The University Of Sheffield.

Data provided:

Electronic charge:	1.602×10^{-19} C
Free electron rest mass:	$m_0 = 9.110 \times 10^{-31}$ kg
Speed of light in vacuum	$c = 2.998 \times 10^{8}$ m s^{-1}
Planck's constant:	$h = 6.626 \times 10^{-34}$ Js
Boltzmann's constant:	$k = 1.381 \times 10^{-23}$ JK^{-1}
Permittivity of free space:	$\varepsilon_0 = 8.854 \times 10^{-12}$ Fm^{-1}
Permeability of free space:	$\mu_0 = 4\pi \times 10^{-7}$ Hm^{-1}

DEPARTMENT OF ELECTRONIC AND ELECTRICAL ENGINEERING

Autumn Semester 2007-2008 (2 hours)

Principles of Semiconductor Devices and Circuits 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.** A silicon wafer is doped with acceptors at 5×10^{20}m^{-3}. The intrinsic carrier density of silicon is 2×10^{16}m^{-3} and the mobilities of the electrons and holes are m_e=0.13V^{-1}.m^{2}S^{-1} and m_h=0.05m^{2}V^{-1}s^{-1} respectively. Assuming all the acceptors are ionised, calculate:

i) the hole concentration
ii) the electron concentration
iii) the conductivity of the wafer
iv) the resistance of a piece of wafer of cross-sectional area 1mm^2 and length 10mm **(6)**

b. (i) What type and concentration of impurities could we use to make the surface of this wafer n-type with an electron concentration of 1×10^{22}m^{-3}?

(ii) Show how it would be very difficult to use the same method to achieve an electron concentration of 1×10^{17}m^{-3} **(4)**

c. A light emitting diode (LED) is comprised of a semiconductor p-n junction under forward bias. **(6)**

i) Draw an energy level diagram for the junction under typical light emission conditions, marking clearly the position of the conduction and valence bands, the Fermi level and the direction of the carrier flow.

ii) Describe using energy-momentum diagrams the process of photon emission for a direct and for an indirect gap semiconductor. In which case is the emission of a photon more favourable? Explain your reasons.

iii) If the semiconductor has a direct gap of 2.2eV, what is the wavelength of the photon?

d. A semiconductor laser can be made from identical material to that used for a light emitting diode (LED), but using a different fabrication process

i) Draw typical light intensity versus forward current characteristics and typical spectral outputs for the two cases. What is the major difference between the emission processes for the laser and the LED?

ii) Describe the advantages of fibre optical communication compared to wired connections **(4)**

2. a. Draw the energy band diagram for a metal to n-type semiconductor junction in equilibrium for the following cases. Indicate whether Ohmic or Schottky (rectifying) behavior is expected from this combination.

i) A metal work-function is greater than the semiconductor work-function.

ii) A semiconductor work-function greater than the metal work-function.

(6)

b. For a rectifying (Schottky) junction the diode saturation current (I_o) is measured to be 2nA.

i) Assuming ideal diode characteristics, calculate the current at: -5V and at +500mA bias.

ii) Metal semiconductor junctions have similar characteristics to p-n junctions, but are generally preferred for high speed operation. Why?

(4)

c. A metal-oxide silicon (MOS) transistor is formed on a p-type wafer with ohmic source and drain contacts and a gate contact separated from the semiconductor by a thin insulating oxide.

i) Draw a cross-sectional diagram of the metal-oxide-silicon transistor under the conditions of a large positive voltage. Indicate the position of the induced channel.

ii) Draw curves showing the typical variation of drain current against drain-source voltage for different values of the gate voltage

(4)

d. The unsaturated drain characteristic of the MOS Transistor is given by:

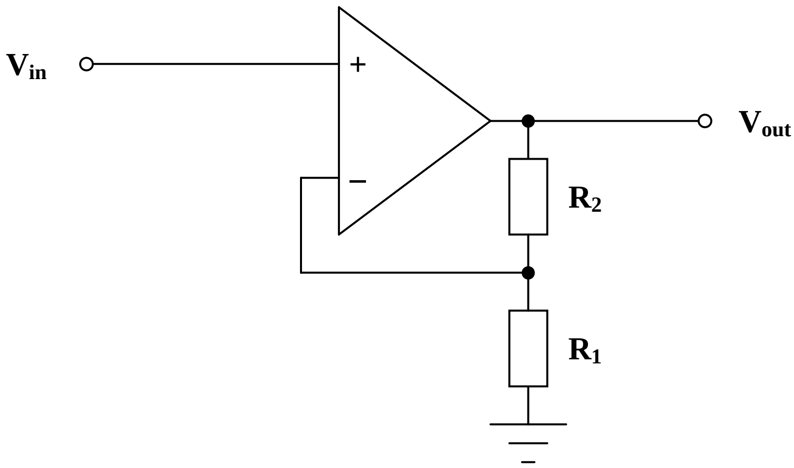
$$I_d = \frac{\mu_e C_g}{l^2}\left[V_g - V_T - \frac{V_d}{2}\right]V_d$$

