Exit Test: Semiconductor Technologies

Module Assessment • Semiconductor Physics & Electronics Engineering

> **Instructions:** Please complete all three sections of this assessment. Pay close attention to unit notations and physical equations.

PART 1: SINGLE CHOICE QUESTIONS (SCQ)

1. Which property primarily distinguishes semiconductors from conductors and insulators at absolute zero ($0\ K$)?

A) Higher density of free electrons than conductors

B) A completely filled valence band separated from an empty conduction band by a small energy gap ($E_g \approx 1\ eV$)

C) Infinite electrical conductivity

D) Absence of a forbidden energy bandgap

2. In an N-type semiconductor at room temperature, the dominant charge carriers are:

A) Holes created by acceptor impurities

B) Electrons provided primarily by donor impurities

C) Equal numbers of thermal electrons and holes

D) Positive ions moving through the crystal lattice

3. Under thermal equilibrium, what fundamental law governs the relationship between electron concentration (n_0) and hole concentration (p_0)?

A) Ohm's Law

B) Mass-Action Law ($n_0 \cdot p_0 = n_i^2$)

C) Gauss's Law

D) Continuity Equation

4. Poisson's equation directly relates the second spatial derivative of electrostatic potential $\nabla^2 V(r)$ to:

A) Carrier diffusion velocity

B) Total space charge density $\rho(r)$ divided by permittivity ε

C) Magnetic flux density

D) Recombination lifetime τ_n

5. Carrier drift is defined as particle motion driven by:

A) Concentration gradients

B) Thermal diffusion alone

C) An applied electric field

D) Photon absorption

6. Under high-level injection conditions in a P-type semiconductor, the excess carrier concentration Δn is:

A) Negligible compared to equilibrium minority carrier concentration n_0

B) Comparable to or greater than the equilibrium majority carrier doping concentration p_0

C) Zero

D) Independent of recombination mechanisms

7. The 1D continuity equation for minority electrons ($\partial n / \partial t$) expresses the conservation of charge by combining:

A) Drift current only

B) Current divergence ($(1/q) \cdot (\partial J_n / \partial x)$), generation rate G_n, and recombination rate R_n

C) Poisson's equation and Fermi energy

D) Dielectric relaxation time only

8. Thermal noise (Johnson-Nyquist noise) in a resistor or semiconductor is fundamentally caused by:

A) External electromagnetic radiation

B) Random thermal motion of charge carriers in equilibrium

C) Discrete passage of carriers across potential barriers

D) Surface traps at low frequencies

9. A heterojunction is formed by joining:

A) P-type and N-type regions of the same semiconductor material

B) Two different semiconductor materials with different energy bandgaps

C) A metal and an insulator without energy band offsets

D) Two identical intrinsic semiconductors at different temperatures

10. In a High Electron Mobility Transistor (HEMT), high carrier mobility is achieved by:

A) Heavily doping the channel region

B) Spatially separating free carriers (2DEG) from their donor impurity ions using a heterojunction

C) Eliminating the gate dielectric layer

D) Operating the device at extreme high temperatures

PART 2: MULTIPLE CHOICE QUESTIONS (MCQ)

(Select all correct statements that apply)

11. Which of the following statements regarding Silicon (Si) as a semiconductor material are correct?

A) It has a diamond cubic crystal structure with covalent bonding.

B) It is a direct bandgap semiconductor suitable for efficient light emission.

C) Native silicon dioxide (SiO_2) acts as an excellent electrical insulator and passivating layer.

D) Increasing temperature increases its intrinsic carrier concentration n_i.

12. Which statements correctly describe an extrinsic P-type semiconductor?

A) Group III elements (e.g., Boron) act as acceptor dopants.

B) The Fermi level E_F shifts closer to the conduction band edge E_c.

C) Hole concentration p_0 is significantly larger than electron concentration n_0.

D) At complete ionization, $p_0 \approx N_A$ (where N_A is the acceptor concentration).

13. Which of the following conditions hold true for a semiconductor in thermal equilibrium?

A) The Fermi level E_F is spatially constant throughout the material.

B) Net electric current density J is strictly zero.

C) External light excitation continuously generates excess carriers.

D) Carrier generation rate G_0 equals recombination rate R_0.

