Task 1 (5p)

The probability of an electronic state in a semiconductor material being filled at $E_C + kT$ is equal to the probability of a state being empty at $E_C + 3kT$. Use this given information, to determine where the Fermi level is located?

a) Use a graphical method to solve the problem. (3p)
b) Provide an exact answer. (2p)

Task 2 (5p)

The photo in Fig. 1 shows a piece of a semiconductor wafer with a pattern consisting of small integrated circuits. What can you tell about the bandgap energy and why. Hint: color appears yellowish in the range 570 – 590 nm.

Figure 1. Piece of semiconductor wafer. Hint: color appears yellowish in the range 570 – 590 nm.

Task 3 (5p)

Derive the Einstein relationship, that relates the diffusion constant to the mobility of a semiconductor at temperature *T*. Recall that the electron concentration is given by

$$n = N_C e^{-(E_C - E_F)/kT}$$

where all symbols have their usual meaning.

Task 4 (5p)

Explain the principle behind a so called ohmic contact, motivate the choice of contact metal and doping concentration in the silicon substrate. Use at least one band diagram in your solution.
Extra hint: What type of IV-curve does one expect from theory, is this in agreement with real case observations?

Task 5 (5p)

Figure 2 below shows the total charge per unit area for a MOS capacitor at 300 K. The silicon substrate has P-type doping.

a) What is the oxide (SiO_2) thickness? (2p)

b) What is the doping concentration in the substrate? (3p)

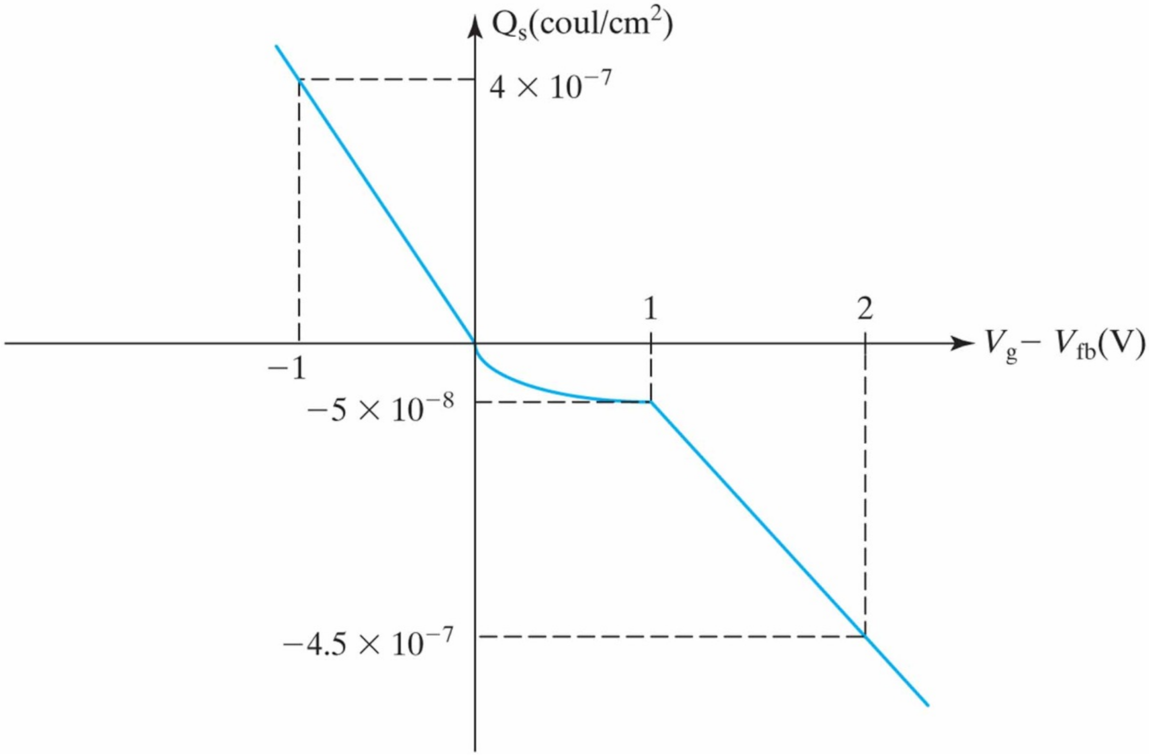

Figure 2. Total charge per unit area for a MOS capacitor at 300 K

Task 6 (5p)

Use the basic MOSFET IV model to plot the drain current vs. drain source voltage under the following conditions:

$$I_{ds} = \frac{W}{L} C_{oxe} \mu_{ns} (V_{gs} - V_t - \frac{m}{2} V_{ds}) V_{ds}$$

The gate-source voltage is 1 V, the threshold voltage is 0.3 V, the bulk-charge factor is 1.2, the oxide (SiO_2) thickness is 4 nm, the gate length is equal to the gate width, L = W = 10 µm. The electron surface mobility is 100 cm^2/Vs.

