The University Of Sheffield.

Data Provided: A list of material parameters and formulae at the end of the paper

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Spring Semester 2012-13 (2.0 hours)

EEE6040 High Speed Electronic Devices 6

Answer **THREE** questions. **No marks will be awarded for solutions to a fourth question.** Solutions will be considered in the order that they are presented in the answer book. Trial answers will be ignored if they are clearly crossed out. **The numbers given after each section of a question indicate the relative weighting of that section.**

1. **a.** i) Sketch and label the typical current-voltage characteristics of a MESFET for different gate voltages. Identify the linear, saturation and breakdown regions.

ii) Describe the mechanisms that control the current flow in the linear, saturation and breakdown regions. **(8)**

b. MESFET is used to achieve high speed amplification in military and satellite communications. Consider an n-channel GaAs MESFET, shown in figure 1.1, with a channel doping $N_D = 2\text{x}10^{15}$ cm^{-3}, a barrier potential $\Psi_{BN} = 0.8$ V, a channel length $L = 1$ um, $a = 0.5$ µm and $Z = 50$ µm.

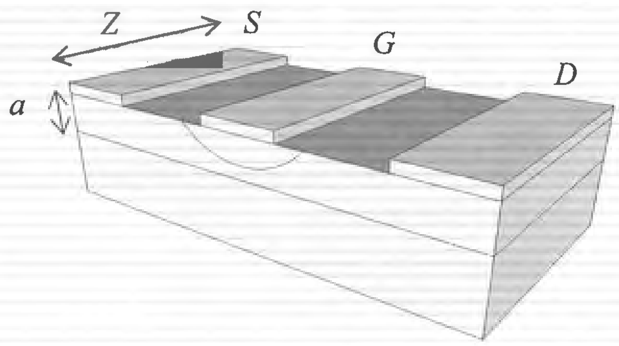


Figure 1.1

i) Describe what is the pinch off voltage and calculate its value.

ii) Calculate the cutoff frequency f_T.

iii) Calculate the threshold voltage, V_T. **(8)**

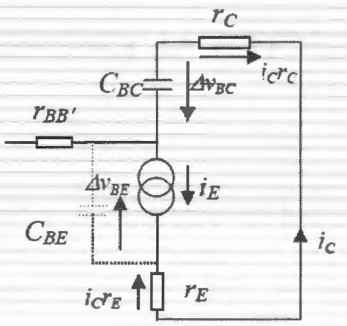
c. Suggest 2 modifications to the basic GaAs MESFET in figure 1.1 so that f_T can be increased to above 100 GHz. Explain how your modifications lead to $f_T > 100$ GHz. **(4)**

2. **a.** Discuss 4 important approaches to increase the cutoff frequency, f_T, of a Si bipolar junction transistor (BJT). **(4)**

b. In most Si BJTs each of the approaches you provided will only be practical for f_T< 20 GHz. Discuss the limitations of each of your proposed approaches in (a). **(4)**

c. In order to improve the f_T of Si BJT, Ge is incorporated so that a SiGe HBT can be fabricated. Describe how SiGe improves the gain and high frequency operation. **(5)**

d.



Parameter	Value
r_C (Ω)	45
r_E (Ω)	26
$r_{BB'}$ (Ω)	300
C_{BC} (fF)	4
C_{BE} (fF)	14

Figure 2.1

The equivalent circuit of a Si BJT is shown in figure 2.1.The drive current is 1 mA. Calculate the f_T for this BJT if the base and collector widths are 75 nm and 200 nm respectively. **(7)**

3. **a.** The expression for the threshold voltage of a Si n-channel MOSFET is given by

$$V_T = -|V_{FB}| + 2|V_B| + \frac{(2q\varepsilon_s N_A|2V_B|)^{1/2}}{C_{ox}}$$

where V_{FB} is the flat band voltage, V_B is the voltage separation between the midgap energy and the bulk Fermi level of the semiconductor, ε_s is the semiconductor dielectric constant, N_A is the semiconductor doping concentration, q is the electronic charge and C_{ox} is the gate oxide (SiO_2 in this case) capacitance per unit area.

i) Describe the effects of each of these parameters on the threshold voltage V_T as the dimensions of CMOS devices reduce.

ii) Explain why it is important to reduce V_T and why it will be difficult to continue to reduce V_T in future CMOS technologies. **(8)**

b. In order to maintain the transistor density, as proposed by Moore's Law, MOSFET dimensions have to be reduced. Discuss how each of the following parameters, i) oxide thickness, ii) gate length and iii) junction depth, influences the scaling process in IC manufacturing. **(6)**

c. Discuss the physical limits of each parameter in part (b) on scaling and how these can be overcome. **(6)**

4. **a.** IMPATT diodes are used in many high speed applications such as RADAR and high frequency oscillator. Sketch an ideal IMPATT diode structure and use it to explain the working principles of an IMPATT diode. **(4)**

b.

