ECE 340 Homework XVI Spring 2003

Due: Monday, May 5, 2003

1. *On a semi-insulating GaAs substrate a lightly n-type doped GaAs is epitaxially grown, and an MESFET with a gate length of 3 μm is fabricated. (In practice, ion implantation instead of epitaxial growth is used to realize MESFET devices to reduce the cost.) The epitaxial layer is 0.6 μm thick and has a doping concentration of $4x10^{16}/cm^3$. Assume that the Schottky barrier is 0.8V and gate width is 100 μm. Given $n_i = 2x10^6/cm^3$, $\mu_n = 6000\ cm^2/V\text{-}s$ at room temperature a gate width Z=50 μm, and the relative dielectric constant for GaAs is 13.2. (a) Determine the drain voltage, V_D, required to pinch off the channel for $V_G = -1$ V and (b) estimate the channel current for $V_D = 0.1$ V and $V_G = -1$ V and (c) estimate the saturation current for $V_G = -1$ V where V_G is the gate voltage, and (d) estimate the saturation current for $V_G = -5$ V.*

(a), Refer to fig 6-7, the MESFET is very similar to a typical JFET. The gate voltage is applied only on one side of the channel. Pinch off happen when the channel width at drain is zero.

$$E_F - E_i = \frac{kT}{q}\ln\frac{n}{n_i} = 0.0259\times\ln\frac{4\times10^{16}}{2\times10^{6}} = 0.614eV$$

$$E_c - E_F = \left(\frac{E_g}{2} - (E_F - E_i)\right) = \frac{1.43}{2} - 0.614 = 0.101eV$$ (look up appendix III to get E_g.)

$$qV_0 = q\Phi_B - (E_c - E_F) = 0.8 - 0.101 = 0.699eV$$ (Please refer to fig 5-40 if you are not clear on this)

At pinch-off, the depletion width is same as channel width at drain, we have:

$$a = \left[\frac{2e(V_0 - V_G + V_D)}{qN_d}\right]^{1/2} = 0.6mm$$

Plug in numbers, we get:

$$V_P = V_0 - V_G + V_D = \frac{qa^2N_d}{2e} = \frac{1.6\times10^{-19}\times(0.6\times10^{-4})^2\times4\times10^{16}}{2\times13.2\times8.85\times10^{-14}} = 9.86V$$ (please notice that the e for GaAs is different from Si, also that gate voltage is only applied to onside of channel in MESFET (i.e, a=0.6um)

Therefore, if V_G = -1 V, V_D must be at least 9.86-0.699-1 =8.16V to pinch off the MESFET.

(b), $$G_0 = \frac{aZ}{rL} = \frac{s\,aZ}{L} = \frac{qm_n naZ}{L} = \frac{1.6\times10^{-19}\times6000\times4\times10^{16}\times0.6\times10^{-4}\times100\times10^{-4}}{3\times10^{-4}} = 0.0768\Omega^{-1}$$

We can solve the problem by modifying the equation 6-9 to (you can't use 6-9 without modifying it because 6-9 doesn't count for V_0.):

$$I_D = G_0V_p\left[\frac{V_D}{V_P} - \frac{2}{3}\left(\frac{V_0 - V_G + V_D}{V_P}\right)^{3/2} + \frac{2}{3}\left(\frac{V_0 - V_G}{V_P}\right)^{3/2}\right]$$

Plug in numbers, we get:

$$I_D = 0.0768\times9.86\left[\frac{0.1}{9.86} - \frac{2}{3}\left(\frac{0.699+1+0.1}{9.86}\right)^{3/2} + \frac{2}{3}\left(\frac{0.699+1}{9.86}\right)^{3/2}\right]$$

$$= 4.50mA$$

(c),

$$I_{D.SAT} = G_0 V_p \left[\frac{1}{3} - \left(\frac{V_0 - V_G}{V_P} \right) + \frac{2}{3} \left(\frac{V_0 - V_G}{V_P} \right)^{3/2} \right]$$

$$= 0.0768 \times 9.86 \times \left[\frac{1}{3} - \left(\frac{0.699 + 1}{9.86} \right) + \frac{2}{3} \left(\frac{0.699 + 1}{9.86} \right)^{3/2} \right]$$

$$= 158 mA$$

(d),

$$I_{D.SAT} = G_0 V_p \left[\frac{1}{3} - \left(\frac{V_0 - V_G}{V_P} \right) + \frac{2}{3} \left(\frac{V_0 - V_G}{V_P} \right)^{3/2} \right]$$

$$= 0.0768 \times 9.86 \times \left[\frac{1}{3} - \left(\frac{0.699 + 5}{9.86} \right) + \frac{2}{3} \left(\frac{0.699 + 5}{9.86} \right)^{3/2} \right]$$

$$= 36.6 mA$$

2. *Refer to Fig. 1-13. Assuming the lattice constant varies linearly with composition x for a ternary alloy, what composition of InxGa1-xP is lattice-matched to GaAs? What is the bandgap energy of the $In_xGa_{1-x}P$ layer? Also, assume that a p-n junction is made in the corresponding lattice-matched epitaxial layer to form a light emitting diode and isotropic light emits. In general, about half of the photons go toward the substrate side. If the $In_xGa_{1-x}P$ diode can be grafted from its original GaAs substrate onto different substrates, which substrate among GaSb, InP, GaP and SiC is considered to be transparent? Namely, which substrate would not considerably absorb the light emitted from the p-n junction toward the substrate?*

Solutions:

For $In_xGa_{1-x}P$, the lattice constants are: GaAs: 5.66Å, InP: 5.87 Å, GaP: 5.45 Å.

$\frac{5.87 - 5.66}{x} = \frac{5.66 - 5.45}{1 - x}$, therefore: $x = 0.50$

At $x = 0.50$, $In_xGa_{1-x}P$ has $E_g \approx 1.95 eV$.

GaSb: $E_g = 0.7 eV$, InP: $E_g = 1.35 eV$

GaP: $E_g = 2.26 eV$, SiC: $E_g = 2.86 eV$

GaP and SiC can't absorb the light emitted from the diode because GaP and SiC has larger E_g than the light energy emitted from the diode. Therefore, GaP and SiC will be considered transparent.