3.091 OCW Scholar

Self-Asessment

Electronic Materials

Supplemental Exam Problems for Study

Solutions Key

Problem #3

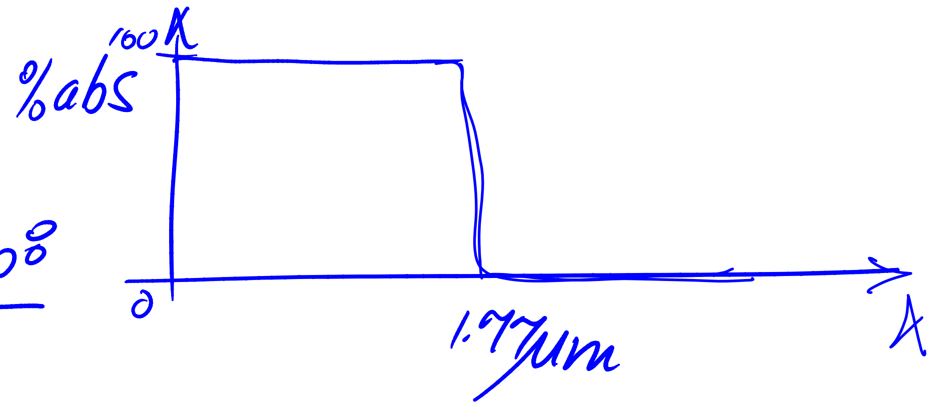
(a) Germanium is a semiconductor with a band gap energy, E_g, of 0.7 eV. Sketch the absorption spectrum of germanium, i.e., % **absorption** *versus* **wavelength**, λ. Show the value of $\lambda_{abs\ edge}$.

$E_g = \frac{hc}{\lambda}$

$\therefore \lambda = hc/E_g$

$= \frac{6.6 \times 10^{-34} \times 3 \times 10^{8}}{0.7 \times 1.6 \times 10^{-19}}$

$= 1.77\ \mu m$



(b) You wish to make *n*-type germanium.

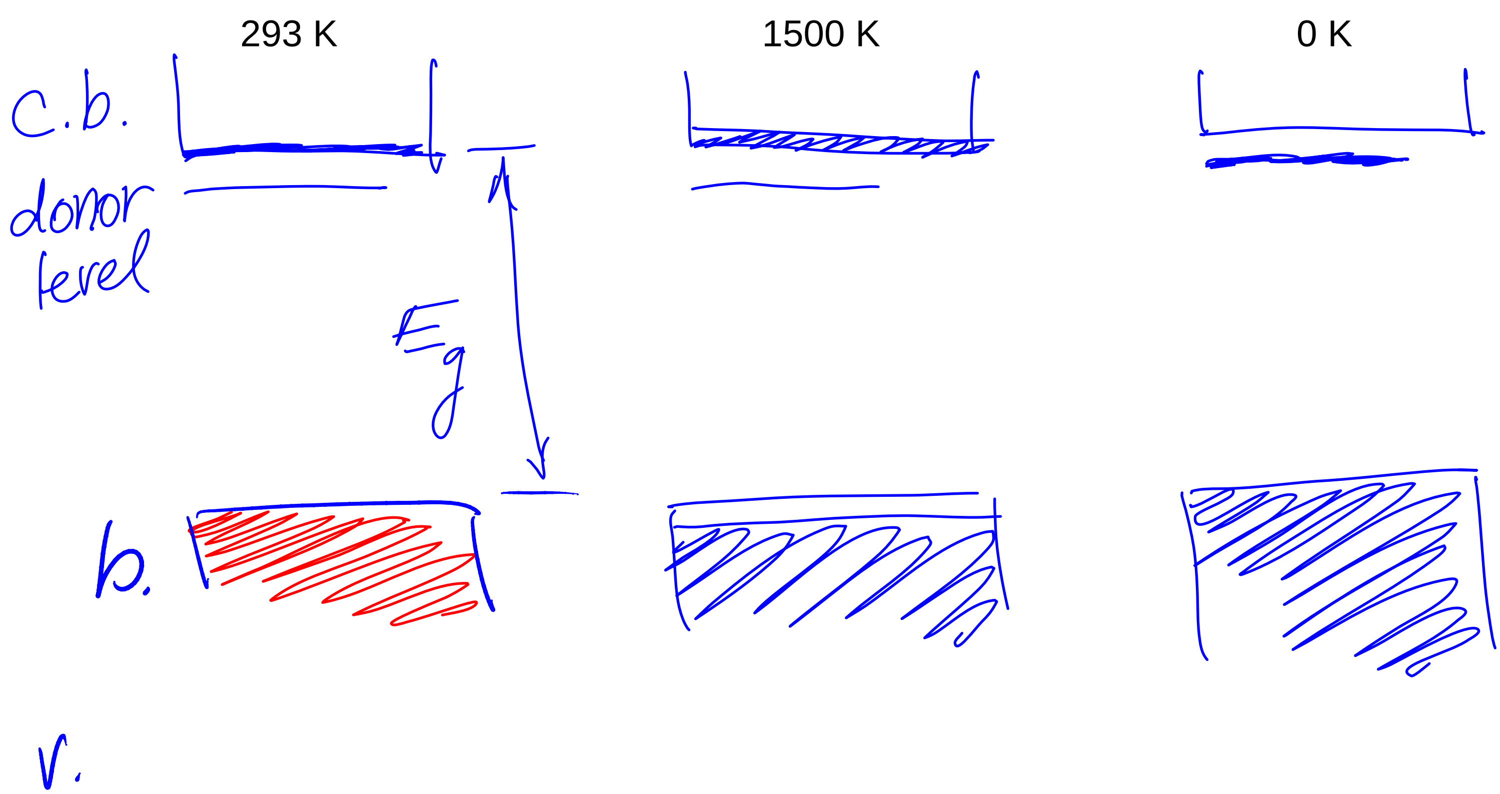
(i) Name a suitable dopant.