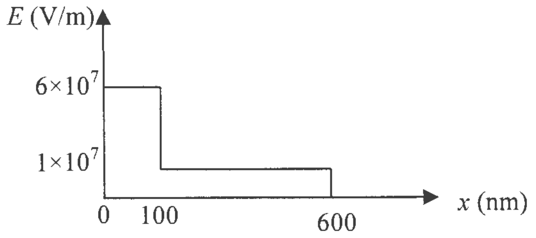


Figure 4.1

In one such GaAs IMPATT diode with an electric field profile, as shown in figure 4.1, calculate the oscillation frequency and the maximum applied voltage assuming a breakdown field of 6×10^{7} V/m in GaAs. **(3)**

c. i) Using the band diagram of a GaAs/AlGaAs High Electron Mobility Transistor (HEMT) biased at its threshold voltage, explain how a high cutoff frequency is achieved. **(4)**

ii) Consider a HEMT with a gate length of 100 nm, a gate width of 200 nm, a 2-DEG concentration of 3×10^{16} m^{-2} and a mobility of 1.6 m^{2}V^{-1}s^{-1}. Estimate the maximum intrinsic transconductance and cutoff frequency. **(3)**

d. i) Pseudomorphic HEMT (p-HEMT) and metamorphic-HEMT (m-HEMT) are two approaches used for fabrication of HEMTs. Describe what p-HEMT and m-HEMT are. **(2)**

ii) Explain the potential device improvements and limitations of p-HEMTs and m-HEMTs. **(4)**

CHT

LIST OF MATERIAL PARAMETERS

Electronic charge, $q = 1.6\times10^{-19}$ C

Permittivity of free space, $\varepsilon_o = 8.85\times10^{-12}$ Fm^{-1}

Planck constant, $h = 6.63\times10^{34}$ Js

Relative permittivity, $\varepsilon_r = 11.7$ (Si), 3.9 (SiO_2), 12.9 (GaAs)

Saturation velocity, $v_{sat} = 1\times10^5$ ms^{-1} (Si), 1×10^5 ms^{-1} (GaAs)

Conduction band density of states, $N_c = 2.86\times10^{19}$ cm^{-3} (Si), 4.71×10^{17} cm^{-3} (GaAs)

Electron mobility at room temperature, $\mu_e = 0.15$ m^{2}V^{-1}s^{-1} (Si)

Semiconductor bandgap, $E_g = 1.43$ eV (GaAs), 2.16 eV (AlAs), 1.12 eV (Si)

LIST OF USEFUL FORMULAE

All symbols have their usual definitions.

$$V_s = 2V_B = \frac{2kT}{q} ln\left(\frac{N_A}{n_i}\right)$$

$$W_m = \sqrt{\frac{2\varepsilon_s 2V_B}{qN_A}} = 2\sqrt{\frac{\varepsilon_s kT ln\left(\frac{N_A}{n_i}\right)}{q^2 N_A}}$$

$$I_D = \frac{9\varepsilon_s \mu_n A V_D}{8L^3}$$

$$I_D = \frac{Z}{L}\mu_n C_o\left(V_G - V_T - \frac{V_D}{2}\right)$$

$$V_T = -|V_{FB}| + 2|V_B| + \frac{(2q\varepsilon_s N_A |2V_B|)^{1/2}}{C_{ox}}$$

$$V_P = \frac{qa^2 N_D}{2\varepsilon_s}$$

$$V_{bi} = \Psi_{BN} - V_n$$

$$V_T = V_{bi} - V_p$$

$$V_n = \frac{kT}{q} ln\left(\frac{N_C}{N_D}\right)$$

$$I_{Dsat} = \frac{Z\mu\varepsilon_s}{2aL}(V_G - V_T)^2$$