POLITONG – SHANGHAI

ELECTRONICS DEVICES -June 2012

NAME (Pinyin/Italian):…………………………………………………………

MATRICULATION NUMBER:………………………………………………….

SIGNATURE:……………………………………………………………………….

NOTES:

- **Use only these pages (including the back) for answers.**
- **Use of any book, note or other didactic material is not allowed. Only the use of simple calculator is allowed (notebooks or electronic tablets of any kind are not allowed).**
- **Write clearly and be explicit and concise in your answers. Include the basic formulas and logical steps used to reach the results. Provide the final numerical values.**
- **Questions in bold are considered more difficult.**

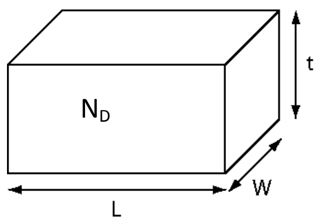
Exercise 1

a) Consider the resistor shown in **Fig.1.** Determine the donors concentration $\mathbf{N_D}$ to have a value of resistance R=200Ω.

b) Given the electron mobility μ_n and the effective mass of the electron $m_n=0.12m_0$, calculate the relaxation time τ_n for the electrons.

c) Compensate now the semiconductor with acceptors to increase the resistance. Which is the concentration $\mathbf{N_A}$ necessary to have a value of resistance R=2kΩ? (consider the mobility not modified by the different dopants concentrations)

d) Supposing now the relaxation time τ_n inversely proportional to the dopants concentration, determine the mobility μ_n of the material in the conditions at point c).



L=300µm
W=150µm
t= 10µm
R=200Ω

Figure 1

Electron charge	$q= 1.6\cdot10^{-19}$C
Electron mobility	$\mu_n= 1400\ cm^2/Vs$
Hole mobility	$\mu_p= 400\ cm^2/Vs$
Electron effective mass	$m_n= 0.12\ m_0$
Electron rest mass	$m_0= 9.1\cdot10^{-31}$Kg

Exercise 2

a) Consider the pn junction at equilibrium represented in **Fig.2**. Calculate the built-in voltage ϕ_i, the width of the depletion layer and specify the type of junction.

b) Consider to bias the junction with a reverse voltage $\mathbf{V_R}$=15V. Calculate the maximum electric field $\boldsymbol{F_{MAX}}$ in the junction. Justify used approximations.

c) Calculate the capacitance of the junction biased at point b).

Consider now the junction forward biased with $\mathbf{V_D}$**=0.62V**.

d) Determine if it is a short or long diode in the two regions.

e) Calculate the minority carriers concentration at the border of the neutral zone: **n(-x_p)** and **p(x_n).** Draw the minority carriers profile in the two regions.

f) From the forward bias condition above, the diode is suddenly biased with a reverse current density of J=1mA/cm^2. Give an estimation of the time necessary for the diode to reach the condition V_D=0V.

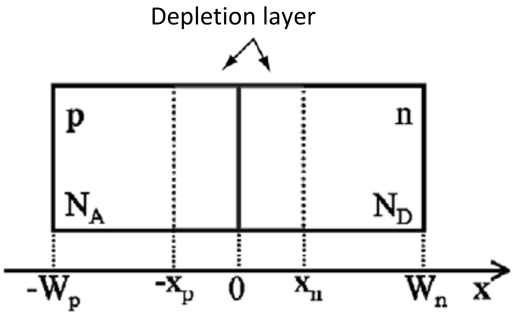


Figure 2

$N_A = 10^{17}$ cm^{-3}	τ_p= 180ns
$N_D = 2\cdot10^{19}$ cm^{-3}	τ_n= 0.3µs
W_P= 100µm	μ_n= 1005 cm^2/Vs
W_N= 221µm	μ_p= 408 cm^2/Vs

