POLITONG – SHANGHAI

ELECTRONICS DEVICES -September 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

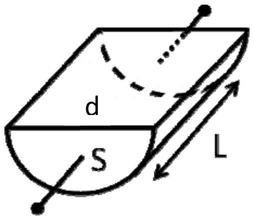

Figure 1

$L=100\mu m$
$N_D= 10^{16}\,cm^{-3}$
$R=10k\Omega$

Electron charge	$q= 1.6\cdot 10^{-19}C$
Electron mobility	$\mu_n= 1400\ cm^2/Vs$
Hole mobility	$\mu_p= 400\ cm^2/Vs$

a) Consider the resistor shown in **Fig.1.** Determine the value of the diameter ***d*** of the half circle of surface ***S*** to have a value of resistance **R=10kΩ**.

b) Given the current **I= 1mA** flowing in the resistor, calculate the applied electric field ***F***.

c) Compensate now the semiconductor with acceptors. Calculate the concentration $\mathbf{N_A}$ necessary to have still a n-type material with a concentration of majority carriers 10^6 times larger than the concentration of minority carriers.

d) Consider again the semiconductor with floating terminals (no current flowing) and with a gradient of doping between the two opposite surfaces (the ones where the terminals are applied) given by $N_{D1}= 10^{16}cm^{-3}$ and $N_{D2}= 5\cdot 10^{16}cm^{-3}$. Determine the voltage difference in the semiconductor which is set between the two surfaces by the doping difference.

Exercise 2

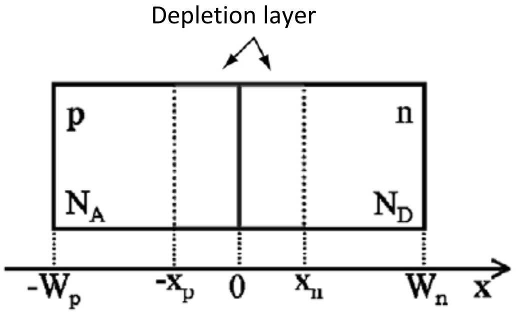

Figure 2

$N_A = 10^{17}\ cm^{-3}$	$\tau_p = 100ns$
	$\tau_n = 300ns$
$W_P = 200\mu m$	$\mu_n = 1400\ cm^2/Vs$
$W_N = 200\mu m$	$\mu_p = 400\ cm^2/Vs$

Intrinsic concentration	$n_i = 1.45 \cdot 10^{10}\ cm^{-3}$
Dielectric constant in vacuum	$\varepsilon_0 = 8.85 \cdot 10^{-14}\ F/cm$
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	$k = 1.38 \cdot 10^{-23}\ J/K$
Thermal voltage	$V_{TH} = 25mV$
Electron charge	$q = 1.6 \cdot 10^{-19}C$

a) Consider the pn junction at equilibrium represented in **Fig.2**. Supposing $\mathbf{N_D \gg N_A}$ and the width of the depletion layer **W=110nm**, calculate the built-in voltage ϕ_i and the doping $\mathbf{N_D}$, justifying the approximation above.

b) Consider to bias the junction with a reverse voltage $\mathbf{V_R}$=10V. Calculate the maximum electric field F_{MAX} in the junction and the depletion capacitance (per unit of area) C'_j. Justify used approximations.

Consider now the junction forward biased with $\mathbf{V_D=0.65V}$.

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

d) Calculate the minority carriers concentration at the border of the neutral zone: $\mathbf{n(-x_p)}$ and $\mathbf{p(x_n)}$. Draw the minority carriers profile in the two regions.

e) Find the voltage V_D at which the diffusion capacitance C'_d is equal to the depletion capacitance C'_j (both per unit of area).

Exercise 3

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

a) Given a potential difference ΔV_{SD}=0.67V in the silicon at threshold condition, calculate the doping concentration $\mathbf{N_A}$.

b) Calculate the threshold voltage $\mathbf{V_T}$.

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

c) Calculate the channel conductance $\mathbf{G_{CH}}$ at the bias conditions: $\mathbf{V_{SB}=0}$, $\mathbf{V_{GS}=2.0V}$, $\mathbf{V_{DS}=0.6V}$.

d) Given $\mathbf{V_{SB}=0}$, $\mathbf{V_{GS}=2.0V}$ and $\mathbf{V_{DS}=2.0V}$, determine the operation region of the MOSFET and calculate the transconductance $\boldsymbol{g_m}$.

e) Operate the MOSFET at $\mathbf{V_{SB}=0}$, $\mathbf{V_{GS}=2.0V}$ in ohmic region and determine $\mathbf{V_{DS}}$ to have 50% of the transconductance of the point d).

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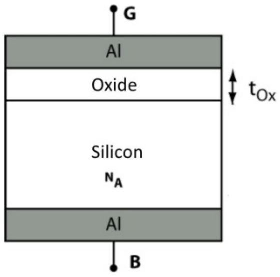
<td>

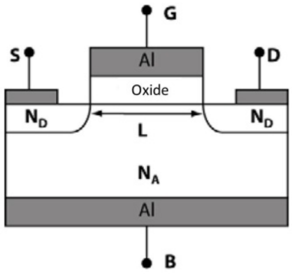
Figure 3.a</td>
<td>Flat-band voltage V_{FB} = -0.7V
t_{Ox}=80nm
Table 3.a</td>
</tr>
<tr>
<td>

Figure 3.b</td>
<td>L= 10 µm
W= 100 µm
μ_n= 1400 cm^2/Vs
Table 3.b</td>
</tr>
<tr><td>Intrinsic concentration</td><td>n_i= 1.45·10^{10} cm^{-3}</td></tr>
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<tr><td>Dielectric constant in Oxide</td><td>ε_{Ox}= $\varepsilon_0\, \varepsilon_{r\text{-}Ox}$ ≈1/3pF/cm</td></tr>
</table>

Theory question #1:

Demonstrate the formula of the drift current in a semiconductor. Ohm law, conducibility, resistance, dependence from dopant concentration. Why in semiconductors there is a bipolar current? Give its expression.

Theory question #2:

MOSFET transistor: discuss the change current with the drain voltage in relation to a change of the pinch-off point. What it is introduced in the transistor model to take into account of this phenomenon?
