BIRLA INSTITUTE OF TECHNOLOGY AND SCIENCE – PILANI, K K BIRLA GOA CAMPUS
FIRST SEMESTER 2022-2023

PHY F426 Comprehensive Exam (Closed book) Time: 3 hrs
Physics of Semiconductor Devices Date: 22/12/2022 Time: 10 AM – 1 PM
Max. Marks: 90

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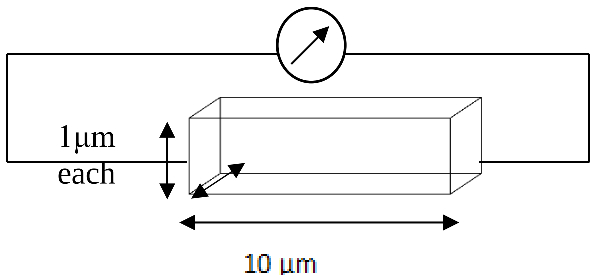
1) Why is the concept of effective mass introduced? How do you interpret effective mass with the E-*k* diagram? Is it possible to have positive and negative effective mass for an electron in an energy band? Explain **[7]**

2) (a) Consider an n-type silicon sample with $N_d = 10^{16}$ cm^{-3}. The dimensions of the sample are given in the figure below. The carrier life time (electrons and holes) is 1 μs. The mobilities are $\mu_n = 625$ cm^2/Vs and $\mu_p = 200$ cm^2/Vs. What is the resistance of the sample (in ohms)?



(b) The sample is illuminated with light, which gives rise to a uniform external generation $G_n = G_p = G = 10^{22}$ $cm^{-3}s^{-1}$ uniformly throughout in the sample. What is the resistance of the sample (in ohms)? **[4+4]**

3) What are the two material parameters that determine the carrier transport in semiconductors? How are they related? Discuss the carrier transport in semiconductors with necessary equations. **[2+2+5]**

4) A semiconductor has $N_c = 10^{19}$ cm^{-3}, $N_v = 5x10^{18}$ cm^{-3} and $E_g = 2$ eV. If it is doped with 10^{17} cm^{-3} donors (fully ionized), calculate the electron, hole and intrinsic carrier concentrations at 627°C. Sketch the simplified band diagram showing the position of E_f. **[6]**

5) (a) Draw the band diagram of a pn junction at thermal equilibrium. Derive the expression for the built-in potential barrier.
(b) A pn junction formed from Ge has a conductivity of 0.8 $\Omega^{-1}cm^{-1}$ on the p side and 1.6 $\Omega^{-1}cm^{-1}$ on the n-side. Calculate the potential barrier at 300 K. (Given $\mu_p = 2000$ cm^2/Vs and $\mu_n = 4000$ cm^2/Vs and $n_i = 2.1x10^{13}$ cm^{-3}) **[6+3]**

6) Explain the Zener breakdown in a pn junction with an appropriate band diagram. **[6]**

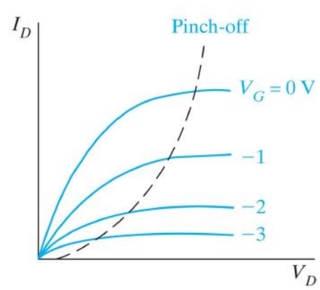
7) Consider a Schottky contact between tungsten and n-type silicon doped to $N_d = 10^{16}$ cm^{-3} at 300 K. Sketch the energy band diagram (with work functions, electron affinity and potential barrier marked) before and after contact. The work function for tungsten is 4.55 V and the electron affinity for silicon is 4.01 V. Calculate the barrier height as seen by the electron on

the metal side, built-in potential barrier and maximum electric field for zero bias. Given, space charge width = 0.207 x 10^{-4} cm. **[3+2+3+3]**

8) With help of an example and band diagram, explain how do you achieve high mobility in a HEMT **[6]**

9) (a) Consider a forward biased ideal (abrupt junction, no recombination or generation in the depletion region) long p-n junction diode under forward bias. Sketch the variation of current as a function of position assuming that the p-side of the junction is heavily doped compared to the n-side. Mark the electron and hole components of current on both sides and the total current throughout the device.
(b) Consider a long base diode (the length of the quasi neutral regions are larger than the diffusion length of minority carriers) and a short base diode (the length of the quasi neutral regions are shorter than the diffusion length of minority carriers). For both the diodes, sketch (in the same plot) the excess hole concentrations as a function of position on the n-side and label them.
(c) How does diffusion capacitance arise in a pn junction? Why is this neglected in reverse bias? **[5+4+3]**

10) (a) Explain the term ‘pinch off’ in a FET.
(b) Consider a MOS capacitor with a p-type substrate. Draw and explain the band diagram corresponding to accumulation, depletion and inversion. How do you define threshold voltage?
(c) Consider the IV characteristics of the J-FET given. Is this an n-channel or p-channel JFET? Why? Is it a depletion mode or enhancement mode device? Why? Explain the variation of pinch -off voltage with V_G as shown. **[2+8+6]**



Useful parameters: The symbols have the usual meaning

ε_s (Si) = 11.7, $\varepsilon_0 = 8.85\times 10^{-12}$ F/m

Boltzmann’s constant $k_B = 1.38 \times 10^{-23}$ m^2 kg s^{-2} K^{-1}

The electric field associated with the n-side of a pn junction = $\frac{-qN_d}{\varepsilon_s}(x_n - x)$

$$n = N_c exp\left(\frac{E_F - E_C}{k_B T}\right) \qquad p = N_v\, exp\left(\frac{E_v - E_F}{k_B T}\right)$$

For an n-type semiconductor,

$$N_d = n_i\, exp\left(\frac{E_F - E_i}{k_B T}\right)$$