Intrinsic concentration	$n_i = 1.45\cdot10^{10}$ cm^{-3}
Dielectric constant in vacuum	$\varepsilon_0 = 8.85\cdot10^{-14}$ F/cm
Relative dielectric contant in Si	$\varepsilon_{r\text{-}Si}$= 11.7
Dielectric constant in Si	$\varepsilon_{Si} = \varepsilon_0 \cdot \varepsilon_{r\text{-}Si} \approx$1pF/cm
Boltzmann constant	$k=1.38\cdot10^{-23}$ J/K
Thermal voltage	V_{TH}= 25mV
Electron charge	$q= 1.6\cdot10^{-19}$C

Exercise 3

Consider the MOS junction shown in **Fig.3a** with parameters reported in **Table 3.a**.

a) Given a potential difference ΔV_{SD}=0.65V in the silicon <u>at threshold condition</u>, calculate the doping concentration $\mathbf{N_A}$.
b) Determine the oxide thickness $\boldsymbol{t_{ox}}$ to have a threshold voltage $\mathbf{V_T}$**=0.7V**.

Consider now the MOSFET shown in **Fig.3b** with parameters reported in **Table 3.b** and based on the same MOS structure considered at point a).

c) Calculate the transistor width **W** to have a channel conductance $\mathbf{G_{CH}}$ **=0.3mS** at the bias conditions: $\mathbf{V_{SB}}$**=0**, $\mathbf{V_{GS}}$**=1.5V**, $\mathbf{V_{DS}}$**=0.5V.**
d) Given $\mathbf{V_{SB}}$**=0**, $\mathbf{V_{GS}}$**=1.5V**, determine $\mathbf{V_{DS}}$ to have the channel charge $\mathbf{Q_{CH}}$**(D)** at the drain point equal to **90%** of the channel charge $\mathbf{Q_{CH}}$**(S)** at the source point. (charge is per unit of area)
e) Consider the MOSFET biased now at $\mathbf{V_{SB}}$=0, $\mathbf{V_{GS}}$=1.5V, $\mathbf{V_{DS}}$=3V. Consider an increase of the Drain voltage of 1V which produces a variation of the channel length of the transistor (L→L') of 10%. Is L'<L or L'>L? Calculate the output resistance of the transistor. Calculate the maximum gain achievable for the transistor used as amplifier.

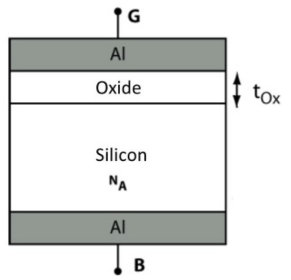


Figure 3.a

Flat-band voltage V_{FB} = -0.7V

Table 3.a

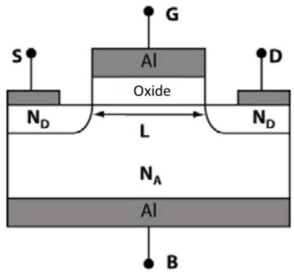


Figure 3.b

L= 10 µm
μ_n= 1350 cm^2/Vs

Table 3.b

Intrinsic concentration	n_i= 1.45·10^{10} cm^{-3}
Dielectric constant in vacuum	ε_0= 8.85·10^{-14} F/cm
Relative dielectric contant in Si	$\varepsilon_{r\text{-}Si}$= 11.7
Dielectric constant in Si	ε_{Si}= $\varepsilon_0 \cdot \varepsilon_{r\text{-}Si}$ ≈1pF/cm
Boltzmann constant	k=1.38·10^{-23} J/K
Thermal voltage	V_{TH}= 25mV
Electron charge	q= 1.6·10^{-19}C
Dielectric constant in Oxide	ε_{Ox}= $\varepsilon_0\, \varepsilon_{r\text{-}Ox}$ ≈1/3pF/cm

Theory question #1:

Introduce the concept of mobility of charges in semiconductor: intuitive demonstration of proportionality between velocity and electric field, relaxation time. Discuss the effective mass concept.

Theory question #2:

Describe the inversion condition in a MOS junction. Calculate the expression of the Threshold voltage. Justify possible approximations made.
