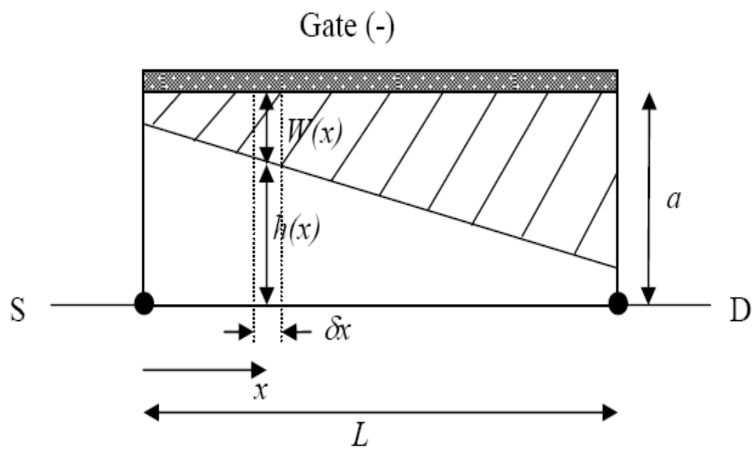
EE416 Problem Sheet 1- March 2013

1. A GaAs MESFET has a channel thickness of 0.3 μm doped to a value $N_D = 2 \times 10^{22}$ m^{-3}. Calculate the pinch-off voltage, V_P. What drain voltage, V_D, would cause the 1 μm metallic gate to effectively reduce by 10%, assuming that the lateral depletion after pinch-off occurs equally under the gate and towards the drain contact (use ε_r (GaAs) = 13.2).

1.23 V, 1.78 V.



Depletion region pinches off at V_p

$$V_p = \frac{qa^2N_D}{2\varepsilon}$$

A=0.3micron =3×10^{-7}m

$N_D = 2 \times 10^{22}$m^{-3},

$\epsilon = \epsilon_r \epsilon_0 = 13.2 \times 8.85 \times 10^{-12}$ F·m^{-1}

q = 1.6×10^{-19} C

→ **V_p=1.23V**

1 micron gate effectively reduced by 10% = 100nm

Pinch off equally under the gate and towards the drain contact. ΔL= 200nm

For MESFET

$$\Delta L = \sqrt{\frac{2\varepsilon(V_{DS} - V_P + V_G)}{qN_D}}$$

$$\frac{2\varepsilon}{qN_D} = 7.29x10^{-14} = k$$

so $\Delta L^2 = k.(V_{DS}-V_P+V_G)$.

$(V_{DS}-V_P+V_G) = \Delta L^2/k = (200 \times 10^{-9})^2 / 7.29 \times 10^{-14} = 0.54$

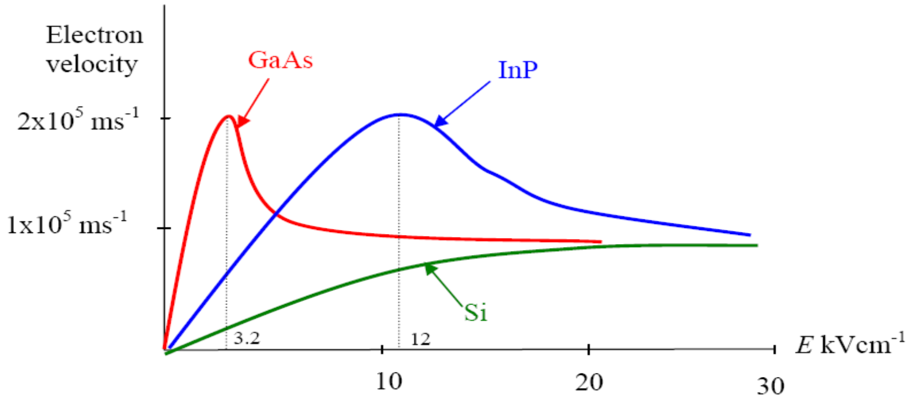
$V_{DS} + V_G = V_P + 0.54 = 1.78$. Assume V_G=0 or small (should have said that in the question)

V_{DS}= 1.78

2. For the device of question 1, show why it is unreasonable to use mobility, μ, to calculate the transit time under the gate.

