Task 1 (5p)

The state distribution in a system is given in Fig. 1., where each circle represents two electron states (one is spin-up; one is spin-down). Each electron state can be occupied by one electron. There is no state below E_{min} . The Fermi level at 0 K is given in the figure. How many electrons are there in the system?

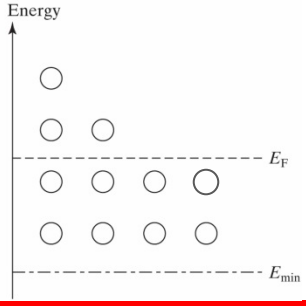

Figure 1. State distribution in a system at T = 0 K

Task 2 (5p)

In Metal-Oxide-Semiconductor transistors (MOSFET) it is useful to know the Fermi level for a doped semiconductor with respect to the Fermi level of the semiconductor in the intrinsic (undoped) case. Assume that N_V=N_C for the semiconductor.
Derive an expression for

$$\phi_B = \frac{\left|E_i - E_F^{Doped}\right|}{q}$$

Task 3 (5p)

A Si crystal is doped with 10^{16} donor atoms per cm^3. Light with a suitable wavelength shines on the crystal and creates a uniform steady-state concentration of excess electron hole pairs of 10^{14} cm^{-3}. At t = 0 s the light is turned off. The recombination lifetime is 1 µs. After how long time has the excess concentration dropped to $1/e$ of its initial value. How does the result change if the excess concentration is 10 times higher at t = 0 s?

Task 4 (5p)

Draw the band diagram of an ohmic contact to n-type silicon. Assume a small forward bias. Illustrate the charge flow at the contact interface.

Task 5 (5p)

Draw the so-called voltage transfer curve of a CMOS inverter with matched NMOS and PMOS devices (symmetric drive current).

Task 6 (5p)

SONOS is a family of non-volatile memory devices. It is similar to the floating gate transistor used in mainstream Flash memories. Instead of using a floating poly gate, the charge storage medium is a nitride film (the N in ONO). SONOS has some advantages for harsh environments as compared to the floating gate transistor.

A SONOS device (see Fig. 2) is n^+-poly / 8 nm SiO_2 / 5 nm Si_3N_4 / 3 nm SiO_2 / p-Si, where the p-type doping is 5×10^{17} cm^{-3}. Si_3N_4 is a high-κ material, with $\varepsilon_{N,r} = 7$. SiO_2 has $\varepsilon_{O,r} = 3.9$.

Estimate the threshold voltage, assuming that there are no charges in the nitride.
Hint: The ONO behaves as 3 capacitors in series.

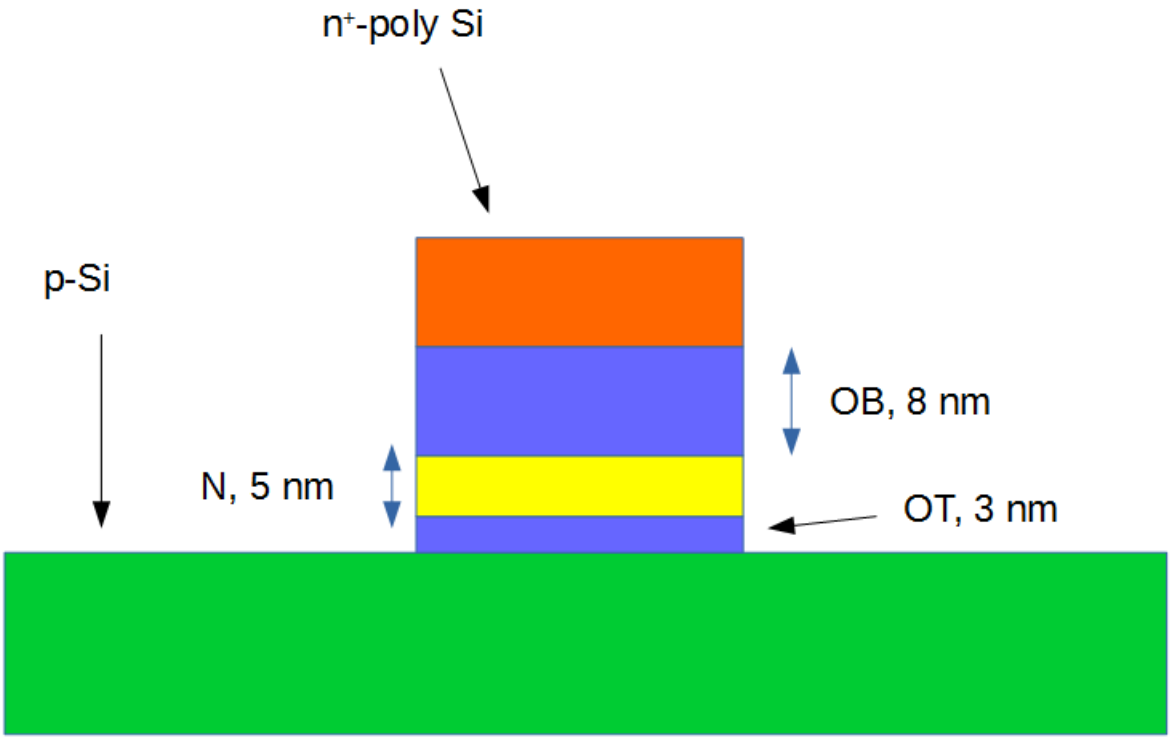

Figure 2. A SONOS device.

Task 7 (5p)

A long channel nMOSFET with $N_A = 5\cdot10^{17}$ cm^{-3} has $V_{gs} = V_{fb}$, $V_{sb} = 0$ V and V_{ds}=1 V. The source and drain areas are n^+. Draw the band diagram from source to drain. Calculate the maximum electric field in the channel.

Task 8 (5p)

Consider the experimental set-up in Fig. 3. Explain how the sign of the measured voltage can be used to determine the majority carrier type in the sample. Use the concepts of drift and diffusion currents.

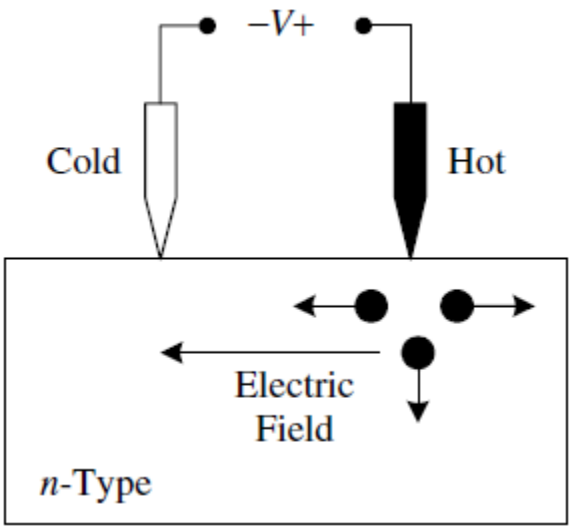

Figure 3. Experimental set-up using a hot-probe to determine conductivity type