University of Sheffield

Department of Electronic and Electrical Engineering

EEE207 Semiconductors for Electronics and Devices

Problem Sheet 2

1. Germanium has a band gap of 0.7eV and, for pure material, the Fermi level lies near the middle of the gap. What is the probability that a state in the upper band is occupied at 0K, 300K, and 500K? Explain the physical significance of these results. What other property of the band structure, other than the probability of occupancy of states, influences the electrical properties of the material?

2. A thermistor made from intrinsic silicon is to be used to control the current surge in a projector when it is switched on. The thermistor has a resistance of 100Ω at room temperature (17°C). When it is connected in series with the projector lamp, at what temperature will its resistance fall to 1.0Ω? Assume that the energy gap for silicon is 1.08eV and that the carrier mobilities do not vary appreciably over the operating range of temperatures. Comment on the result.

3. Intrinsic germanium has a gap energy of 0.72eV and its conductivity is 2.13S m^{-1} at 300K. What is its conductivity at 400K? Comment on the result. Would the conductivities at each of these temperatures be changed if the semiconductor received radiation of wavelength (*a*) 1μm and (*b*) 2μm?

4. A particular semiconductor, which is initially intrinsic with an energy gap, E_g, of 1.1eV, is doped very slightly n-type, in such a manner that the Fermi level is displaced by 10% of the gap energy from its intrinsic position. Compare the conductivities at 20°C before and after doping, assuming carrier mobilities of $\mu_h = 0.05 m^2\, V^{-1}\, s^{-1}$ and $\mu_e = 0.13 m^2\, V^{-1}\, s^{-1}$, commenting on the result.

5. A sample of intrinsic semiconductor has a gap energy of 0.8eV. The resistivity of the sample is found to be 0.028Ω m at 384K and 0.0013Ω m at 556K. Assuming that the electron and hole mobilities are approximately proportional to *the same* certain power of absolute temperature T over this measurement range, find the temperature dependence of the carrier mobilities.

6. In a certain semiconductor the ratio of electron mobility, μ_e, to hole mobility, μ_h, is equal to 10, the number density of free holes is $p = 10^{20} m^{-3}$, and the number density of free electrons is $n = 10^{19} m^{-3}$. The measured conductivity is 0.455S m^{-1}. Calculate the mobilities.

7. A sample of germanium doped with 10^{20} donor atoms per cubic metre and 7×10^{19} acceptor atoms per cubic metre. At the same temperature as the sample, the resistivity of intrinsic germanium is 0.6Ω m. Find the total current density when an electric field of 200V m^{-1} is applied. The electron and hole mobilities in germanium may be assumed to be $0.38 m^2\, V^{-1}\, s^{-1}$ and $0.18 m^2\, V^{-1}\, s^{-1}$ respectively.

8. A sample of germanium is doped with 3 × 10^{21}m^{-3} donor atoms and 4 × 10^{21}m^{-3} acceptor atoms. Calculate the number densities of electrons and holes at (*a*) 300K and (*b*) 400K, commenting on the results. (Assume that the intrinsic carrier number density is $n_i^2 = 3.1\times10^{44}(T/\mathrm{K})^3\exp\left(\frac{-9100}{T/\mathrm{K}}\right)$ m^{-6} in germanium, where (*T/K*) signifies absolute temperature measured in kelvin.)

9. A 10mm × 10mm × 10mm cube of silicon at room temperature has 10^{19}m^{-3} of gallium (p-type) impurities and 1.5 × 10^{19}m^{-3} of arsenic (n-type) impurities in the material. Determine the resistance of the cube between any two faces, assuming: n_i = 1.5 × 10^{16}m^{-3}; μ_e = 0.12m^2 V^{-1} s^{-1}; and μ_h = 0.05m^2 V^{-1} s^{-1}.

Numerical Answers

1. 0, 1.4 × 10^{-6}, 3 × 10^{-4}
2. 96°C
3. 69.1S m^{-1}; (*a*) σ increases (*b*) σ constant
4. $\sigma_n/\sigma_i = 56$
5. $\mu \propto T^{-1.8}$
6. 0.14m^2 V^{-1} s^{-1} and 0.014m^2 V^{-1} s^{-1}
7. 524A m^{-2}
8. (*a*) 5.6 × 10^{17}m^{-3}, 1.0 × 10^{21}m^{-3}; (*b*) 1.2 × 10^{21}m^{-3}, 2.2 × 10^{21}m^{-3}
9. 1.04kΩ