MASSACHUSETTS INSTITUTE OF TECHNOLOGY
Department of Electrical Engineering and Computer Science

6.012 MICROELECTRONIC DEVICES AND CIRCUITS

Answers to Exam 2 - Spring 2006

Problem 1: Graded by Prof. Fonstad

a) i) A less than B, because K varies inversely with L.

ii) A similar to B, because the threshold voltage does not depend on L.

iii) A greater than B, because A has a smaller K and thus must be biased stronger.

iv) A less than B, because V_A is bigger for the longer device, and thus g_o is smaller.

v) A greater than B, because the area of the gate (WxL) is larger.

vi) A similar to B, because C_{gd} is proportional to the device width and that is the same in both devices.

b) i) A less than B, because I_{ES} is dominated by N_{AB} and proportional to $1/N_{AB}$.

ii) A similar to B, because I_{CS} is dominated by N_{DC} and that is the same in both devices. A less than B was also accepted.

iii) A less than B, because the emitter defect increases with N_{AB}, and $\beta \approx 1/\delta_E$.

iv) A similar to B, because $g_m = qI_C/kT$ and is the same for both devices.

v) A less than B, because V_A increases as the doping increases, and $g_o = I_C/V_A$

vi) A similar to B, because C_μ is nominated by the collector doping, which is the same in both devices. A greater than B was also accepted.

c) i) Essentially unchanged, because the sum of the n- and p-channel MOSFET gate areas is still $3W_{min}L_{min}$.

ii) Decreased, because the p-FET is now narrower and delivers less current.

iii) Increased, because the n-FET is now wider and can draw more current.

iv) Essentially unchanged, because the static power is zero. (Trick question?)

v) Essentially unchanged, because the logic HI voltage is still V_{DD}.

iv) One increased, one decreased, because the nearly vertical portion of the transfer characteristic is no longer centered about $V_{DD}/2$.

Problem 2: Graded by Prof. Hoyt

a) $\beta_F = i_C/i_B = 9.25\ \text{mA}/92.5\ \mu\text{A} = 100$

b) $\delta_B = 0$, because the lifetime is infinite, meaning the minority carrier diffusion length is also infinite.

c) The factor in question appears in the emitter defect expression, and we can find the emitter defect because we know β_F and $\beta_F \approx 1/\delta_E$, when δ_B is negligible, as it is here:

β_F and $\beta_F \approx 1/\delta_E = (D_e W_{E,eff} N_{DE})/(D_h W_{B,eff} N_{AB}) = (D_e/D_h)\ r$, so $r = \beta_F (D_e/D_h) = 50$

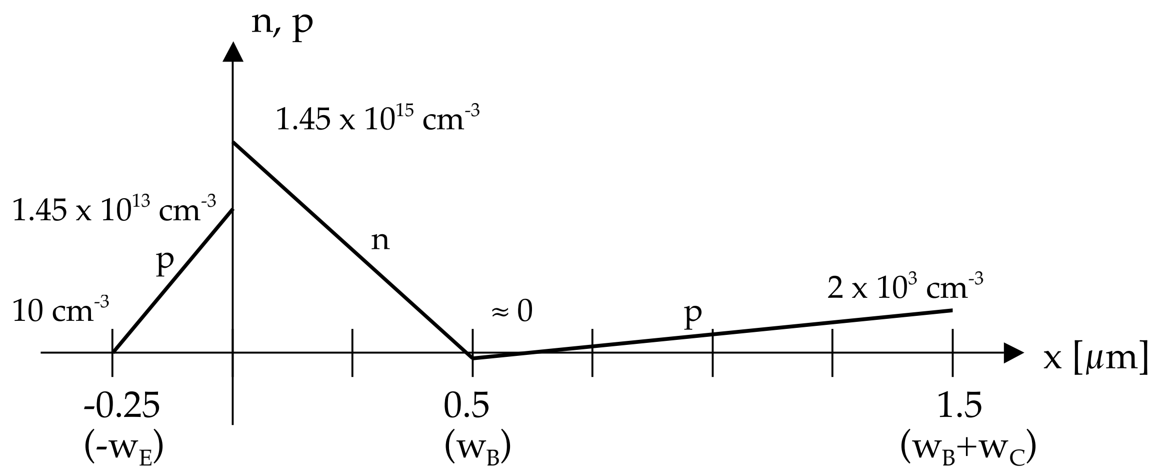
d) Use the Gummel plot to find a value for I_{ES}, and then use I_{ES} to find N_{AB}:

$I_C \approx I_{ES} \exp(qV_{BE}/kT)$, and $I_{ES} \approx\ Aqn_i^2(D_e/W_{B,eff} N_{AB})$,

