This is a closed book exam. You may use a calculator and the formula sheet at the end of this exam.

There are four equally weighted questions. To receive full credit, you must show your work (scratch paper is attached).

The exam is designed to be taken in 60 minutes, but you may use the full, 75 minute class period.

Be sure to fill in your name and Purdue student ID at the top of the page.

DO NOT open the exam until told to do so, and stop working immediately when time is called.

40 points possible, 10 per question

1) 2 points for each part

2) 2a) 4 points  2b) 3 points  2c) 3 points

3) 2 points for each part

4) 4a) 2 points  4b) 2 points  4c) 3 points  4d) 3 points
1) Answer the **five multiple choice questions** below by choosing the **one, best answer**.

1a) An MOS capacitor biased so that **majority** carriers in the semiconductor pile up at the oxide semiconductor interface is biased in which region?
   a) Accumulation  
   b) Flat band  
   c) Depletion  
   d) Inversion  
   e) Beyond pinch-off  

1b) How is the electric field on the SiO₂ side of the SiO₂: Si interface, \( x = 0^- \), related to the electric field on the Si side, \( x = 0^+ \)? (Assume there is no charge at the SiO₂: Si interface.)
   a) They are equal.  
   b) The electric field on the oxide side is **larger** than the electric field on the Si side.  
   c) The electric field on the oxide side is **smaller** than the electric field on the Si side.  
   d) The answer depends on the doping of the semiconductor.  
   e) The answer depends on the metal-semiconductor work function difference.  

1c) For a p-type MOS capacitor, how does the minority electron charge (in \( C/cm^2 \)) vary with surface potential and with gate voltage **above threshold**.
   a) Linearly with surface potential and linearly with gate voltage.  
   b) Linearly with surface potential and exponentially with gate voltage.  
   c) Exponentially with surface potential and linearly with gate voltage.  
   d) Exponentially with surface potential and exponentially with gate voltage.  
   e) Exponentially with surface potential and quadratically with gate voltage.  

1d) Why is it hard to bend the bands in an MOS capacitor by more than about \( 2\phi_F \)?
   a) Because of Fermi-Dirac statistics when \( E_F \) approaches the band edge.  
   b) Because the electric field in the oxide is so high that it breaks down.  
   c) Because the electric field in the semiconductor is so high that it breaks down.  
   d) Because SRH generation places an upper limit on the minority carrier density.  
   e) Because the increased gate voltage needed to increase \( \phi_S \) primarily increases the voltage drop in the oxide, not in the semiconductor.  

1e) If we measure the IV characteristics of a transistor, what is the “signature” of velocity saturation inside the MOSFET?
   a) The drain current increases as \( (V_{GS} - V_T)^{1/2} \).  
   b) The drain current increases as \( (V_{GS} - V_T)^1 \).  
   c) The drain current increases as \( (V_{GS} - V_T)^{3/2} \).  
   d) The drain current increases as \( (V_{GS} - V_T)^2 \).  
   e) The drain current increases as \( (V_{GS} - V_T)^{5/2} \).
2) Consider an n-channel MOSFET with the following parameters:

\[ N_A = 3 \times 10^{18} \text{ cm}^{-3} \quad T = 300\text{K} \quad \text{SiO}_2 \text{ thickness: } x_0 = 2.0 \; \text{nm} \quad \kappa_{ox} = 4 \quad \kappa_s = 11.7 \]

NO metal-semiconductor work function difference and no charge in the SiO2

2a) What is the threshold voltage for this MOSFET?

2b) What is the magnitude of the electric field in the oxide for \( V_G = V_{th} \) ?

2c) Estimate the magnitude of the electric field in the oxide for \( V_G = -1 \; \text{V} \) ? (Hint: Make reasonable approximations).
3) For each of the energy band diagrams sketched below, identify the region of band bending.

3a) Select one: a) accumulation  b) flat-band  c) depletion  d) inversion

3b) Select one: a) accumulation  b) flat-band  c) depletion  d) inversion

3c) Select one: a) accumulation  b) flat-band  c) depletion  d) inversion

3d) Select one: a) accumulation  b) flat-band  c) depletion  d) inversion

3e) Select one: a) accumulation  b) flat-band  c) depletion  d) inversion
4) Consider a p-type Si substrate doped as shown below. For $0 \leq x \leq x_1$, the Si is undoped (i.e. it is intrinsic) and for $x > x_1$, it is doped at $N_d(x) = N_{d1}$. Assume that the sample is depleted for $0 \leq x \leq x_n + x_1$. It is neutral for $x > x_n + x_1$. (This semiconductor is part of an MOS capacitor. The oxide and gate to the left of $x = 0$ are not shown.)

4a) Sketch the space charge density vs. position. (label the maximum absolute value).

4b) Sketch the electric field vs. position.
4c) Develop an expression for the maximum electric field in terms of the doping, $N_{A1}$, and the parameters, $x_i$ and $x_n$.

4d) Develop an expression for the depletion layer depth, $x_n$, in terms of the doping, $N_{A1}$, and the potential drop across the semiconductor, $\phi_s$. 

SCRATCH PAPER
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