University of KwaZulu-Natal
School of Engineering

Examination: **Physical Electronics II (**ENEL2PBH2**)**
Date: November 2025
Duration: 2 hours **Total Marks: 100**

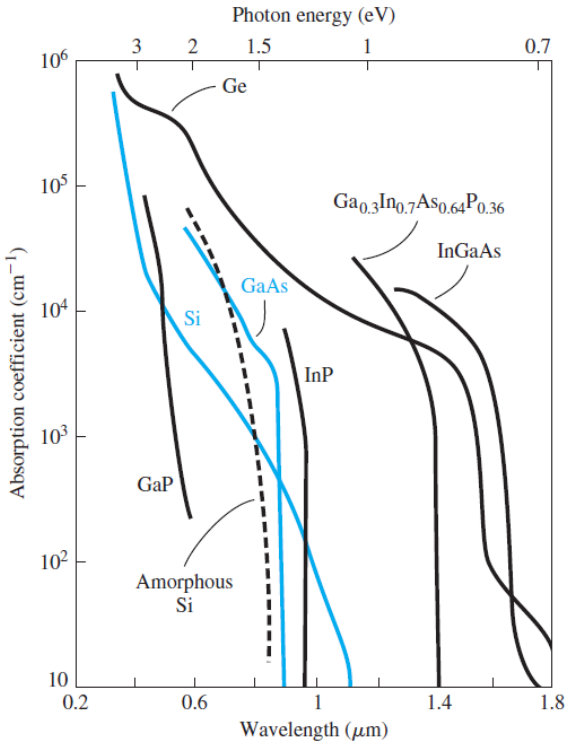
Examiners: Internal Prof Leigh Jarvis
External Dr Fayaz Khan

General Instructions:
1. Answer all questions.
2. Full marks equal 100 marks.
3. Assume variables carry normal meanings.
4. Your answer should be neat and concise.
5. The use of any Engineering calculator is permitted provided that it is not used to subvert the purposes of the examination.
6. This exam has 5 pages (inclusive of data and formulae sheets).

SECTION A OPTICAL ELECTRONICS 35 Marks

QUESTION 1 – *Solar Cell*

(a) A Si based junction solar cell is 9.2 μm thick, where 60 percent of incident monochromic photon energy is absorbed. By use of the graph below, determine the incident photon wavelength.



(5)

(b) A Maximum Power Point Tracker (MPPT) is used to consistently ensure maximum power from a solar panel. With the use of *I-V* curve of a solar panel explain why the MPPT is an important device in a solar system.

(8)

(c) GaAs junction solar cell has the following parameters:

$N_d = 5 \times 10^{19}$ cm^{-3}, $N_a = 2 \times 10^{15}$ cm^{-3},
$D_n = 225$ cm^2/s, $D_p = 7$ cm^2/s and $\tau_{p0} = \tau_{n0} = 5 \times 10^{-8}$ s.

Assuming the excess carriers of the solar cell are uniformly generated and $J_L = 50$ mA/cm^2. Calculate the open circuit voltage, V_{oc}.

(6)

QUESTION 2 – *Photodetectors*

With the help of a diagram, explain the principle of how the combination of a photo-detector and an infra-red laser can be used to identify different gases. What is the name of such a device?

(10)

QUESTION 3 – *Light Emitting Diodes*

In LEDs, the external quantum efficiency is less than internal quantum efficiency; name and discuss three photon loss mechanisms within the above pn-structure.

(6)

SECTION B METAL/SEMICONDUCTOR JUNCTIONS **15 Marks**

QUESTION 4 – *Metal- Semiconductor Junctions*

(a) Other than rectifying (diodes) why are metal/semiconductor junction important to consider?

(2)

(b) Draw an ideal energy band diagrams of an n-type semiconductor non-rectifying junction, before and after joining.

(8)

(c) Pn-junction and Schottky diodes both operate at T = 300 K with the same cross-sectional areas of $A = 5 \times 10^{-4}$ cm^2 sustaining a forward-bias current equal to 5 mA.

Determine the forward-bias voltage for each type of diode. [Note: the reverse saturation current density of the pn diode is 3×10^{-12}A/cm^2, and 3×10^{-8} A/cm^2 for the Schottky diode.]

(5)

SECTION C MOSFETs **50 Marks**

QUESTION 5 – *MOS Capacitor*

(a) (i) Draw a well labeled MOS capacitor and discuss charge issues related to the oxide layer, that can impact the threshold voltage.

(15)

(ii) Calculate the threshold voltage, for an MOS transistor, has an aluminum gate (3.20 V) is fabricated on a p-type silicon substrate with Na = 2×10^{15} cm^{-3}. The oxide thickness is t_{ox} = 450 Å and the equivalent fixed oxide charge is $Q'_{ss} = 2 \times 10^{11}$ cm^{-2}.

(8)

QUESTION 6 – *MOSFET HIGH FREQUECY MODEL*

(a) Draw the high frequency small signal equivalent circuit of a MOSFET.

(6)

(b) (i) Using your model in (a), derive the following famous MOSFET equation,

$$C_M = C_{gdT}\left(1 + g_m R_L\right).$$

(9)

(ii) What popular name is the variable C_M known by?

(2)

QUESTION 7 – *CMOS*

Draw a CMOS inverter circuit and explain its operation.

