**UNIVERSITY OF CALIFORNIA, BERKELEY**

**College of Engineering**

**Department of Electrical Engineering and Computer Sciences**

EE 130/230M Spring 2013

Integrated Circuit Devices Prof. Liu & Dr. Xu

**QUIZ #6**

Time allotted: 25 minutes

**NAME:** \_\_\_\_**SOLUTIONS**\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_ \_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_\_

(print) Last First Signature

**INSTRUCTIONS:**

**1. Use the values of physical constants provided below.**

**2. SHOW YOUR WORK, & write legibly!**

**3. Underline or box numerical answers and SPECIFY UNITS where appropriate.**

**Problem 1 [12 points]**

1. Indicate how a long-channel MOSFET’s performance parameters would be affected (*i.e.* check the appropriate column) **if the channel/body doping is increased by a factor of 2. Explain briefly.**

|  |  |  |
| --- | --- | --- |
| **Parameter** | [1 pt each]: **Value would** | **Brief explanation** [2 pts each] |
| **increase** | **decrease** | **not change** |
| **Subthreshold swing, *S***[units: mV/dec] | ✓ |  |  | ***W*T ∝ 1/(√*N*B) decreases****🡪 *C*dep ∝ 1/*W*T increases****🡪 *S* ∝ [1 + *C*dep/*C*oxe] increases** **Capacitive coupling between gate and channel is degraded due to increased coupling between body and channel** |
| **Transconductance, *g*m**[units: A/V] |  | ✓ |  | ***V*T increases****🡪 Gate overdrive (*V*GS−*V*T) decreases****Also, effective mobility eff decreases due to increased average electric field within the inversion-layer channel, and the bulk charge factor *m* increases** |

1. What is a retrograde channel doping profile, and why is it used in short-channel MOSFETs? [3 pts]

**A retrograde profile comprises a lightly doped surface region and a heavily doped sub-surface region.**

**It is used to suppress punchthrough with less detrimental impact on *V*T and **eff, as compared with a uniformly heavily doped channel.**

1. What is the MOSFET short-channel effect, what causes it, and why is it undesirable? [3 pts]

**The short-channel effect refers to a reduction in |*V*T| with decreasing channel length *L*, caused by depletion of the channel region near to the source and drain junctions. This effect is undesirable because it results in significant *V*T variation (and hence significant variations in on-state drive current and off-state leakage current) with process-induced channel-length variations.**

**Problem 2 [8 points]**

Consider a short n-channel MOSFET with *W* = 1 m, *L* = 0.1 m, *C*oxe = 10-6 F/cm2, and *m* = 1.

1. Estimate the drain saturation voltage (*V*Dsat) for *V*GS − *V*T = 1 V, assuming **eff = 400 cm2/V⋅s. [3 pts]

(Recall that *v*sat = 8×106 cm/s for electrons in Si.)

**Esat = 2*v*sat/**eff = 2⋅(8×106 cm/s)/(400 cm2/V⋅s) = 4×104 V/cm**

**1/Esat*L* = 1/(4×104 V/cm)(10-5 cm) = 1/0.4 = 2.5 V-1**

***m*/(*V*GS − *V*T) = 1 V-1**

**1/*V*Dsat = 1/Esat*L* + *m*/(*V*GS − *V*T) = 2.5 + 1 = 3.5 V-1🡺 *V*Dsat = 1/3.5 ≅ 0.3 V**



1. Draw the *I*D-*V*DS curve for *V*GS − *V*T = 1 V on the axes provided.

Indicate *V*Dsat and the value of *I*D at *V*DS = *V*Dsat. [3 pts]

**Since Esat*L*=0.4V is much smaller than (*V*GS-*V*T)/*m* = 1V, we can use the short-channel *I-V* equation to estimate *I*Dsat:**

***I*Dsat = *Wv*sat*C*oxe(*V*GS − *V*T)**

***=* (10-4 cm)(8×106 cm/s)(10-6 F/cm2)(1 V)**

**= 8×10-4 A = 0.8 mA**

**More accurately, using the full MOSFET *I-V* equation:**

***I*Dsat = (*W*/2*mL*)**eff *C*oxe(*V*GS − *V*T)2/[1+(*V*GS − *V*T)/(*m*Esat*L*)]**

**= (1/2∙0.1)(400)(10-6)(1)2/[1+(1/0.4)] ≅ 0.6 mA**

1. Draw another *I*D-*V*DS curve to qualitatively show how a large source resistance and large drain resistance would affect the *I-V* characteristic. [2 pts]

**Problem 3 [5 points]**

Suppose that a BJT with the common-emitter output characteristics shown below is operating under applied voltages such that *I*C ≅ 1 mA with the following energy band diagram:



**(a)** What type of BJT is this (PNP or NPN)? [1 pt]

 **This is an NPN BJT.**

**(b)** Indicate (by drawing a large dot) the operating point of this BJT on the *I-V* plot above. [2 pts]

**Since *V*CB = 0 V this BJT is operating at the edge of saturation.**

**(c)** Estimate the d.c. current gain, **dc. [2 pts]

**For *I*C = 1 mA, *I*B = 12 uA 🡪 **dc = *I*C/*I*B = 10-3/12×10-6 ≅ 83**