where μ_e=0.05m^2 V^{-1} s^{-1} , C_g=10pF and l =800nm. The turn on voltage, V_T, has been determined as 0.5V for this device.

i) Simplify the above to give an expression for the saturated drain current. Determine the saturated drain current for gate voltages (V_g) of 0.6V, 1V and 2.0V. **(6)**

ii) Using the above, or otherwise, derive an expression for the transconductance (g_m) of the MOS Transistor in terms of the drain-source voltage. Determine the transconductance for the same gate voltages as above

3. a. The figure below shows a non-inverting op-amp circuit. The op-amp has a first-order gain response given by the expression $A_V = \dfrac{A_0}{1 + \dfrac{jw}{w_0}}$, a gain-bandwidth product of 50 MHz, and an open-loop dc gain of 10^5 V/V.



(i) Show that the transfer function of the circuit is given by:-

$$\frac{V_{out}}{V_{in}} = \frac{\dfrac{R_1 + R_2}{R_1}}{1 + \left(\dfrac{jw}{w_0 A_0}\right)\left(\dfrac{R_1 + R_2}{R_1}\right)} = \frac{k}{1 + \dfrac{jw}{w_1}}$$

(5)

(ii) Assuming $R_1 = 1$ kΩ, and $R_2 = 100$ kΩ, calculate the dc gain and the small signal upper -3dB frequency of the circuit. **(5)**

b. A particular amplifier with an infinite input resistance and a gain of 100 V/V has equivalent input noise voltage and current generators of 10 nV $Hz^{-1/2}$ and 1.2 pA $Hz^{-1/2}$ respectively. The amplifier is driven by a signal source with a Thevenin equivalent resistance of 1.5 kΩ.

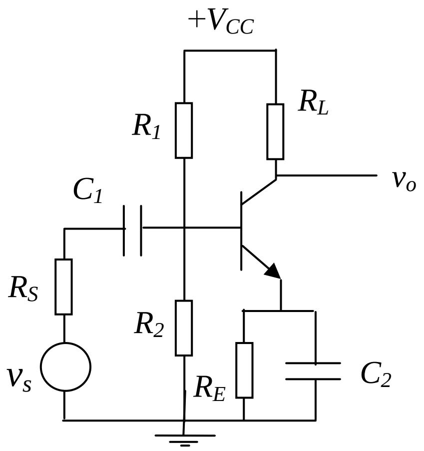
The mean square thermal noise voltage generated by a resistor R is 4kTR V^2 Hz^{-1} where k = 1.38 x 10^{-23}. The ambient temperature, T, is 300K throughout the question.

(i) Evaluate the noise factor of the amplifier. **(5)**

(ii) Calculate the reading that you would expect to find on a true rms voltmeter, with a noise equivalent bandwidth of 20kHz, connected to the amplifier output. **(5)**

4. **a.** Draw the hybrid π model commonly used as a small signal equivalent circuit for the BJT. Describe the physical origins of each of the circuit elements. State whether any of these elements are commonly ignored, and if so, under what conditions. **(8)**

b. The figure below shows a single-stage transistor amplifier.



i) Derive an expression for the mid-frequency gain of the circuit shown above. You should state any assumptions which you make. **(6)**

ii) Draw the high-frequency small signal equivalent for this circuit. Use the miller transformation to simplify the circuit. **(2)**

iii) Assuming $R_1 = 200\text{k}\Omega$, $R_2 = 100\text{k}\Omega$, $R_L = 5\text{k}\Omega$, $R_E = 4.3\text{k}\Omega$, $R_S = 10\ \text{k}\Omega$, $r_{be} = 12\text{k}\Omega$, $c_{cb} = 5\text{pF}$, $c_e = 20\text{pF}$, $g_m = 0.04$, find the upper -3dB frequency of the circuit. **(4)**

MH-JW / JW-MH