P, As, Sb

(ii) Name the majority charge carrier in the doped material.

electron

(iii) Draw the schematic energy-level diagram of *n*-type germanium indicating electron occupancy at ❶ room temperature (293 K); ❷ elevated temperature (1500 K); ❸ absolute zero (0 K). Label the valence band, conduction band, energy gap, and any energy levels associated with the presence of the dopant. Assume that the positions of the energy levels themselves do not vary with temperature. Show electron occupancy by shading.



Problem #3

(a) Germanium (Ge) is a semiconductor with a band gap energy, E_g, of 0.7 eV. Ge has been doped with phosphorus (P) to a level of 3.091 mg P / kg Ge. Calculate the charge-carrier population in the doped material. Express your answer in units of carriers/cm^3.

$$3.091 \text{ mg P} = 3.091 \times 10^{-3} \text{g} = \frac{3.091 \times 10^{-3} \text{g}}{30.97 \text{ g/mol}} \times \frac{N_{Av}}{\text{mol}}$$

$$= 6.01 \times 10^{19} \text{ P atoms/kg Ge}$$

1 carrier / P atom

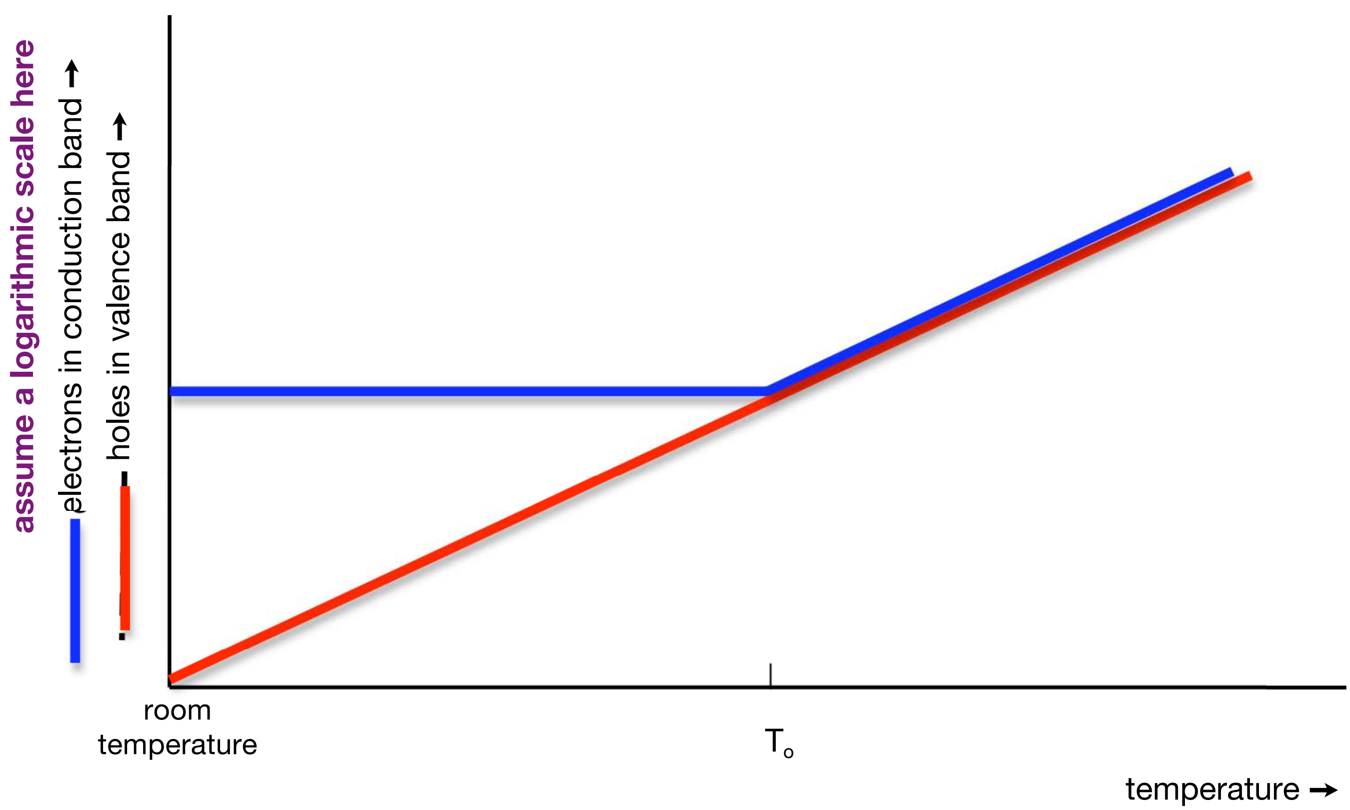
$$\rho_{Ge} = 5.35 \text{ g/cm}^3 \therefore 1 \text{ kg} = 1000 \text{ g occupies } \frac{1000}{5.35} = 187 \text{ cm}^3$$

$$\therefore \text{carrier density} = \frac{6.01 \times 10^{19} \text{ carriers}}{187 \text{ cm}^3} = 3.22 \times 10^{17} \frac{\text{carriers}}{\text{cm}^3}$$

