ECE 221B Spring 2004 Homework #3 Due: Tuesday, May 18, 2004

Question 1

The small signal capacitance of a (Metal-SiO$_2$-Si-Metal) MOS capacitor is equal to a series connection of two capacitors—

1) one capacitor formed by a plate in bulk Si and the other plate at the SiO$_2$-Si interface, and

2) the second capacitor, which has its plates separated by the oxide layer.

Prove this using Gauss’ law.

Question 2

A frequently needed quantity in experimental studies of MOS transistors is $\phi_S$, the surface potential.

1) Using your result of question 1, show that when the gate voltage $V_G$ is changed in a MOS capacitor biased in the depletion region, it is possible to find the corresponding change in $\phi_S$ by using the measured capacitance of the MOS system. The change is calculated from the relation

$$\phi_S(V_{G2}) - \phi_S(V_{G1}) = \int_{V_{G1}}^{V_{G2}} \left(1 - \frac{C}{C_{ox}}\right) dV_G$$

2) If $V_{G1}$ is taken as $V_{FB}$ (Flat band voltage), sketch a low frequency MOS capacitance curve for p-type silicon bulk. Normalize it to $C_{ox}$ and indicate by shading an area of the curve equal to $\Delta \phi_S$. 

Question 3

Consider that a MOS system on p-type silicon is biased to deep depletion by the sudden deposition of a total charge $Q_g$ on the gate at time $t=0$. Carrier generation in the space charge region at the silicon surface results in a charging current for the channel charge $Q_n$ according to the net generation rate equation

$$J_G = \frac{q n_i x_i}{2\tau_0}$$

where $\tau_0$ is the maximum recombination rate, and $x_i$ is the width of the space charge region. This allows us to write

$$\frac{dQ_n}{dt} = -\frac{q n_i (x_d - x_{df})}{2\tau_0}$$

where $x_d$ is the (time dependent) depletion-region width at the surface. The quantity $x_{df}$ is the space-charge region width at thermal equilibrium; that is, when $x_d = x_{df}$, channel charging by generation is zero.

1) Show that the time evolution of $Q_n$ is governed by the differential equation

$$Q_n + \left(\frac{2\tau_0 N_A}{n_i}\right) \cdot \left(\frac{dQ_n}{dt}\right) = -\left[Q_G - qN_A x_{df}\right]$$

2) Solve this equation subject to $Q_n(t=0) = 0$ and thus show that the characteristic time to form the surface inversion layer is of the order

$$T \sim \frac{2N_A \tau_0}{n_i}.$$

Question 4

Calculate the area density of surface states that would lead to a surface generation rate of a fully depleted surface to equal twice the generation rate in the surface depletion region. Consider the states to be characterized by a capture cross-section of $10^{-15}$ cm² and the thermal velocity to be $10^7$ cm/s. Assume the surface depletion region to be 1μm wide and the time constant $\tau_0$ is 1μs.
**Question 5**

Design an AlInAs/GaInAs HEMT for maximum $g_m$ such that charge in the channel is $3 \times 10^{12} \text{cm}^{-2}$. Assume the doping in the AlInAs is $5 \times 10^{12} \text{cm}^{-2}$. Assume the surface barrier is 0.8V and $\Delta E_C$ is 0.55eV. Also, assume that the substrate is GaInAs and is doped p-type such that $E_F = E_V$ in the substrate. Assume the buffer is 0.5µm thick. Also assume the minimum spacer allowed is 2nm.

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AlInAs

GaInAs undoped buffer

P-GaInAs substrate
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What is the current available from the device. At zero gate bias assuming a gate length of 1µm. The velocity-field wave is shown below.

![Velocity-field wave diagram](image-url)