What's the field across the source-drain region? E= dV/dx

V_{DS}=1.78 x= 1micron. E= 1.78×10^{6} $V.m^{-1}$ or $17.8kV.cm^{-1}$



This is well into

Well into velocity saturation. Mobility is no longer a function of the E-field but is constant with a saturated velocity

3. Calculate the maximum transconductance per mm of gate width for a GaAs MESFET with a doping of 1×10^{17} cm^{-3} in the channel, channel thickness of 0.2 μ m, gate length of 1 μm and mobility of 0.5 $m^{-1}V^{-1}s^{-1}$. What is the pinch-off voltage for this device? Estimate the saturated drain current for a gate voltage equal to half the pinch-off voltage and a gate width of 500 μm (use ε_r=13.2 and assume that the Schottky barrier voltage is negligible compared to V_P).

1.6 S/mm, 2.75 V, 0.56 A.

Transconductance of MESFET

$g_m = \frac{dI_D(sat)}{dV_G} = -\frac{Za}{\rho L}\left[1-\left(\frac{V_G}{V_p}\right)^{1/2}\right]$. Whats the maximum of this term?

When V_G is zero term in brackets goes to [1]. g_m=-Za/ ρL

a=0.2micron, L=1micron

$\rho = {}^{1}/_{\sigma} = {}^{1}/_{ne\mu}$ can safely assume $n=N_D=1\times10^{17}cm^{-3} = 1\times10^{23}m^{-3}$

So $\rho= 1/1\times10^{23}\times1.6\times10^{-19}\times0.5 = 1.25\times10^{-4}$

Asking for g_m per unit gate width, so we can drop the Z term

So $g_m = a/\rho L =$ 1600 S per m. **g_m= 1.60 S per mm**

Pinch off (same as before)

$$V_p = \frac{qa^2N_D}{2\varepsilon}$$ a=0.2micron =2×10^{-7}m, $N_D=1\times10^{23}$m^{-3},

$\epsilon = \epsilon_r\epsilon_0 = 13.2\times 8.85\times 10^{-12}$ F·m^{-1} q = 1.6×10^{-19} C

→ **V_p=2.75V**

Saturated drain current

$$I_D(sat) = \frac{Za}{\rho L} V_P \left[\frac{1}{3} - \frac{V_G}{V_P} + \frac{2}{3}\left(\frac{V_G}{V_P}\right)^{3/2}\right]$$

V_p=2.75V V_g= half this value =1.375

Vg/Vp =0.5 so term in brackets becomes $0.333-0.5+0.666\times0.5^{1.5}$= 0.0688

Gate width (z) is 500micron= 5×10^{-4}m. A=0.2µm, so a/ρL = 1600

I_D(sat) = 0.8 x2.75 x0.0688 = 0.152A

4. Currently the minimum gate length possible in MESFETs is ~0.2 µm. Assuming the channel characteristics of the previous problem, except for a thickness of 0.1 µm, and a gate length of 0.2 µm, calculate the maximum intrinsic g_m in Sm^{-1} and f_T, from both the capacitance charging and transit time points of view. What is the extrinsic (including parasitics) g_m assuming a source-gate separation of 0.3 µm and the resulting f_T from this? (use v_{sat} = 1×10^5 ms^{-1}). *Hint: Use $R_S = \rho l/A$ between source and gate.*

4000 Sm^{-1}, 2725 GHz (charging time), 79.6 GHz (transit time), 1600 Sm^{-1}, 1090 GHz.

Same as before $g_m = \frac{dI_D(sat)}{dV_G} = -\frac{Za}{\rho L}\left[1-\left(\frac{V_G}{V_p}\right)^{1/2}\right]$ at a maximum with therm in the brackets going to [1]. In this case g_m=-Za/ ρL

a=0.1micron, L=0.2micron

g_m (max) =4000S.m^{-1}

Cut of frequency $f_T = \frac{1}{2\pi\tau}$. Easiest to consider is where τ is the transit time

Velocity= distance/time. Electrons are always in saturation for short gate lengths

So $f_T = \frac{V_{sat}}{2\pi L}$ = $8.0\text{x}10^{10}$= **80GHz**

What about considering this as a charging gate capacitor?

