \left(\frac{1}{L}\right) = 0.026 \times \frac{1}{200\mu m}$$
$$= 1.3\ V/cm$$

Reflect and remember: In most of the cases, we use/mention uniform doping of the semiconductor, and there is no carrier density gradient; hence the built-in field is zero. On the other hand, there is a special case of non-uniform doping in the semiconductor that varies with the position (x), such that there is a diffusion of carriers leading to a fixed space charge, and, thereby, a non-zero built-in field is created.

(For Q7-Q9): The energy band diagram of a semiconductor is shown below.



@ CB min KE = 0.

@ x_1 → E_F near to CB ⇒ n-type

7. (2 marks) At position x_1, what is the type of semiconductor?

   A. n-type B. p-type C. intrinsic D. Cannot be determined

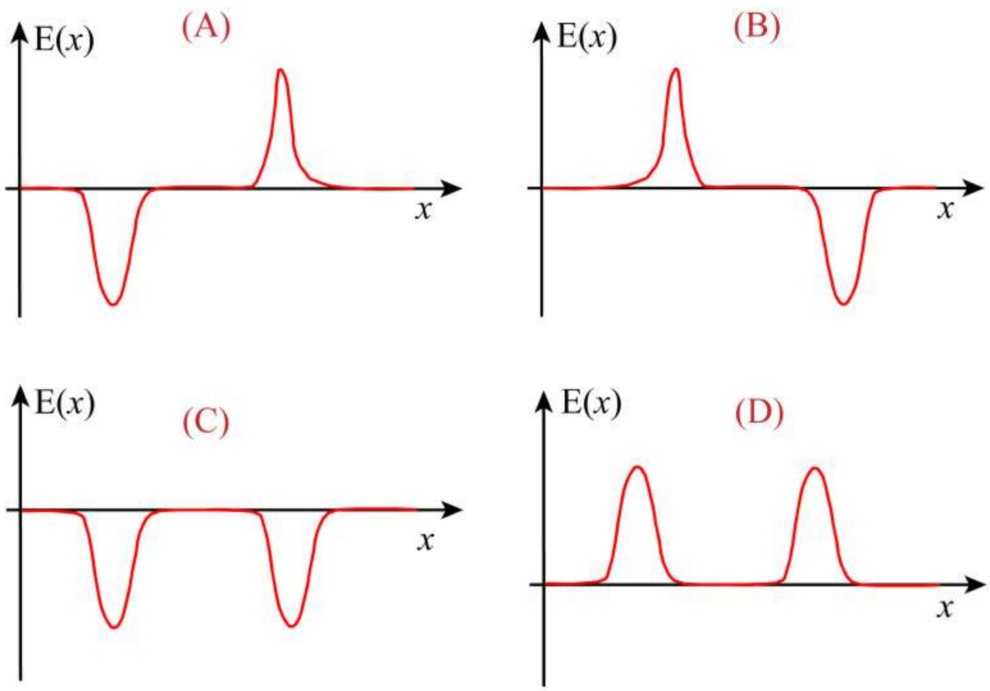
8. (2 marks) At position x_2, what is the kinetic energy of the electron (red) in eV?

   A. 1.1 B. 0.9 **C. 0** D. 1.3

9. (2 marks) Based on the band diagram, which of the following describes approximate electric field vs position?

   A. A B. B C. C D. D

$$\mathcal{E} = \frac{1}{q} \cdot \frac{dE_c}{dx}$$



10. (2 marks) **(EC-GATE 2022)** Consider a long rectangular bar of direct bandgap p-type semiconductor. The equilibrium hole density is $10^{17}\ cm^{-3}$ and the intrinsic carrier concentration is $10^{10}\ cm^{-3}$. Electron and hole diffusion lengths are $2\ \mu m$ and $1\ \mu m$, respectively. The left side of the bar (x = 0) is uniformly illuminated with a laser having photon energy greater than the bandgap of the semiconductor. Excess electron-hole pairs are generated ONLY at x = 0 because of the laser. The steady-state electron density at $x = 0$ is $10^{14}\ cm^{-3}$ due to laser illumination. Under these conditions and ignoring the electric field, the closest approximation (among the given options) of the steady state electron density at $x = 2\mu m$, is ______ cm^{-3}.