(b) Name the dominant charge carrier in P-doped Ge, and specify whether the material is *p*- or *n*-type.

electron; n-type

(c) For P-doped Ge, on the plot below draw the temperature dependence of ❶ electrons in the conduction band and ❷ holes in the valence band. Label clearly each line. T_o is the temperature at which the contributions to the electrical conductivity from intrinsic and extrinsic behaviors are identical. Be ***qualitative*** – no calculation necessary.



Problem #10

Photovoltaic cells that convert sunlight into electricity are made of silicon (Si) which has a band gap energy (E_g) of 1.1 eV. Night vision systems that identify objects by their thermal radiation have active elements made of indium antimonide (InSb) which has a band gap energy (E_g) of 0.18 eV. Explain the choice of semiconductor in each application.

Photovoltaic cells

- sunlight lies in the region of the electromagnetic spectrum defined by $400 < \lambda < 700$ nm

- to excite electrons by photons requires that $E_g < hc / 700 \text{ nm} = 1.77$ eV

- Si satisfies this requirement

Night vision systems

- thermal radiation at room temperature is centered about $k_BT = 0.026$ eV
- InSb with its E_g of 0.18 eV will capture some of the thermal spectrum

$\left(e^{-E_g/kT} \approx 10^{-3}\right)$ – not great but still works

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