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

EECS 130 Fall 2006 Professor Ali Javey

# 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 <sup>-19</sup> C
Permittivity of vacuum	ε <sub>0</sub>	$8.845 \times 10^{-14} \text{ F cm}^{-1}$
Relative permittivity of silicon	$\epsilon_{Si}/\epsilon_{0}$	11.8
Relative permittivity of SiO <sub>2</sub>	$^{\epsilon}{ m Si02}^{/\epsilon}0$	3.9
Ratio of permittivity of Si/SiO <sub>2</sub>	<sup>ε</sup> Si <sup>/ε</sup> SiO2	3
Boltzmann's constant	k	8.617 x 10 <sup>-5</sup> eV/ K or 1.38×10 <sup>-23</sup> J K <sup>-1</sup>
Thermal voltage at $T = 300$ K	kT/q	0.026 V
Effective density of states	N <sub>c</sub>	$2.8 \times 10^{19} \text{ cm}^{-3}$
Effective density of states	N <sub>v</sub>	$1.04 \times 10^{19} \text{ cm}^{-3}$
Electron Affinity of Silicon	χ	4.05eV
Silicon Band Gap	E <sub>G</sub>	1.12eV

### MOSCAP Warmup [20pts]

The energy band diagram for an ideal MOS-C operated with gate oxide thickness  $T_{OX}=0.2 \ \mu m$  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<sub>2</sub> interface. Invoke the delta-depletion approximation as required in answering the questions that follow.

[3 pts] Sketch the electrostatic potential ( $\phi$ ) 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

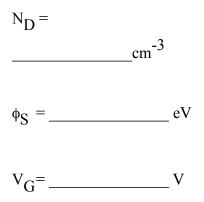
[2 pts] Do equilibrium conditions prevail inside the semiconductor? Explain.

[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<sub>D</sub>, surface potential  $\phi_S$ , and gate voltage V<sub>G</sub>.



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  $\Phi_p$ =4.96eV and an N-type region with  $\Phi_n$ =4.13 eV, the MS junction has a p-type Si region with  $\Phi_p$ =4.96eV and a metal with  $\Phi_M$ =4.13. Answer the following questions:

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

V<sub>bi</sub>(PN) =\_\_\_\_\_

V<sub>bi</sub>(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  $\Phi_M = 4.51$  eV, and substrate doping density of  $N_{SUB} = 10^{15}$  cm<sup>-3</sup>. 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<sub>2</sub> = \_\_\_\_\_ 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.

### SHAPE \\* MERGEFORMAT

[5 pts] Given below is the low frequency C-V curve of a MOSCAP with metal gate. The work function of the metal is  $\Phi_{M} = 4.05$  eV. 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  $\Phi_{M} = 4.05$  eV. 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).

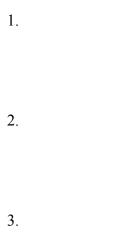
4. Schottky Barrier MOSFET [30pts]

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  $E_c$ ,  $E_v$ ,  $\Phi_B$ , 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.



[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:  $\uparrow$  for increase,  $\downarrow$  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<sub>d</sub> is the doping density of the Si body, T<sub>ox</sub> is the oxide thickness, and W<sub>dep</sub> and C<sub>dep</sub> are the depletion width and capacitance respectively)

	SB height at source	W <sub>dep</sub> at source	C <sub>dep</sub> at drain
$\mathbf{N_d}$ $\uparrow$			
$T_{ox} \downarrow$		X	Χ
SB height at drain↓			

Metal (drain)

Metal (source)

oxide

n-type Si body

Gate