High-speed Electronics 2019 – Exercise 1

”Basic Properties”

1. a) Calculate E_F-E_c for a 3D $In_{0.53}Ga_{0.47}As$ at $N_d=10^{16}$,10^{18} and 10^{19} cm^{-3} for T=300K.
   b) Calculate the number of holes at each N_d from E_F-E_V.
   c) Calculate n_0p_0 and compare with the mass action law. When is the mass action law valid?

2. To describe the carrier concentration in a semiconductor one can use the Fermi-Dirac integral: $F_j(\eta_F) = \frac{1}{\Gamma(j+1)}\int_0^\infty \frac{x^j dx}{1+e^{x-\eta_F}}$, where the order $j = D/2 - 1$ is given the dimensionality D = 0, 1, 2, 3 of the system, while $\eta_F = (E_F - E_C)/k_BT$. Assuming GaAs with $E_F - E_C$ = 0.1 eV, use this integral to calculate
   a) $n_{1D} = N_{1D}F_{-\frac{1}{2}}(\eta_F)$
   b) $n_{2D} = N_{2D}F_0(\eta_F)$
   c) $n_{3D} = N_{3D}F_{\frac{1}{2}}(\eta_F)$
   d) Plot and compare n_{1D}/N_{1D} n_{2D}/N_{2D} and n_{3D}/N_{3D} in the range $-10 < \eta_F < 10$. What is the general trend?

3. A single subband 2D quantum well has $n_s = 3\times10^{12}$ cm^{-2} at a low temperature. Obtain E_F-E_1 if the quantum well is made of
   a) InAs, b) GaAs or c) $In_{0.53}Ga_{0.47}As$.

4. For a double gate FET with an oxide thickness t_{ox} = 2 nm and L_g = 10 nm – estimate the thickest quantum well that can be utilized with reasonable small short channel effects? You can assume $\varepsilon_r = \varepsilon_{ox} = 12$.

5. For a single subband $In_{0.53}Ga_{0.47}As$ quantum well FET with t_{well} = 5 nm, t_{ox} = 2 nm (ε_{ox} = 20),
   a) Calculate the oxide capacitance
   b) Calculate the quantum capacitance
   c) Calculate the total gate capacitance

6. A single subband quantum well FET has an effective mass m^* and a high-k dielectric with thickness t_{ox} and dielectric constant ε_r = 25.
   a) Ignoring effects due to band bending inside the quantum well, derive an expression for the total gate capacitance, C_G.
   b) For GaN ($m^* = 0.20m_0$) plot C_G as a function of $0.1 < t_{ox} < 10$ nm.
   c) For InAs ($m^* = 0.023m_0$) plot C_G as a function of $0.1 < t_{ox} < 10$ nm.
   d) Calculate C_G / C_{ox} for GaN and InAs as function of t_{ox} and compare the two materials. In which material is the gate stack most scalable? Why is this?