Task 1 (5p)

In Figure 1 four different concepts, band diagram, density of states, fermi distribution, and carrier concentration, are illustrated for semiconductor materials with different net doping. Complete the missing pictures (labelled 1-3) and explain the meaning of the symbols and equations that appear in the figure.

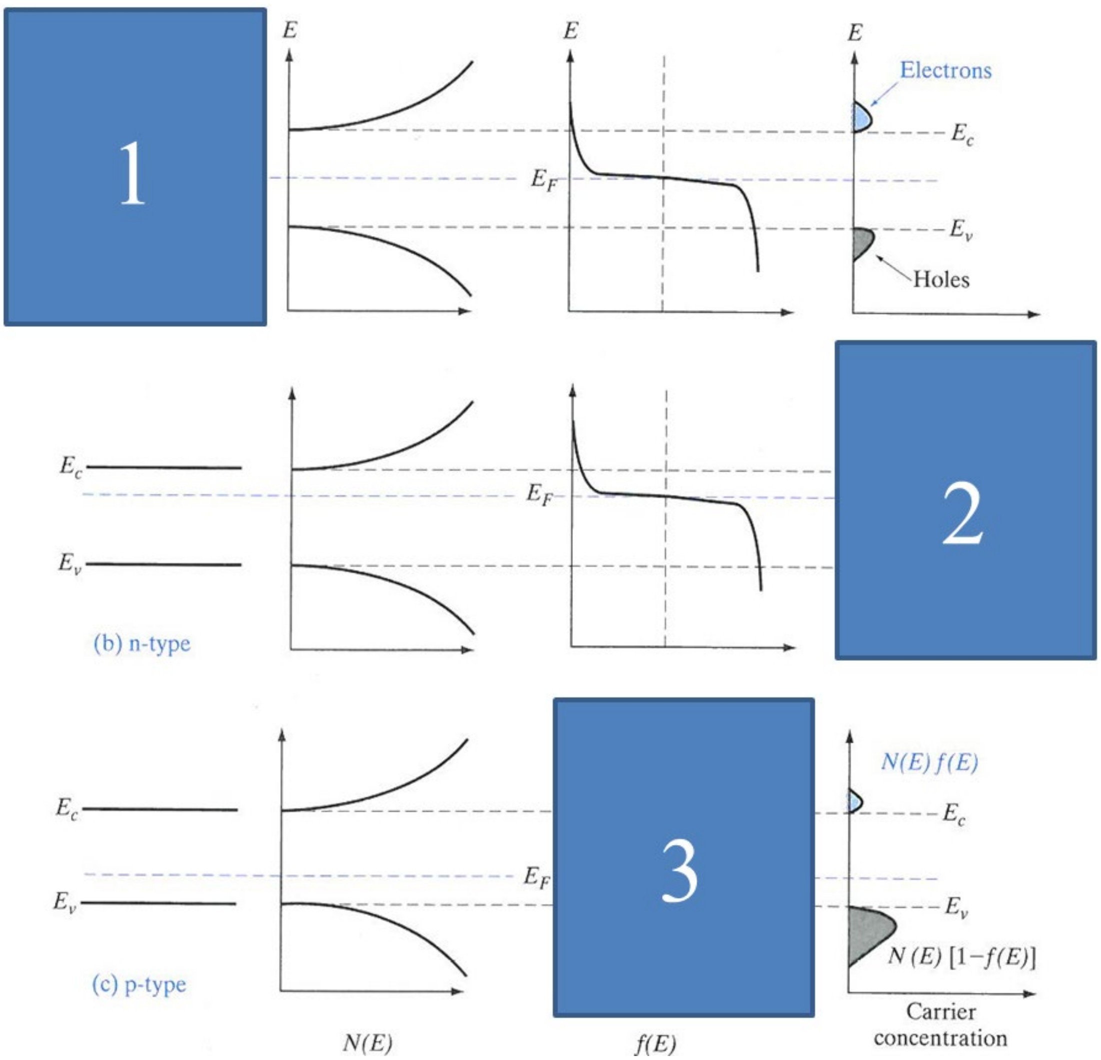

Figure 1. Illustration of the concepts – band diagram, density of states, fermi distribution, and carrier concentration

Task 2 (5p)

Use the information in Fig. 2 to determine the approximate value of the energy bandgap for the material SiC. Which type of Ohmic contact would be easier to form towards SiC, what doping polarity should the semiconductor have?

