

EE566 Solid State Devices

Spring 2009

Dept of Electrical Engineering

University of Notre Dame

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Assignment 8

Posted: 04/05/2009

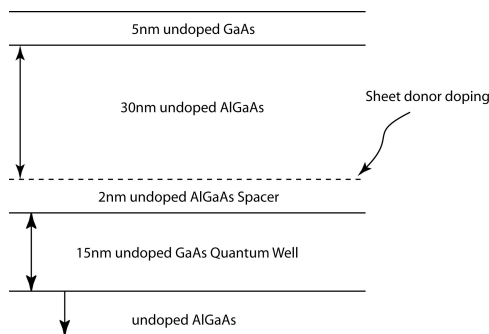
Due: 04/14/2009

Reading: Chapters 8 & 9 of the Textbook (MS).

Problem 1: (MESFETs – 2-dimensional problem)

Derive and plot the two-dimensional potential profile in the depletion region under the gate of a MESFET with zero gate voltage, and drain-source bias high enough that the current I_{ds} is saturated. Plot the electric field, potential, and band diagrams along the channel from source to drain, and perpendicular to the channel at the source- and drain-ends of the gate. Assume the MESFET channel to be long, such that gradual channel approximation holds near the source end. Explain everything you assume in the derivation. (Read the Grebene and Gandhi paper!).

Problem 2: (HEMTs – Design your own structure)



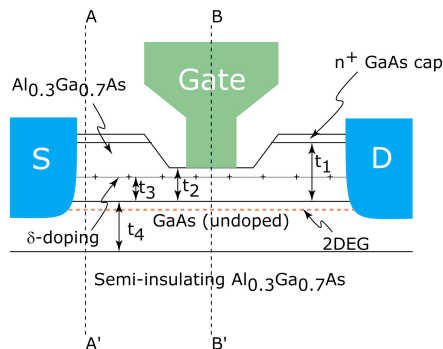
Consider the AlGaAs/GaAs ($\Delta E_c=0.25\text{eV}$) HEMT layer structure shown. Assume that surface states pin the GaAs surface Fermi level 1eV below the conduction band. I require the sheet density of the channel to be $n_s=10^{12}/\text{cm}^2$.

- Calculate the sheet doping in the donor layer required to achieve that. Clearly draw the charge, field, and band diagrams. Verify with 1D Poisson. Note that the quantum well is triangular in shape.
- Calculate the g_m vs V_{gs} curve for the HEMT, assuming $v_{sat}(\text{GaAs})=10^7\text{cm/s}$, $v_{sat}(\text{AlGaAs})=2 \times 10^6\text{cm/s}$, gate length to be short,

and V_{ds} is high, such that the saturated velocity model holds. Make any simplifying assumptions you think reasonable. Calculate the threshold voltage V_{th} required to deplete the channel.

- Now, I want the quantum well to be flat instead of triangular. Design that for me.
- Why would anyone need a flat quantum well? Are there any disadvantages?

Problem 3: (AlGaAs/GaAs HEMT charge control and transconductance)



Consider the AlGaAs/GaAs HEMT structure shown. The structure is grown by MBE, and the thickness and doping of the layers are - cap layer: $N_D=7 \times 10^{17}/\text{cm}^3$, $t_{cap}=5\text{nm}$, $\text{Al}_{0.3}\text{Ga}_{0.7}\text{As}$ layer thickness $t_1=25\text{nm}$, after gate-recess etch, AlGaAs thickness $t_2=17\text{nm}$, delta-doped layer thickness=1nm & effective 3D-doping= $3.5 \times 10^{19}/\text{cm}^3$, $t_3=5\text{nm}$, and GaAs quantum well thickness $t_4=10\text{nm}$. Assume the surface barrier is pinned at $q\Phi_s=0.6\text{eV}$ below the conduction band edge for both GaAs and AlGaAs.

- Calculate the 2DEG sheet density in the GaAs QW below the gate. Draw the charge-field-band diagram along line B-B'

for finding the sheet density. Verify your calculated value with 1D Poisson simulation of the charge-field-band diagram. Is there any quantum-confinement*? How many quantum-confined states are formed in the GaAs QW? What are the eigenvalues? (Contd...)

* Run the "schrodingerstart", and "schrodingerstop" functions, and use the "*.status" file in 1-D Poisson.

b) Calculate the 2DEG sheet density in the GaAs QW below the source-and drain-access regions. Draw the charge-field-band diagram along line A-A' for finding the sheet density. Verify your calculated value with 1D Poisson simulation of the charge-field-band diagram. Comment on quantum confinement and eigenvalues.

c) What is the gate-capacitance C_g ? Assuming the HEMT to be a short-channel FET, calculate the transconductance g_m using GaAs material parameters. Calculate the threshold voltage V_{th} for the HEMT.

d) Explain, using 2DEG-sheet density results of parts a) and b) and the transconductance of part c), what is gained by the gate-recess process. What would the transconductance be if the gate was not recessed?

Problem 4: (AlGaN/GaN HEMTs)

III-V Nitride heterostructures exhibit electronic polarization, which is distinct from other III-V semiconductors. Answer the following:

a) What is the physical origin of the spontaneous and piezoelectric polarization in nitride semiconductors?

b) What are the consequences of polarization on HEMT design?

c) Solve **problem 8.19** (page 426, textbook – MS) on AlGaN/GaN HEMT structures.

d) What advantages/disadvantages do AlGaN/GaN HEMTs offer over those made from other III-V semiconductors? Answer in the form of two tables: one for digital devices, and the other for analog devices. Compare FET technologies based on Silicon, GaAs, InGaAs, SiC, and GaN for each table. Choose the metrics that are key to FET digital and analog applications.