Birla Institute of Technology and Science, Pilani, Rajasthan
First Semester 2015-16
End-Semester Examination (Part A Closed Book)
Course Title: Physics and Modeling of Microelectronic Devices,   Date: 05/12/2015

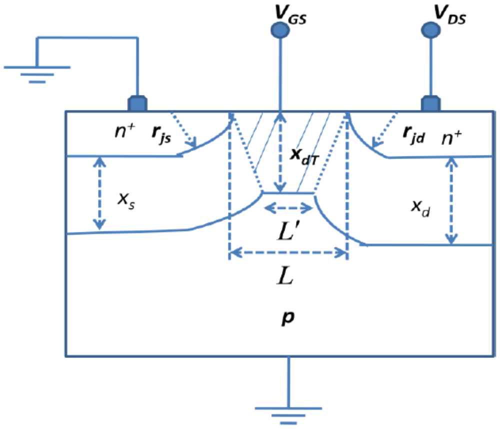
Course No. MEL G631   Maximum Marks: 95   Maximum Time: 150 Mins

1. (a) Show that due to the channel length modulation in an n-channel MOSFET, the expression for ΔL is given as: $\Delta L = \sqrt{\frac{2\varepsilon_s}{qN_a}}\left[\sqrt{\phi_{fp} + V_{DS}(sat) + \Delta V_{DS}} - \sqrt{\phi_{fp} + V_{DS}(sat)}\right]$.

(b) Calculate the ratio $\left(\frac{L}{L-\Delta L}\right)$ for an n-channel MOSFET with Silicon substrate doping concentration of $N_a = 2\times10^{16} cm^{-3}$, a threshold voltage of $V_T = 0.4V$, and a channel length of $L = 1\mu m$. The device is biased at $V_{GS} = 1V$ and $V_{DS} = 2.5V$. ($n_i = 1.5\times10^{10} cm^{-3}$)
[7+8]

2. (a) An n-channel MOSFET has the following parameters: $L = 1\mu m$, $W = 10\mu m$, $t_{ox} = 250$ Å , $N_a = 5\times10^{15} cm^{-3}$, and applied voltages of 3V. If the device is to be scaled using constant field scaling, then determine the new device parameters for a scaling factor of κ=0.7. Also determine the effect of this scaling on the "device density", "power dissipation per device" and to the "power density" of the device.

(b) The expression for the change in the threshold voltage is given as $\Delta V_T = -\frac{qN_a x_{dT}}{C_{ox}}\left[\frac{r_j}{L}\left(\sqrt{1+\frac{2x_{dT}}{r_j}} - 1\right)\right]$ when we assume the three space-charge widths to be equal i.e, $x_s \approx x_d \equiv x_{dT}$. However, when a drain voltage is applied, the above condition is no longer valid (See the figure below). Now, using the same trapezoidal method, obtain the expression for ΔV_T when $x_s \neq x_d \neq x_{dT}$.



(c) Assuming that, $x_s \approx x_d \equiv x_{dT}$, what should be the minimum channel length L so that the ΔV_T should be no more than -0.20 V for an n-channel MOSFET with a substrate doping of $N_a = 3\times10^{16} cm^{-3}$ and has an oxide thickness of $t_{ox} = 800$ Å. The diffused junction radius r_j for this device is 0.60 μm.

[10+10+10]

3. (a) A uniformly doped npn bipolar transistor at T= 300K is biased in saturation. Starting with the continuity equation for the minority carriers, obtain the expression for excess minority carrier concentration in the base region for $\frac{x_B}{L_B} << 1$ where x_B is the neutral base width. [10]

(b) Consider an npn bipolar transistor at T=300K with $J_{r0} = 10^{-8}$ A/cm^{-2} and $J_{s0} = 10^{-11}$A/cm^{-2} respectively. What should be the forward biased B-E voltage required to achieve a recombination factor equal to $\delta = 0.9967$ for this device operating under forward-active mode. [10]

(c) Sketch all the current density components of a npn bipolar transistor which is operating in the forward-active mode. Label all the current density components. [10]