A. 3.7×10^{13}

B. 6.3×10^{12}

C. 3.7×10^{15}

D. 1×10^{3}

$N_A = p \sim 10^{17}$

$\Delta n(x=0) = 10^{14}$

$n_i = 10^{10}$

$\Delta n(x=2) = ?$

$n_{p_0} = \frac{10^{20}}{10^{17}} = 10^3$

$\Delta n \approx \Delta n(0).\, e^{-x/L_n}$

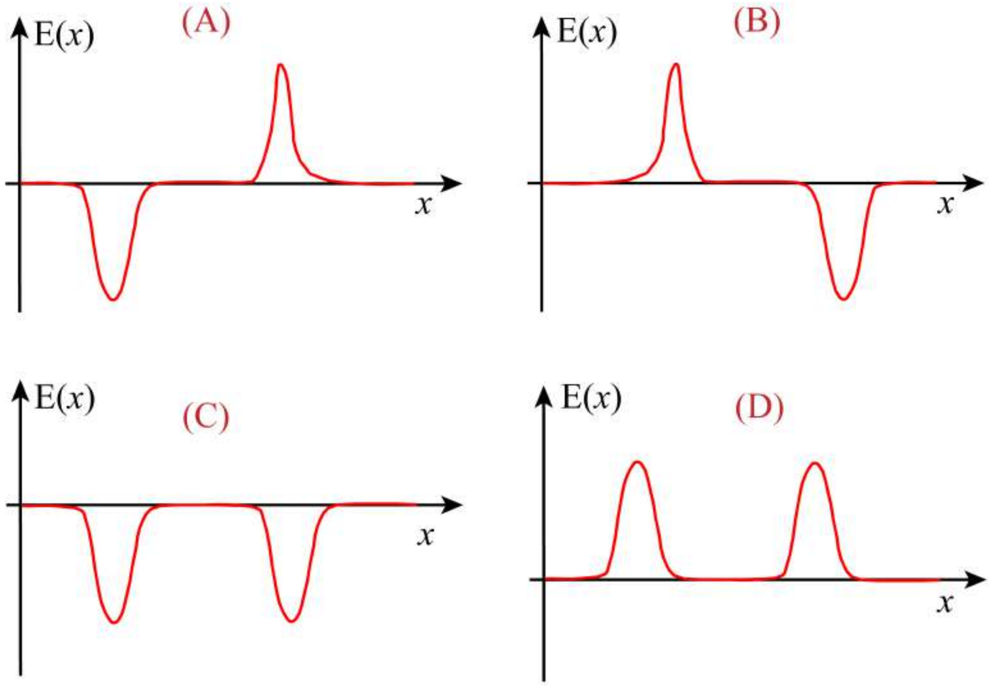
$= 10^{14} .\, e^{-2/2} = e^{-1} .\, 10^{14}$

$= 0.37 \times 10^{14}\ /cm^3$

Usually $n_p(x) = n_{p_0} + \Delta n(0).\, e^{-x/L_n}$

$= 10^3 + 10^{14} .\, e^{-2/2}$

$\simeq 0.37 \times 10^{14}\ /cm^3$



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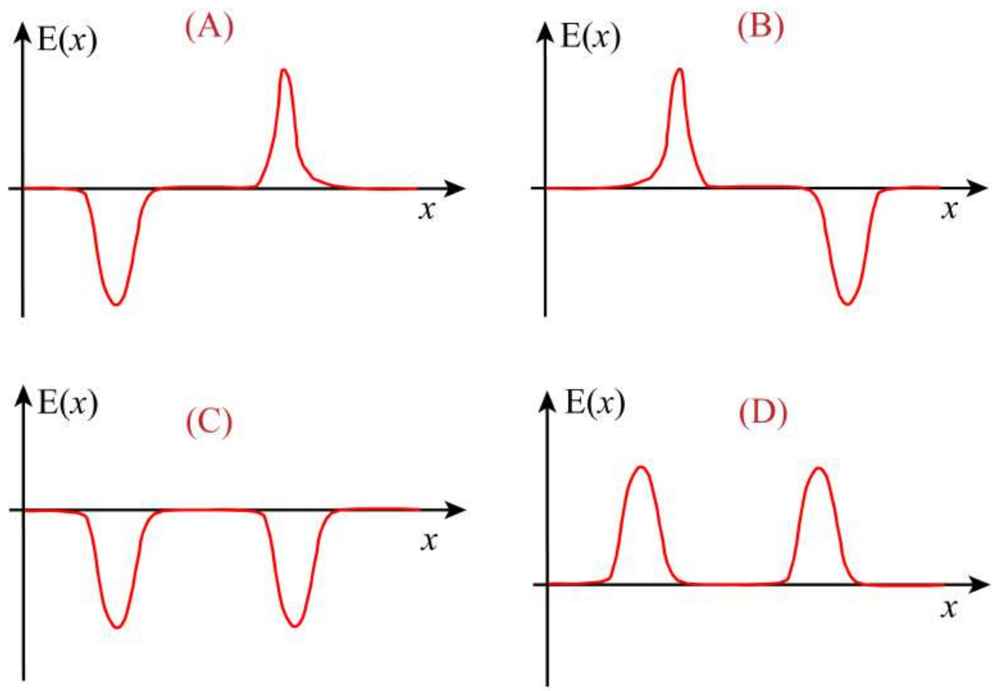

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