Calculate I_{ds} at each of the given V_{ds} values and plot the resulting data:

V_{ds} (V)	V_{ds} (V) continued
0	0.6
0.1	0.7
0.2	0.8
0.3	0.9
0.4	1.0
0.5	

Task 7 (5p)

Figure 3 below illustrates the band diagram from source to drain when a **long-channel** MOSFET transistor is biased at V_{gs} = 0 V and $V_{gs} = V_t$.

Use a similar figure to illustrate these two bias cases for a so-called **short channel** transistor. What effect is observed on the threshold voltage for the **short channel** case?

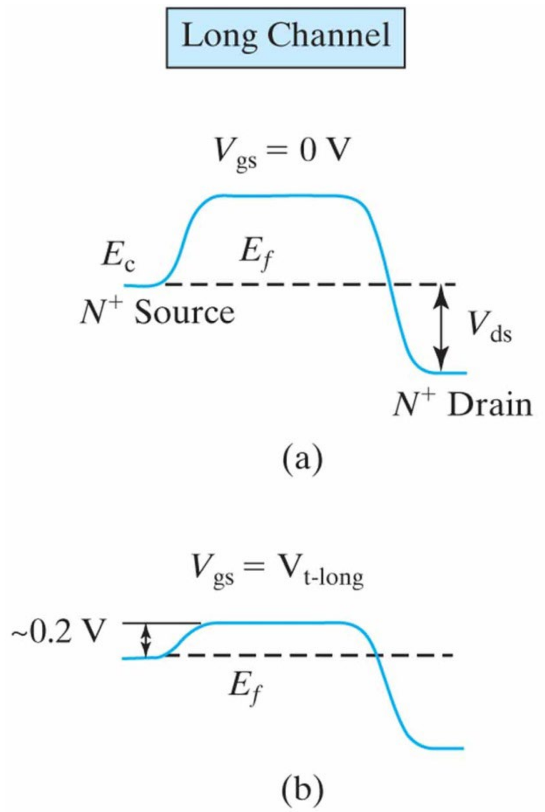

Figure 3. Energy band diagram from source to drain.

Task 8 (5p)

Figure 4 below shows a P+N solar cell under short circuit condition and also the excess carrier concentration profile resulting from a generation rate of *G* electron-hole pairs for a certain light intensity. The recombination lifetime τ_p is a property of the semiconductor material, in this case silicon.
Derive the short circuit current I_{sc}. Hint use the following form of the continuity equation and solve for the current at $x = 0$. The cross sectional area is *A*.

$$\frac{d^2p'}{dx^2} = \frac{p'}{L_p^2} - \frac{G}{D_p}$$

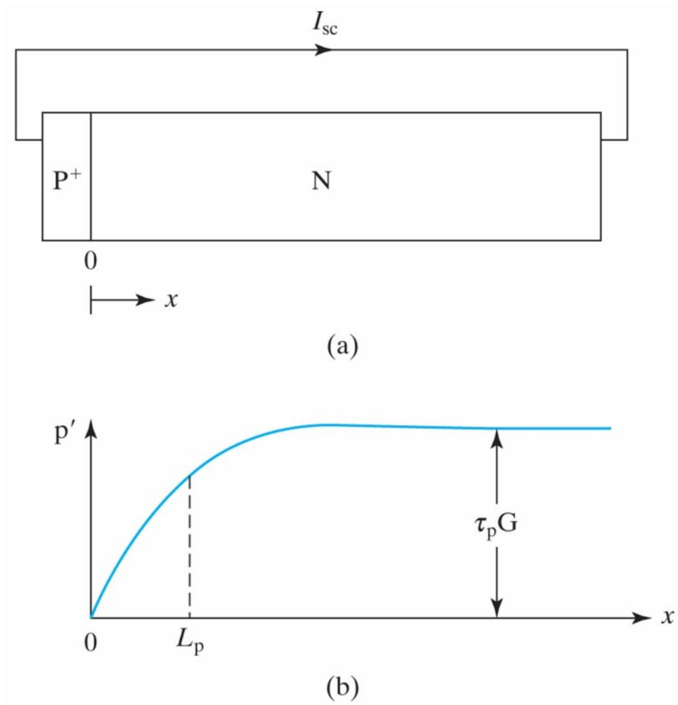

Figure 4. a) A P+N solar cell under short circuit condition and b) the excess carrier concentration profile under solar light illumination.