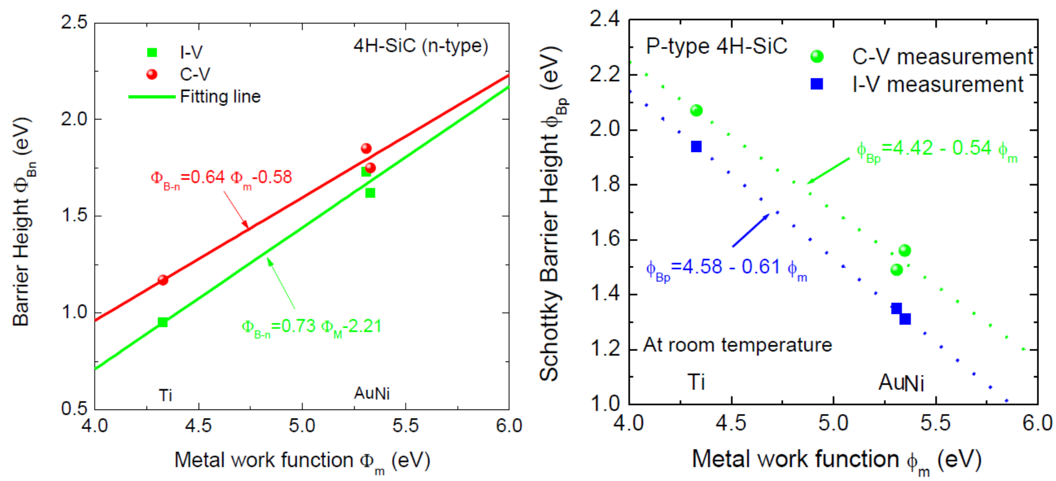

Figure 2. Schottky barrier height of Ni, Ti, and Au to n- and p-type 4H-SiC using IV and C-V characteristics as a function of each metal work function . Source thesis published at KTH.

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)

A n^+-polysilicon-gate n-channel transistor is fabricated on a p-type Si substrate with 5×10^{15} cm^{-3} of acceptor dopants. The gate oxide thickness is 10 nm and there is a positive interface charge Q_i of $4 \times 10^{10}\ q$ C/cm^2, where q is the electron charge.
Find the threshold voltage V_T.
Hint, the interface charge Q_i is treated is the same way as the depletion charge.

Task 5 (5p)

Draw the carrier distribution and band diagram for the device shown in Fig. 3 at thermal equilibrium. Calculate the built-in field (ϕ_{bi}) and the depletion layer widths at the n and p-type side respectively. The semiconductor material is silicon and the acceptor and donor dopings are $N_A=10^{18}$ cm^{-3} and $N_D=10^{16}$ cm^{-3}.

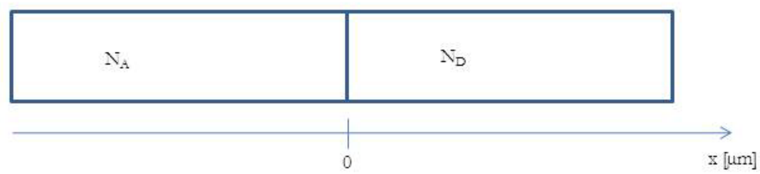

Figure 3. Schematic of semiconductor device with acceptor and donor doping regions

Task 6 (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.

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

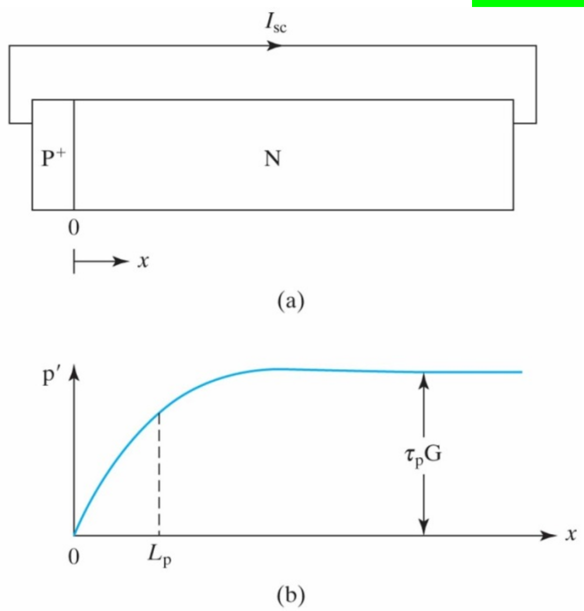

Figure 4. a) A P+N solar cell under short circuit condition and b) the excess carrier concentration profile under solar light illumination.