4. In heavily doped semiconductors, the Fermi level is very close to the energy levels in the bands and the state occupancy approximation by the Maxwell-Boltzmann distribution is no longer accurate. For an N-type semiconductor, this occurs when the condition $\exp[(E - E_F)/kT] >> 1$ is no longer satisfied because the bottom of the conduction band is too close to the Fermi level. In this case, the Fermi-Dirac distribution has to be used:

$$n_0 = \int_0^\infty g_C(E) f_D(E) dE = \frac{8\sqrt{2}}{h^3}\pi\left(m^*\right)^{3/2}\int_0^\infty \frac{E_{kin}^{1/2}}{1 + \exp[(E_{kin} + E_C - E_F)/k_B T]} dE_{kin}$$

(Here, $E_{kin} = E - E_C$)

(i) Express the electron concentration n_0 in terms of the effective density of states, $N_C = \frac{4\sqrt{2}}{h^3}\left(\pi m^* k_B T\right)^{3/2}$ and the Fermi integral, given by $F_{1/2}(\eta) = \int_0^\infty \frac{x^{1/2} dx}{1 + e^{x-\eta}}$

(ii) Derive electron-concentration equation for heavily doped semiconductors using the following approximation for the Fermi integral $F_{1/2}$

(a) $F_{1/2} \approx \frac{\sqrt{\pi}}{2} e^{\eta}$, for $-\infty < \eta \le -1$

(b) $F_{1/2} \approx \frac{\sqrt{\pi}}{2} \frac{1}{\frac{1}{4} + e^{-\eta}}$, for $-1 < \eta < 5$

(c) $F_{1/2} \approx \frac{2}{3}\eta^{3/2}$, for $5 \le \eta < \infty$ [5+15]

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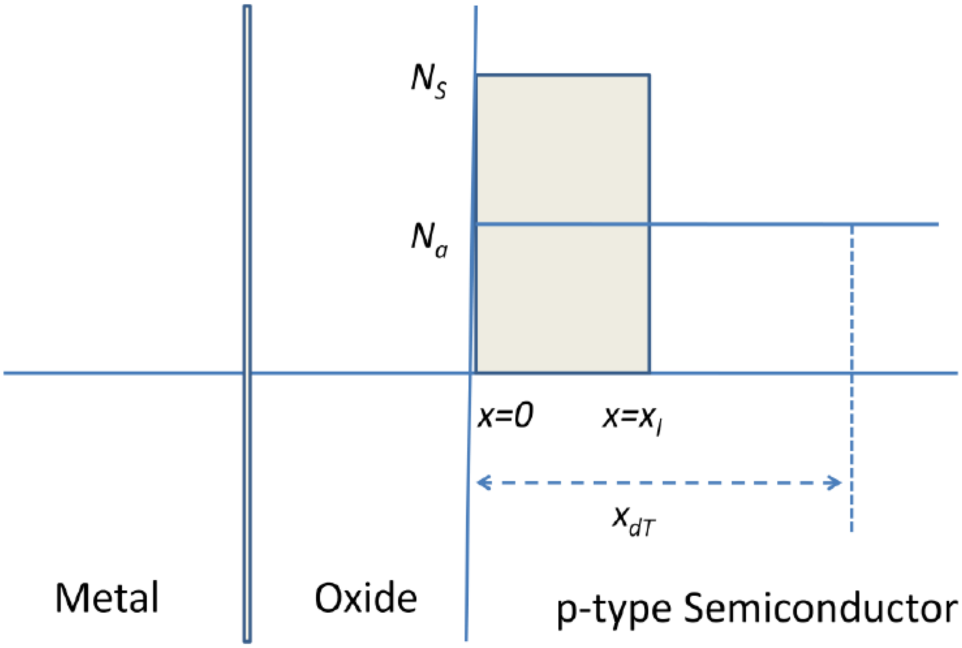
Figure 1 shows the doping profile of the p-type substrate of an n-channel MOSFET. Show that the expression of the depletion width x_{dT} is given as:

$$x_{dT} = \sqrt{\frac{2\varepsilon_s}{qN_a}}\left\{2\phi_{fp} - \frac{qx_l^2}{2\varepsilon_s}\left(N_s - N_a\right)\right\}^{1/2}$$

when the MOSFET is at the threshold inversion point.



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