14. In a space charge (depletion) region of a semiconductor, which sources contribute to the total volume charge density ρ?

A) Mobile electrons ($q \cdot n$)

B) Mobile holes ($q \cdot p$)

C) Ionized donor atoms ($q \cdot N_D^+$)

D) Ionized acceptor atoms ($-q \cdot N_A^-$)

15. Which mechanisms contribute to the total current density in a semiconductor under low-level perturbation?

A) Electron drift current ($J_{n,drift} = q \cdot n \cdot \mu_n \cdot E$)

B) Hole diffusion current ($J_{p,diff} = -q \cdot D_p \cdot (dp/dx)$)

C) Electron diffusion current ($J_{n,diff} = q \cdot D_n \cdot (dn/dx)$)

D) Displacement current in static DC conditions

16. Which recombination mechanisms play a major role in semiconductors under high excitation levels?

A) Shockley-Read-Hall (SRH) trap-assisted recombination

B) Radiative band-to-band recombination

C) Auger recombination (proportional to n^2p or np^2)

D) Ohmic contact conduction

17. The ambipolar transport equation is particularly useful because it:

A) Simplifies coupled electron and hole equations into a single differential equation for excess carriers.

B) Accounts for internal electric fields generated by unequal electron and hole mobilities.

C) Assumes charge neutrality ($\Delta n \approx \Delta p$) under low-injection and high-injection conditions.

D) Eliminates the need to consider generation or recombination processes.

18. Which of the following noise types are intrinsic to semiconductor devices?

A) Shot noise (associated with DC current flow across potential barriers like PN junctions)

B) $1/f$ (Flicker) noise dominant at low frequencies

C) Generation-Recombination (G-R) noise caused by random trapping/detrapping

D) Quantization noise in analog amplifiers

19. Which parameters must be aligned/matched when constructing an energy band diagram for a heterojunction?

A) The vacuum level must remain continuous (according to Anderson's rule).

B) The Fermi levels E_F must align across the interface in thermal equilibrium.

C) Bandgap discontinuities ΔE_c and ΔE_v appear due to differences in electron affinity χ and bandgap E_g.

D) The conduction bands must meet without any band offset.

20. Which unique features characterize a Two-Dimensional Electron Gas (2DEG) formed at an $AlGaAs/GaAs$ heterojunction?

A) Electrons are confined in a narrow potential well perpendicular to the interface.

B) Reduced ionized impurity scattering leads to extremely high mobility.

C) Electron motion is quantized in the direction perpendicular to the heteroface.

D) Hole concentration exceeds electron concentration inside the channel.

PART 3: SHORT ANSWER QUESTIONS (SAQ)

21. Explain briefly why Silicon is preferred over Germanium in modern microelectronics manufacturing despite Germanium having higher carrier mobility.

22. Define the term *compensation* in doped semiconductors and state the net majority carrier concentration in a silicon sample doped with $N_D = 10^{17}\ cm^{-3}$ donors and $N_A = 4 \times 10^{16}\ cm^{-3}$ acceptors.

23. Write down the Fermi-Dirac distribution function $f(E)$ and explain what $f(E_F)$ represents physically at any non-zero temperature.

24. Write the 1D Poisson equation for a semiconductor region containing ionized donors N_D^+, ionized acceptors N_A^-, free electrons n, and free holes p.

25. **State Einstein's relation connecting carrier mobility μ and diffusion coefficient D. What is its value for electrons at room temperature ($T = 300\ K$) if thermal voltage $V_t \approx 25.9\ mV$?**

26. **Why do we introduce two distinct Quasi-Fermi levels (E_{Fn} and E_{Fp}) under non-equilibrium conditions instead of a single Fermi level E_F?**

27. **Write down the 1D field-free, steady-state diffusion equation for excess minority holes $\Delta p(x)$ with lifetime τ_p and diffusion length L_p.**

28. **Write the expression for the mean-square thermal noise voltage spectral density $S_v(f)$ generated by a resistor R at temperature T.**

29. **Define Anderson's Rule for calculating the conduction band discontinuity ΔE_c at an ideal heterojunction between Semiconductor A and Semiconductor B.**

30. **Explain the concept of *Bandgap Engineering* and give one example of a modern device that relies on it.**