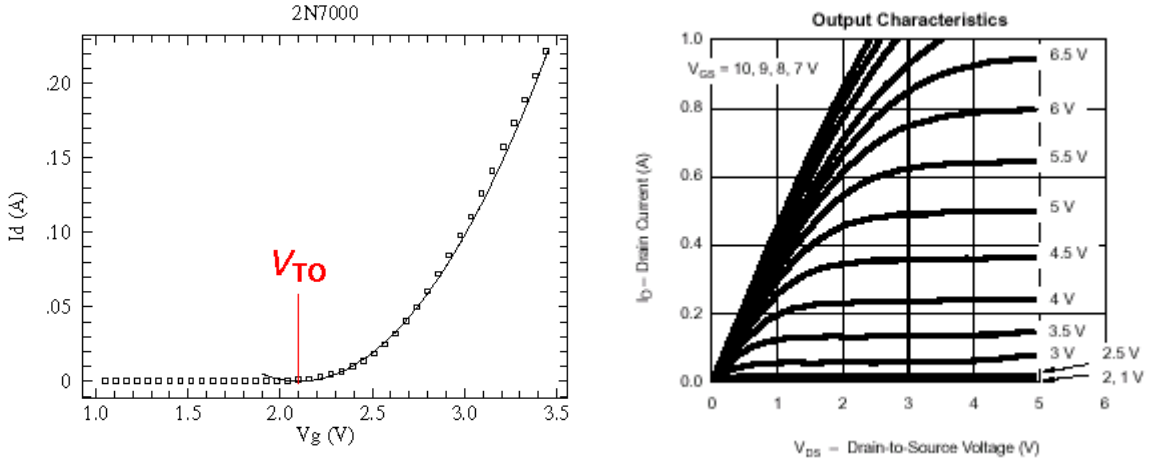
Prof. Dr. H. Föll
Chair for general materials science

Exercises "Electronic Materials"

#8

Exercise 8: MOSFET



(a) **(b)**

Fig. 1: a) Transfer characteristic of a Vishay 2N700 NMOS. The drain current I_D as a function of the Gate voltage V_G. $V_{TO} = V_T$: Threshold voltage.
b) Output characteristics: The drain current I_D as a function of the drain-source voltage V_{DS}.

In **Fig. 1** the input and output characteristics of a typical commercially available nMOSFET are shown. Assume first a drain-source voltage $U_{DS} = 0$ V.

a) Draw a cross section of an integrated NMOS for $U_G < U_T$. Discuss this case in relation to the characteristics.
b) Draw and discuss the same for $U_{G1} > U_T$. What happens for a $U_{G2} > U_{G1}$?

Now we regard the transistor in operation with $U_G = 5$ V and $U_{DS} = 1$ V.

c) Attribute the regimes “linear” and “saturation” to the corresponding curve in the output characteristics (Fig. 1b).
d) Draw and discuss the cross section in relation to the characteristics.
e) How does the channel look like when you go to the saturation regime, i.e. $U_{DS} = 5$ V?

A load ($R = 6\ \Omega$) is added in series on the transistor output, in line with the output of the transistor, the external driving voltage is $U_{DD} = 6$V. Only two possible gate voltages are now allowed: $U_{G1} = 3$ V and $U_{G2} = 5$V.

f) Draw the circuit and give a formula for the current through the load. Draw the so-called load characteristic into the output characteristics to find the working point of the transistor graphically.
g) What point characterizes “ON” and which one is “OFF” in the characteristics? Why do logic applications most likely use the saturation regime?
h) Give two other common applications for MOSFETs in circuitry.

The same nMOSFET shall now be used as a pH Sensor. Therefore the gate electrode is surface functionalized instead of connected to a gate voltage. First the surface is non-charged, i.e. $U_G = 0$ V. Then the gate is brought into contact with a solution of unknown pH (and the gate gets charged because charged molecules attach to the functionalization). The gate dielectric is thermally grown SiO_2 ($\varepsilon_r = 3.9$). The input capacitance is $C = 22$ pF.

i) Calculate the oxide thickness for a gate surface of $A = 6000\ \mu m^2$.

The drain-source voltage is now $U_{DS} = 5$V and the measured current $I_{SD} = 800$ mA.

j) What is the equivalent U_G? How much charge must be on the gate electrode?

k) If 1% of the solution's H_3O^+ gets stuck at the functionalization (and no other species are present), what is the pH of the solution (volume: 1 l)?