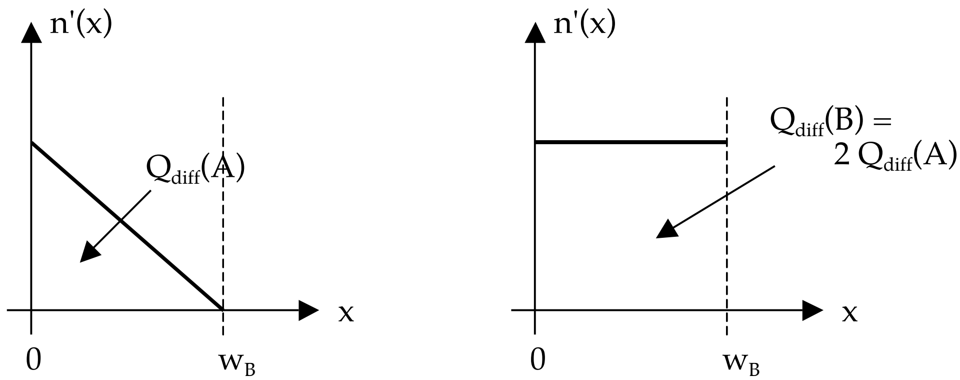
so $N_{AB} = Aqn_i^2(D_e/W_{B,eff} I_C) \exp(qV_{BE}/kT) = 1 \times 10^{17}\ \text{cm}^{-3}$

e) With the results of Parts (c) and (d), we find $N_{DE} = r\ W_{B,eff} N_{AB}/W_{E,eff} = 1 \times 10^{19}\ \text{cm}^{-3}$

f)



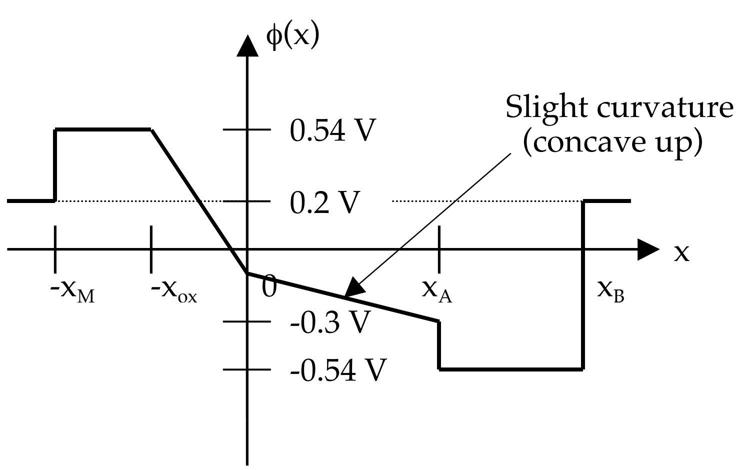
g)



Problem 3: Graded by John Hennessey for Prof. Antoniadis

a) $V_{FB} = -(\phi_{n+} - \phi_p) = -[0.54 - (-0.3)] = -0.84$ V

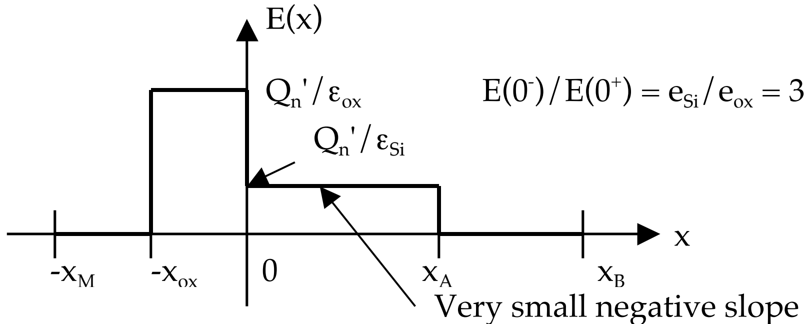
b)



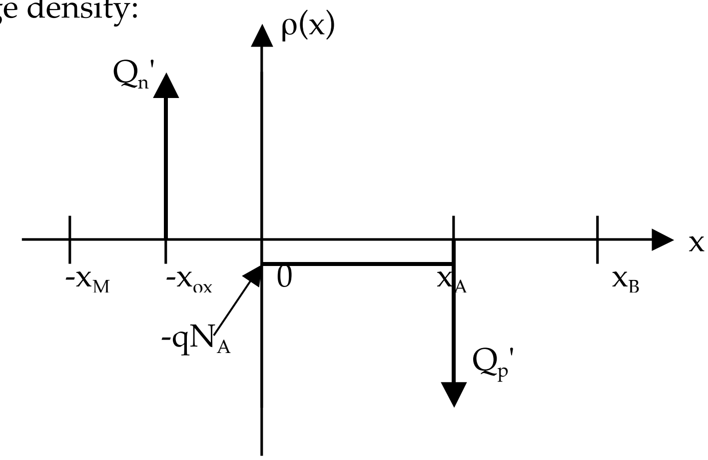
c) $x_p = x_A = (2\,\varepsilon_{Si}\,\Delta\phi / q\,N_A)^{1/2} = 10$ nm. We find $\Delta\phi = 0.08$ V

