Written Examination EITP01 2018-03-15

Useful constants:

$$\hbar = 1.055 \times 10^{-34}\ Js$$

$$k_B = 1.381 \times 10^{-23}\ J/K$$

$$m_0 = 9.109 \times 10^{-31}\ kg$$

$$\epsilon_0 = 8.85 \times 10^{-12} Fm^{-1}$$

$$e = q = 1.602 \times 10^{-19}\ C$$

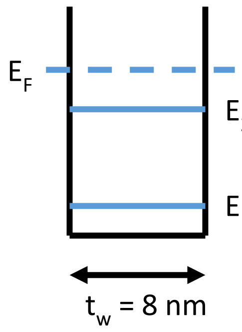
1. Band structure

a) Derive the density of states of a two-dimensional single band system:

$$D_{2D}(E) = \frac{m^*}{\pi\hbar^2}$$

starting from $E(k) = \frac{\hbar^2}{2m^*}\left(k_x^2 + k_y^2\right)$, and k-spacing of $\frac{2\pi}{L}$.

b) For the infinite 2-dimensional quantum well drawn to the right with $m^* = 0.04m_0$ and sheet carrier concentration of 6×10^{12} cm^{-2}, calculate the Fermi energy with respect to the bottom of the conduction band.



2. Ballistic Transistor

a) In a long-channel device the output current saturates above a certain V_{DS} because of channel pinch-off at the drain edge of the channel. However, in ballistic transistor the current saturates for a different reason. Explain.

b) What determines the magnitude of I_{DS} in saturation (for a given V_{GS}) in a 2D single-band fully ballistic MOSFET?

3. An InGaAs single subband quantum well FET has $t_w = 8$ nm, W = 20 µm, $t_{ox} = 5$ nm, $\varepsilon_{ox} = 15$, $\varepsilon_r = 13$ and L_G = 40 nm and is designed to have $\lambda << L_G$. Assume $R_S = R_D = R_G \approx 0$.

a) Calculate the intrinsic C_{GG} at V_{DS} = 0 V **and** in saturation.

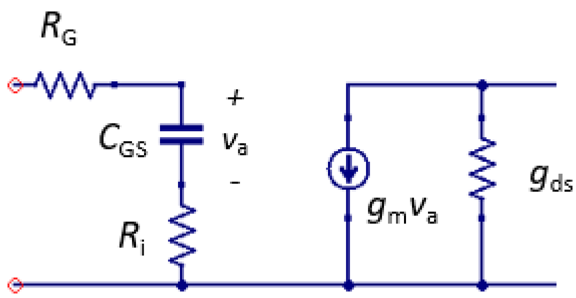
b) How would the capacitances be divided into C_{GS} and C_{GD} for the two cases?

c) For $V_{GS} - V_T$ = 0.5 V, calculate the ballistic I_{DS}.

d) If the device growth has problems so that the long channel mobility is only μ_n = 500 cm^2/Vs, how much lower would be drain current be? Use the thermal velocity $v_T = 2.6 \times 10^7 cm/s$.

e) If the quantum well thickness is decreased by a small amount t_w, without increasing any scattering, would the current calculated at $V_{GS} - V_T$ = 0.5 V change as compared with the result in c)? Motivate you answer!

4. **For a device with a very small (i.e. negligible C_{GD}), the simplified NQS hybrid-π model can be drawn as below. R_G is the gate metal resistance and R_i the channel resistance.**



C_{GS} = 20 fF, g_m = 20 mS, g_{ds} = 5mS, R_G = 10 Ω and a noise excess factor $\gamma = 1$.

a) Determine the y-parameters.

b) Calculate MSG, and explain why this is a not a good metric for the device! Instead, which gain metric should be used for power amplifier design?

c) Calculate f_T.

d) Calculate f_{max}.

e) If the device is cooled so that the *extrinsic* gate resistance becomes superconducting ($R_G \approx 0\Omega$), what is the maximum f_{max} now?

f) Calculate the minimum noise figure at $f = 0.1 f_T$ with and without a superconducting gate.

5. **Consider a two-port system with input impedance of $Z_{in} = 80 + j\omega 5 \times 10^{-9}\ \Omega$ connected to a generator with an impedance $Z_G = Z_0 = 50\ \Omega$.**
Use a Smith chart to solve the following tasks:

a) What fraction of the power incident on the input is reflected at $\omega = 10$ GHz?

b) While operating at the frequency $\left(f = \frac{\omega}{2\pi}\right)$ in a) one inserts a 57.1 cm long loss-less transmission line ($\epsilon_r = 3$) between the two-port and generator. Calculate the new input impedance as seen by the generator.

c) Derive a matching network using only reactances (C, L) for the input of the two-port that works at this frequency.