$f_T = \frac{g_m}{2\pi C_G}$ also from notes. What is C_G?

Consider parallel plate capacitor of width – depleted channel

$C = \frac{\varepsilon_r \epsilon_0 \, Area}{distance} = \frac{\varepsilon_r \epsilon_0 \, L.z}{a}$ but g_m is per unit gate width, so can drop the z from this.

$C = \frac{\varepsilon_r \epsilon_0 L}{a} = \frac{\varepsilon_r \epsilon_0 0.2}{0.1}$ = 13.2x 8.85× 10^{-12} x 2= $2.33\text{x}10^{-10}$

g_m= 4000 Sm^{-1} from before, so f_t= 4000/2 x 3.142 x $2.33\text{x}10^{-10}$= $2.73\text{x}10^{12}$Hz or 2730GHz (somewhat ridiculous)

Modified transconductance with parasitic source resistance

$g'_m = \frac{g_m}{1+R_s g_m}$ so we will need to calculate R_s- the source resistance

$R_s = \frac{\rho L}{A}$ L is the source to gate separation (0.3micron). Area A is the gate width (z) x channel width (a) but we want to keep things as per gate width for the z term can be dropped

So R_s= $1.25\text{x}10^{-4}$ x $0.3\text{x}10^{-6}$/$0.1\text{x}10^{-}$= $3.75\text{x}10^{-4}$ Ohm.m^{-1}

R_s x g_m= 1.5

Extrinsic g_m= 1/ (1+ 1.5)= 1600Sm^{-1}

Use $f_T = \frac{g_m}{2\pi C_G}$ as before where C= $2.33\text{x}10^{-10}$ C.m^{-1}

g_m= 4000 Sm^{-1} from before, so ft= 1600/2 x 3.142 x 2.33x10^{-10}= **1090GHz** (somewhat less ridiculous)

5. Repeat the calculation for the intrinsic g_m in the previous problem but assuming that velocity saturation (v_{sat}) applies because of the short channel.

235 Sm^{-1}.

Need to find g_m in terms of V_{sat} and not mobility

$g_m = \frac{\partial i_D}{\partial v_G}$ by definition. The drain current (I_D) is simply charge per unit (dQ/dt)

I_D= charge $n_S q$ x v_{sat} *(per unit gate width)*

So $g_m = \frac{\partial(n_S q)}{\partial v_G} = \frac{C_G}{L} v_{sat}$ *(because dQ/dV_G= C_G)*

C_G=2.33x10^{-10}F (from before). V_{sat} is 1x10^5m.s^{-1}. L=0.2micron

g_m=116.5S.m^{-1}

6. Calculate the intrinsic g_m and f_T for a HEMT device with the same gate dimensions as in 4 above but with a sheet concentration ($\equiv aN_D$ in the expression for the MESFET) of 3×10^{12} cm^{-2} and a mobility of 1.2 $m^2V^{-1}s^{-1}$. (These are state-of-the-art figures for InGaAs/InP HEMTs).

2.88×10^4 Sm^{-1}, 79.6 GHz (using velocity saturation).

$g_m(max) = -\frac{Za}{\rho L}$ $\quad \rho = {}^1/_\sigma = {}^1/_{ne\mu}$ we are given the sheet concentration n_s of 3x$10^{12}$$cm^{-2}$ (= 3x$10^{16}$$m^{-2}$)

The sheet concentration is equivalent to n.a. so $\rho = {}^a/_{n_s e\mu} = {}^a/_{n_s e\mu}$= 173.6.a. Put this into the equation for g_m and then a drops out (as does the z) and we get 1/9173.6 x **0.2x10^{-6}**)= **2.88x10^4 S.m^{-1} (increases a lot)**

$f_T = \frac{V_{sat}}{2\pi L}$ **= 80x10^{10}= 80GHz (unchanged)**