(10)

Total 100 marks

Data Sheet

Silicon, gallium arsenide, and germanium properties (T = 300 K)			
Property	**Si**	**GaAs**	**Ge**
Atoms (cm^{-3})	5.0×10^{22}	4.42×10^{22}	4.42×10^{22}
Atomic weight	28.09	144.63	72.60
Crystal structure	Diamond	Zincblende	Diamond
Density (g/cm^{-3})	2.33	5.32	5.33
Lattice constant (Å)	5.43	5.65	5.65
Melting Temperature (°C)	1415	1238	937
Dielectric constant	11.7	13.1	16.0
Bandgap energy (eV)	1.12	1.42	0.66
Electron affinity,χ, (volts)	4.01	4.07	4.13
Effective density of states in conduction band, N_c, (cm^{-3})	2.8×10^{19}	4.7×10^{17}	1.04×10^{19}
Effective density of states in valence band, N_v, (cm^{-3})	1.04×10^{19}	7.0×10^{18}	6.0×10^{18}
Intrinsic carrier concentration (cm^{-3})	1.5×10^{10}	1.8×10^{6}	2.4×10^{13}
Mobility (cm^2/V-s)			
Electron, μ_n	1350	8500	3900
Hole, μ_p	480	400	1900
Effective mass (density of states)			
Electrons (m_n^*/m_0)	1.08	0.067	0.55
Holes (m_p^*/m_0)	0.56	0.48	0.37

Physical Constants	
Avogadro's number	$N_A = 6.02 \times 10^{23}$ atoms per gram molecular weight
Boltzmann's constant	$k = 1.38 \times 10^{-23}$ J/K $= 8.62 \times 10^{-5}$ eV/K
Electronic charge	1.60×10^{-19} C
Free electron rest mass	$m_0 = 9.11 \times 10^{-31}$ kg
Permeability of free space	$\mu_0 = 4\pi \times 10^{-7}$ H/m
Permittivity of free space	$\varepsilon_0 = 8.85 \times 10^{-14}$ F/cm $= 8.85 \times 10^{-12}$ F/m
Planck's constant	$h = 6.625 \times 10^{-34}$ J-s $= 4.135 \times 10^{-15}$ eV.s $\hbar = h/2\pi = 1.054 \times 10^{-34}$ J-s
Proton rest mass	$M = 1.67 \times 10^{-27}$ kg
Speed of light in vacuum	$c = 2.998 \times 10^{10}$ cm/s
Thermal voltage (T = 300 K)	$V_t = kT/e = 0.0259$ volt $kT = 0.0259$ eV

A few useful formulae

Please note these are only a few equations; this page is not intended to be a complete set of ALL equations used in the course.

$$I(x) = I_0 \exp(-\alpha x) \qquad t_n = \frac{L}{\mu_n E} \qquad C_{ox} = \frac{\varepsilon_{ox}}{t_{ox}}$$

$$\phi_{ms} \equiv \left[\phi'_m - \left(\chi' + \frac{E_g}{2e} + \phi_{fp}\right)\right] \qquad V_{oc} = V_t \ln\left(1 + \frac{I_L}{I_S}\right)$$

$$\left[1 + {V_m}/{V_t}\right].\exp\left({V_m}/{V_t}\right) = 1 + {I_L}/{I_S} \qquad V_{TN} = \frac{|Q'_{SD}\,(\max)|}{C_{ox}} - \frac{Q'_{ss}}{C_{ox}} + \phi_{ms} + 2\phi_{fp}$$

$$I_D(sat) = \frac{W\mu_n C_{ox}}{2L}(V_{GS} - V_T)^2 \qquad V_{bi} = V_t \ln\left(\frac{N_a N_d}{n_i^2}\right) \qquad a = \left(\frac{2\varepsilon_s V_{p0}}{eN_a}\right)^{1/2}$$

$$\phi_{BN} = V_{bi} + \phi_n \qquad \boldsymbol{V_{p0} = V_{bi} + V_p} \quad \textbf{(p channel)}$$

$$J_{ST} = A^* T^2 \exp\left(\frac{-e\phi_{BN}}{kT}\right) \qquad J_n = J_{ST} \exp\left(\frac{eV_a}{kT}\right) \qquad \boldsymbol{V_{FB} = \phi_{ms} - \frac{Q'_{ss}}{2\varepsilon}}$$

$$J_s = en_i^2\left[\frac{1}{N_a}.\sqrt{\frac{D_n}{\tau_n}} + \frac{1}{N_d}.\sqrt{\frac{D_p}{\tau_p}}\right] \qquad V_a = V_t \ln\left(\frac{J_n}{J_{ST}}\right)$$

$$J_s = \left(\frac{eD_n n_{p0}}{L_n} + \frac{eD_p p_{n0}}{L_p}\right) = en_i^2\left(\frac{D_n}{L_n N_a} + \frac{D_p}{L_p N_d}\right) \qquad L_n = \sqrt{D_n \tau_{no}}$$

$$\Gamma_{ph} = \frac{\tau_p}{t_n}\left(1 + \frac{\mu_p}{\mu_n}\right) \qquad f_T = \frac{g_m}{2\pi C_{gs}} = \frac{\mu_n(V_{GS} - V_T)}{2\pi L^2}$$

$$f_T = \frac{g_m}{2\pi\left(C_{gsT} + C_M\right)} \qquad C_M = C_{gdT}\left(1 + g_m R_L\right) \quad g_{ms} = \frac{W\mu_n C_{ox}}{L}(V_{GS} - V_T)$$

$$\phi_n = V_t \ln\left(\frac{N_c}{N_d}\right) \qquad I = I_L - I_F = I_L - I_S\left[\exp\left(\frac{eV}{kT}\right) - 1\right]$$