The assumption is justified because the total potential change, which is $|V_{FB}|$, is much greater than this value.

d) i) Electric field:



ii) Charge density:



e) Neglecting qN_Ax_A relative to Q_n' and Q_p', then $Q_p' \approx Q_n'$. The situation looks like a parallel plate capacitor with two different dielectrics. The total potential drop from $x = -x_{ox}$ to $x = x_A$ is V_{FB}, or 0.84 V. The drop across the oxide is $Q_p'x_{ox}/\varepsilon_{ox}$ and that across the silicon is $Q_p'x_{Si}/\varepsilon_{Si}$. Adding these together and setting them equal to V_{FB}, $Q_p'x_{ox}/\varepsilon_{ox} + Q_p'x_{Si}/\varepsilon_{Si} = V_{FB}$, we find

$$Q_p' = V_{FB}/(x_{ox}/\varepsilon_{ox} + x_{Si}/\varepsilon_{Si}) = 3.5 \times 10^{-7}\ \mathrm{C/cm^2}$$

f) The charge in the depleted lightly doped p-region is:

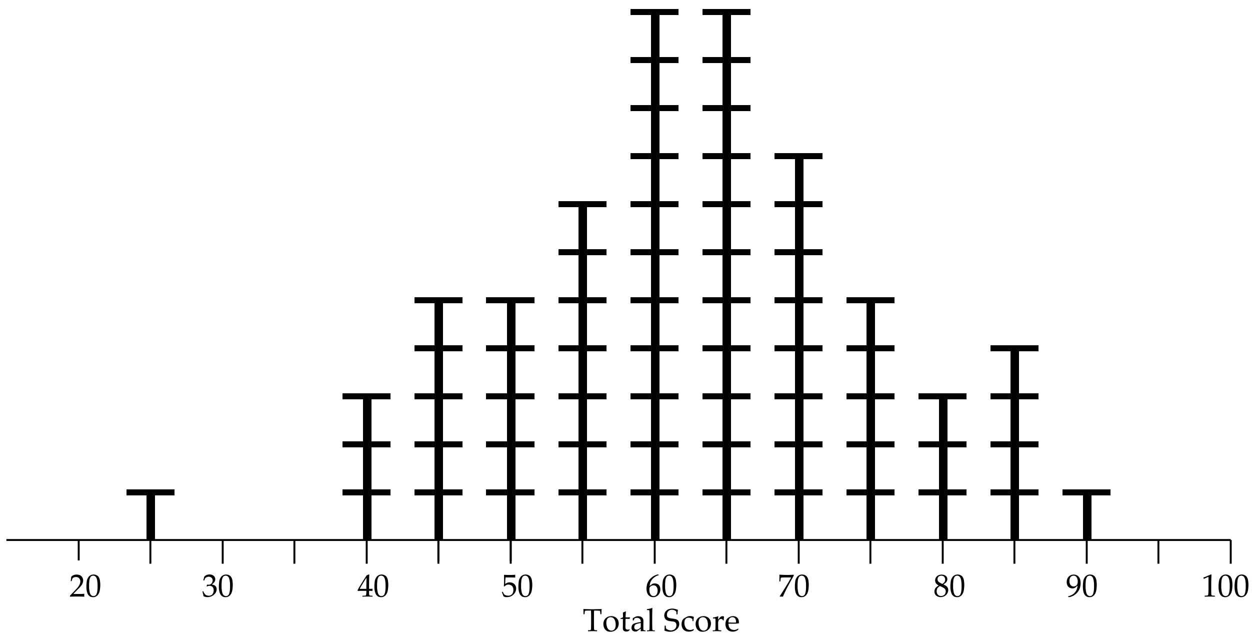
$$-qN_A\,x_A = 1.6 \times 10^{-19}\ 10^{15}\ 10^{-6} = -\,1.6 \times 10^{-10}\ \mathrm{coul/cm^2}$$

This is much less than Q_p', so it neglecting it was a good approximation.

Average/Standard deviation:	Problem 1	28.7	4.6
	Problem 2	18.5	6.1
	Problem 3	14.7	5.5
	Total	62.0	12.7

Distribution to nearest 5:

Find your face in this picture



6.012 Microelectronic Devices and Circuits
Fall 2009