UNIVERSITY OF CALIFORNIA
College of Engineering
Department of Electrical Engineering and Computer Sciences

EECS 130 Professor Ali Javey
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Midterm 2

Name:

SID: ______________________________

Closed book. Two sheets of notes are allowed.

Problem 1		20
Problem 2		25
Problem 3		25
Problem 4		30
Total		100

Physical Constants

Electronic charge	q	1.602×10^{-19} C
Permittivity of vacuum	ε_0	8.845×10^{-14} F cm^{-1}
Relative permittivity of silicon	$\varepsilon_{Si}/\varepsilon_0$	11.8
Relative permittivity of SiO_2	$\varepsilon_{Si02}/\varepsilon_0$	3.9
Ratio of permittivity of Si/SiO_2	$\varepsilon_{Si}/\varepsilon_{SiO2}$	3
Boltzmann's constant	k	8.617×10^{-5} eV/ K or 1.38×10^{-23} J K^{-1}
Thermal voltage at T = 300K	kT/q	0.026 V
Effective density of states	N_c	2.8×10^{19} cm^{-3}
Effective density of states	N_v	1.04×10^{19} cm^{-3}
Electron Affinity of Silicon	χ	4.05eV
Silicon Band Gap	E_G	1.12eV

MOSCAP Warmup [20pts]

The energy band diagram for an ideal MOS-C operated with gate oxide thickness T_{OX}=0.2 μm at T = 300 K is sketched in the figure below. Note that the applied gate voltage causes band bending in the semiconductor such that $E_F = E_i$ at the Si-SiO_2 interface. Invoke the delta-depletion approximation as required in answering the questions that follow.

[3 pts] Sketch the electrostatic potential (ϕ) inside the semiconductor as a function of position.

[3 pts] Roughly sketch the electric field inside the oxide and semiconductor as a function of position

[2 pts] Do equilibrium conditions prevail *inside the semiconductor*? Explain.

[3 pts] Roughly sketch the electron concentration versus position in the semiconductor.

[3 pts] What is the electron concentration at the Si-SiO_2 interface?

n = _______________ cm^{-3}

[6 pts] Find the channel doping N_D, surface potential ϕ_S, and gate voltage V_G.

N_D =

_______________ cm^{-3}

ϕ_S = _______________ eV

V_G = _______________ V

PN vs MS diodes [25pts]

Consider two devices, one PN junction and one MS junction:
The PN junction has a p-type Si region with Φ_p=4.96eV and an N-type region with Φ_n=4.13 eV, the MS junction has a p-type Si region with Φ_p=4.96eV and a metal with Φ_M=4.13. Answer the following questions:

[6 pts] What is V_{bi} for each of these devices?

V_{bi}(PN) = _______________

V_{bi}(MS) = _______________

[4 pts] Which of these devices has a higher reverse leakage current? Why?

[6 pts] What is the reverse bias capacitance C_J for each of these devices at V_A=1V?

C_J(PN) = _______________

C_J(MS) = _______________

[5 pts] Suppose you used each one of these devices as a photodiode by shining light on the junction. Which one of these devices is more likely to have a higher efficiency (photons in vs. current out?). Why?

MOSCAP C-V curve [25 pts]

All curves you will draw in this question will be graded qualitatively and not quantitatively.

[10 pts] Given below is a low frequency CV curve of a MOSCAP with oxide thickness T_{ox} =10 nm, gate work function Φ_M = 4.51eV, and substrate doping density of $N_{SUB} = 10^{15}$ cm^{-3}. What type of dopant (donor or acceptor) is used in the silicon substrate? Calculate the ratio of C_{min}/C_{ox}, V_1 and V_2.

Dopant Type (Circle one): Donor or Acceptor

C_{min}/C_{ox} = ____________

V_1 = ____________ V

V_2 = ____________ V

[5pts] Given below is the low frequency C-V curve of a MOSCAP. Draw a second low frequency curve corresponding to the same device, but with a fixed positive oxide charge at the interface of the oxide and the substrate.

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[5 pts] Given below is the low frequency C-V curve of a MOSCAP with metal gate. The work function of the metal is Φ_M = 4.05eV. Redraw the low frequency C-V curve if the gate were made out of P+ Poly instead of metal. (Note: include poly depletion effect).

[5 pts] Given below is the low frequency C-V curve of a MOSCAP with metal gate. The work function of the metal is Φ_M = 4.05eV. Redraw the low frequency C-V curve if the gate were made out of N+ Poly instead of metal. Assume that the electron affinity for Si is 4.1 eV and the band gap is 1.1 eV. (Note: include poly depletion effect).

4. Schottky Barrier MOSFET [30pts]

In recent years, MOSFET-like structures with metal S/D contacts (rather than heavily doped semiconductor contacts) have received considerable attention due to a number of potential benefits that their offer. These devices are often called Schottky barrier (SB) MOSFETs.

Assume a SB-MOSFET structure as shown below with SB height of 0.3 eV at the source and drain for holes. The body is an n-type Si.

[8 pts] Draw two separate band diagrams for this device from source to drain (along the dashed line), one for the ON-state and the other for the OFF-state for a finite V_{DS} value below the pinch-off. Label E_c, E_v, Φ_B, Fermi (or quasi Fermi) levels, source/drain, and V_{DS} on the two diagrams.

[6 pts] What are the three possible carrier injection mechanisms from the source to the semiconductor? Briefly explain each mechanism.

1.

2.

3.

[3 pts] Redraw the band diagram for the ON-state from part **a)**. On this diagram clearly show and label the three carrier injection mechanisms at the source by using arrows.

[6 pts] Qualitatively draw the I_{DS}-V_{DS} characteristic of this device for an arbitrary gate voltage value where $V_G<V_T$. When plotting the curve, make sure that your maximum V_{DS} is higher than the pinch-off voltage. (Hint: when drawing the I-V curve for this device think how it should be different than a conventional MOSFET with doped contacts)

[7 pts] Fill in the blank cells in the table, using the following symbols: ↑ for increase, ↓ for decrease, and   for no change. If the cell has already been provided with an X it means that you are not responsible for filling that cell out. When moving along a row, consider only the change brought on due to the parameter specified in the first cell of that row. (Note: N_d is the doping density of the Si body, T_{ox} is the oxide thickness, and W_{dep} and C_{dep} are the depletion width and capacitance respectively)

	SB height at source	**W_{dep} at source**	**C_{dep} at drain**
N_d ↑			
T_{ox} ↓		**X**	**X**
SB height at drain↓			

Metal
(drain)

Metal
(source)

oxide

n-type Si body

Gate