Task 7 (5p)

The efficiency of a solar cell can be increased, by using a tandem configuration, where the top layer has a bandgap different from the bottom layer. In Fig. 5 recent experimental data are shown for tandem cells, using a Perovskite film as top layer. Two different bottom electrodes have been considered, CIGS and Si. All layers are semiconductors with a bandgap. Data are shown for the top and bottom layers independent of each other and also for the bottom layer with the incident light filtered by the top layer, so that fewer photons reach the bottom layer. Use this data, to estimate the bandgap of the Perovskite top layer and the CIGS bottom layer!

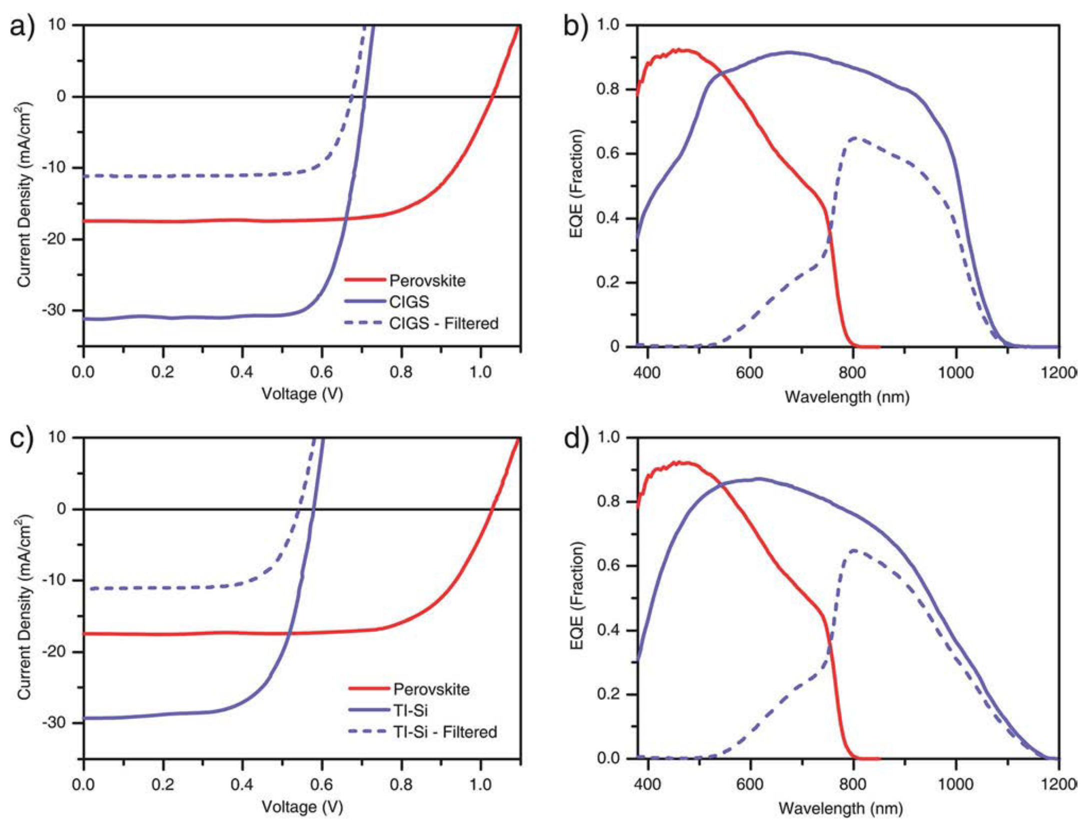

Figure 5. a) and b) IV-data and external quantum efficiency with a CIGS bottom electrode c) and d)) IV-data and external quantum efficiency for a Si bottom electrode. Source online: http://web.stanford.edu/group/mcgehee/publications/EES2014c.pdf