Condensed Matter II

Problem set #8

Spring 2023

Donor impurities in GaAs

Background

We consider the direct band gap semiconductor GaAs, with $N_d = 10^{16}.\text{cm}^{-3}$ hydrogenic donor impurities. The following properties are given:

- direct band gap: $E_g = 1.40$ eV.
- $m_e^* = 0.07 m_0$ for the conduction band effective mass.
- $m_h = 0.7 m_0$ for the valence band holes effective mass.
- $\epsilon_{\text{GaAs}} = 15$

Questions

Temperature dependence of the Fermi level

(i) Compute the concentration of intrinsic carriers in the material at room temperature, and compare it with the concentration of impurities.

(ii) Compute the ionization energy E_d of the impurities.

(iii) Establish the expression of the density of carriers, as a function of T, E_d, N_d, E_F.

(iv) From the previous expression, deduce the expression for $E_F(T)$. Calculate the value of $E_F(T)$ for $T = 300\text{K}$ and $T = 30\text{K}$.

Transport properties

(i) Compute the electron and hole carrier concentrations at room temperature and at 30K.

(ii) What is the critical doping, above which an impurity band would appear as a result of the presence of substitutional impurities in GaAs? (you may use the given value of the Bohr radius $a_0 = 5.3 \times 10^{-11}\,\text{m}$). What is the main difference between the impurity band scenario and the the isolated impurity scenario?